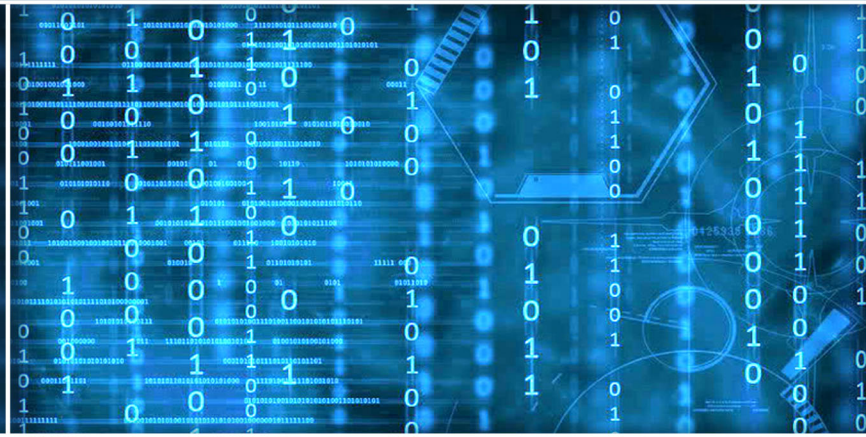


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# Editorial Preface

## *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!**

**Kohei Arai**  
**Editor-in-Chief**  
**IJACSA**  
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# A Fuzzy Reward and Punishment Scheme for Vehicular Ad Hoc Networks

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**Abstract**—Trust management is an important security approach for the successful implementation of Vehicular Ad Hoc Networks (VANETs). Trust models evaluate messages to assign reward or punishment. This can be used to influence a driver's future behaviour. In the author's previous work, a sender-side based trust management framework is developed which avoids the receiver evaluation of messages. However, this does not guarantee that a trusted driver will not lie. These "untrue attacks" are resolved by the RSUs using collaboration to rule on a dispute, providing a fixed amount of reward and punishment. The lack of sophistication is addressed in this paper with a novel fuzzy RSU controller considering the severity of incident, driver past behaviour, and RSU confidence to determine the reward or punishment for the conflicted drivers. Although any driver can lie in any situation, it is expected that trustworthy drivers are more likely to remain so, and vice versa. This behaviour is captured in a Markov chain model for sender and reporter drivers where their lying characteristics depend on trust score and trust state. Each trust state defines the driver's likelihood of lying using different probability distribution. An extensive simulation is performed to evaluate the performance of the fuzzy assessment and examine the Markov chain driver behaviour model with changing the initial trust score of all or some drivers in Veins simulator. The fuzzy and the fixed RSU assessment schemes are compared, and the result shows that the fuzzy scheme can encourage drivers to improve their behaviour.

**Keywords**—VANET; Trust management; fuzzy logic; Markov chain; reward and punishment; driver behaviour model

## I. INTRODUCTION

Vehicular Ad Hoc Networks (VANETs) can play a major role in the successful implementation of the Intelligent Transport System (ITS). However, the implementation of VANETs and ITS face many security threats concerning traffic events. There are many security approaches in state-of-the-art literature which aim to address these threats, though the completeness of these approaches is limited in thwarting both internal and external attacks. Attacks from authorized users can be curbed by a trust model [1-4]. However, each trust model has some limitations. Research to-date presents many models to evaluate the trust of vehicles and their messages. Trust approaches differ by their evaluation mechanism, and the infrastructures considered in the approaches. Some schemes evaluate only the trust of vehicles, whereas others evaluate the trustworthiness of messages. There are also some hybrid approaches which evaluate both the vehicles and messages. In this way, approaches isolate malicious vehicles from benign ones. Typically, the trustworthiness of relayed messages is evaluated using some measures and

computational processes [5]. Once the malicious vehicles are identified, then it possible to limit or ignore their actions. To this end, some schemes also blacklist vehicles and/or drivers [6, 7]. Additionally, approaches incentivize trustworthy announcements (positive behaviour) to motivate vehicles to act honestly in the future [3, 6, 8]. Conversely, approaches punish mischievous behaviours to limit their future actions to avoid launching of future attacks [6, 9]. By arranging punishments to lower their trust score, drivers may feel guilty and be more careful about their future actions. In this way, the VANET can thwart attacks from authorized users by adopting a trust model which penalizes malicious activities and rewards benevolent behaviour. Even so, in some approaches [2, 3, 5, 10, 11], both reliable and unreliable vehicles can announce messages. The approach in [6] does not need any trust metric dissemination unlike these schemes [2, 4, 12] which require substantial trust data dissemination to verify an original announcement.

Trust evaluation can be performed at either the sender [6] and/or receiver side [2, 4, 10, 11, 13]. If receiver vehicles evaluate the trust of sender vehicles and/or messages, then the approach incurs additional delay and results in a higher communication overhead. Whereas, if a device in the sender vehicle can evaluate the trust, then there is typically no need to evaluate the trust of sender messages. Receivers do not need to rely on further communication with other sources (RSU, neighbour vehicles) for opinions or recommendation data.

A trust management framework is proposed in [6] which adopts sender-side trust evaluation inside a Tamper Proof Device (TPD) which is equipped onto every regular vehicle. This TPD is responsible for altering the trust of all drivers of a regular vehicle. In this approach, drivers receive rewards from announcements after the expiration of reward withhold timer. The accuracy of the message, responsiveness of the driver, and the distance travelled from the event location are used to calculate the reward or penalize a driver. The TPD updates the trust of a driver using a standard set of rules. The TPD does not know the truthfulness of a message unless it receives a report/complaint from a reporter vehicle about the announcement. The framework thus includes a collaboration procedure to determine the validity of a disputed event by an RSU. The dispute concerns "an event" announced by a sender whereas a reporter says, "an opposite event". The RSU then collects feedback from the vehicles (trusted clarifiers) which are visiting the presumed event location thereafter. With this data, the RSU decides, and sends rewards and punishment to the respective drivers when the decision is ready. In comparison to TPD reward and punishment, the RSU reward

and punishment mechanism is simple, and it only assigns a fixed reward or punishment to the disputed drivers irrespective of the severity of incident, driver past behaviour, and RSU confidence in the sender or reporter (environmental dynamics). Thus, in this paper an advanced RSU reward and punishment generator is developed to assign a justified level of reward or punishment to the drivers concerned. It is found in the state-of-the-art that many researchers use Mamdani fuzzy logic to deal with the imprecision and uncertainty. In the Mamdani fuzzy logic, each rule output is a fuzzy set, and the rules can be designed intuitively with some expert knowledge.

In [6], an RSU assigns only fixed rewards and punishment based on the decision and does not consider the environmental dynamics. It is found that there is some uncertainty and incompleteness involved in the dispute resolution process.. Thus, our attention is drawn to developing an advanced model to reward or punish drivers using a fuzzy logic based RSU assessment method. This model considers various factors and then allocates justified levels of reward or punishment accordingly. Also, in [6] the driver behaviour is modelled with a straightforward probabilistic distribution. Drivers with higher trust scores send less untrue messages. However, the probability distribution is fixed and not influenced by the changing trust score of the driver. This is why a Markov-chain based driver behaviour model is introduced. The states of the Markov model are associated with a specific range of trust scores. From each state, a driver's lying probability is defined which controls their likelihood of making trustworthy or malicious announcements. From a higher trust state, drivers announce less untrue messages whereas from the lower trust state they are more likely to announce untrue messages. The following contributions are made in this paper:

- The RSU reward and punishment mechanism is amended using Mamdani fuzzy logic-based assessment. This method considers the severity of incident, confidence score in the sender or reporter and driver past behaviour.
- A Markov-chain based driver behaviour model is used to govern the behaviour of drivers from different trust states. The state transition model along with the conditions to move between states is given. Also, from each state, the trustworthy / malicious announcement probability is defined.
- A series of experiments have been conducted to validate and compare the performance of the fuzzy versus fixed reward and punishment schemes.
- The Markov chain behaviour model is examined by defining the probabilistic distribution of sender, reporter drivers from different trust states and changing the initial trust distribution of drivers.

The paper is organized as follows: Section II reviews trust models based on fuzzy logic and Markov chain-based models and similar state-of-the-art. Section III briefly introduces author's earlier trust framework and presents the proposed fuzzy logic based RSU reward and punishment assessment method as well as Markov Chain driver behaviour model. Section IV describes the simulation environment and

parameters for the experiments. Section V gives analysis and validation of results. Section VI compares fuzzy versus fixed RSU rewards and punishments and analyses the driver behaviour model with changing trust scores. Section VII presents the discussions. Finally, this work is concluded in the Section VIII where possible future research directions are indicated.

## II. LITERATURE REVIEW

This work primarily implements a fuzzy logic-based reward and punishment mechanism at RSUs. Additionally, a Markov model-based driver behaviour is developed to control the behaviour of drivers. These are improvements to the trust framework presented in [6]. First, some of the existing state-of-the-art trust models are briefly reviewed including fuzzy logic and Markov-model approaches. Trust approaches vary from different perspectives. For example, they can be differentiated based on whether they are application-oriented (architecture-less) [14] or architecture-based [3, 4]. Some approaches are centralized like [15] whilst others employ a decentralized architecture like [16]. Also, they can differ based on their data collection mechanism. For example, some schemes use only direct recommendations as [17]; others use both direct and indirect recommendations like [12, 34] for trust evaluation. Trust evaluation mechanisms are divided into three main classes which are Entity-Oriented Trust Models (EOTMs), Data-Oriented Trust Models (DOTMs), and Hybrid Trust Model (HTMs). These trust evaluation mechanisms are briefly reviewed next.

### A. Entity-Oriented Trust Models (EOTMs)

Entity-oriented trust models are epitomized by [10], where the researchers securely manage allocated credit using a Tamper Proof Module (TPM) on every vehicle. A vehicle first gets the transmission cost and the signed message from its TPM. Receiver vehicles consider the sender's reputation to decide whether to trust a message and the trust is revised using feedback from all receivers. This approach considers the presence of false attacks and benevolent vehicles. However, the process for setting a revised trust score can lead to excessive communication. In [18], the researchers consider familiarity, packet delivery ratio, timeliness, and interaction frequency to manipulate a weight-based aggregated final trust. They analyse the time-aware trust of vehicles from histories of interactions. However, they do not consider any attacker model for validation. In [4], a trust model uses a false message detection scheme to generate feedback on received messages which computes the trust of vehicles. Vehicles utilize primary and secondary scores from the RSUs for further communication until the next periodic update. The scheme is evaluated in the presence of false messages for both urban and highway environments. Nevertheless, it suffers from excessive trust metric dissemination.

In [15], a Reputation-based Global Trust Management (RGTE) scheme employing a Reputation Management Center (RMC) is presented. The RMC keeps track of the updated reputation of all vehicles. Every vehicle sends its recommendation about its neighbours to the RMC and then it uses central limit theory to exclude unreasonable recommendations. It updates reputation of vehicles for which

it receives recommendations. Whenever a receiver receives a message, it directly consults the RMC about the reputation of the sender. However, in this model, the server is contacted frequently for reputation requests and replies.

A fuzzy logic-based direct trust and Q-learning-based indirect trust is considered in [12]. This approach analyses precision and recall metrics with varying the number of malicious vehicles. However, the overhead is high as it involves repeated sensing of messages from neighbours. The authors in [19] apply fuzzy logic to calculate trust using experience, plausibility, and location accuracy. Furthermore, location accuracy is determined using fog nodes. It can detect bogus attacks and message alteration attacks. However, vehicles consulting with fog nodes for location accuracy raise the communication overhead. The authors in [20] also use fuzzy logic and calculate the relaying trust and coordinating trust. Then the final trust is computed from these two and a path is identified using a set of rules and experiences. However, this model only considers trust-based routing to deliver a message along the most trusted path.

The study [21] selects an optimal path for packet forwarding using fuzzy logic-based transmission method. In this method, driving direction, vehicle speed, link time, hop count are used for relay node selection. Additionally, it considers the future state of vehicles. In [22], a fuzzy logic-based trust model is proposed that uses the RSU assessment, emulation attack attempts, and collaboration degree to assess the trust of vehicles. It incentivises good behaviour and punishes malicious vehicles. However, their analysis only concentrates on network performance measurement considering the malicious behaviour of making the connection slow, modifying messages, and stating false opinions.

In [23], a fuzzy logic-based trust model is proposed to address uncertainty and inaccurate trust estimation in a VANET. In this method, edge servers compute the trust of vehicles using fuzzy logic from packet drop, alteration, and false message injection factors. The analysis considers message alteration attacks and bad-mouthing attacks. In [24], a fuzzy logic-based system is used for vehicle authentication. This system only considers distance and trust factors to classify vehicles as partially or fully trusted or malicious. However, this approach is not analysed in the presence of a known adversary.

In [25], a fuzzy-logic-based trust model is presented where plausibility, experience, and vehicle type are used to decide on the validity of events. The fuzzy decision-making module of receiver vehicles utilizes these factors to compute the trust of the sender to determine whether to accept or reject or to forward a message. The analysis considers simple, opinion tampering, and on-off attacks. Every receiver vehicle applies fuzzy logic independently to forward an announcement to a further vehicle. The researchers in [26] propose a Hidden Markov Model (HMM) based trust evaluation method which computes trust of vehicles at the RSUs. This model improves the accuracy in detecting malicious vehicles compared to a baseline scheme.

### B. Data-Oriented Trust Models (DOTMs)

In [27], the researchers present machine learning based trust models (i.e. KNN, decision tree, naïve Bayes, and random forest). An RSU runs a location spoofing attack detection framework which uses stored data and received Basic Safety Messages (BSMs). The model is trained with both legitimate and malicious data. The analysis examines the accuracy, precision, and recall for all machine learning approaches. However, the analysis is limited to the BSM data. Research [28] differentiates malicious vehicles from benevolent ones using an ensemble learning algorithm and a decision tree-based model. The analysis includes measuring the accuracy, precision, and recall. However, it only identifies fake positional data.

In [29] author proposes a fuzzy system considering network density, relaying distance, and trust inconsistency to predict the relaying trust of vehicles. Then the coordinated trust is computed using velocity, connection degree and loss parameters. After that, the final trust is computed using a fuzzy system considering the relaying and coordinated trust that is used to find a trusted path. However, the model only selects the trusted relayer to confirm the trusted path for delivering messages. In [30], the authors propose a data oriented HMM-based reputation model. This model evaluates the reliability and the legitimacy of the announced messages. The reputation of vehicles is updated based on the correctness of safety and non-safety messages. The study [31] presents a vehicle behavioural monitoring and trust computational model to classify fake and legitimate messages. This model uses a neuro-fuzzy method to evaluate the behaviour of vehicles. It features accurate malicious message detection from speed and emission data. Using this data, the model can isolate misbehaving vehicles and discard messages from them.

### C. Hybrid Trust Models (HTMs)

In [32], the researchers present a Markov Chain-based hybrid trust model for VANETs. In this scheme, a state transition model, and the state transition probabilities are presented considering a cooperation factor and the accurate evaluation of messages. The monitoring process considers trustworthy message broadcasting besides cooperativeness, and they examined camouflaged behaviour. The researchers in [33] consider the likelihood and impact of taking a decision when both the event and the opposite event coexist. This approach is compared with a multi-faceted trust model. The results suggest that this approach always selects a low-risk action relative to a typical trust-based approach. However, the model is designed for a clustered environment.

In [34], the researchers develop a Bayesian inference-based direct and recommendation-based trust model. The direct trust considers penalties and time-decaying information. Also, the confidence of direct trust is checked beforehand to avoid unnecessary recommendation trust calculations. The analysis considers packet drop and interception as malicious behaviours. Alternatively, in [35], a self-organizing hybrid trust model is proposed for both urban and rural scenarios. This approach keeps a history of interactions and then validates the received messages by assigning a credit. This model accepts the message with the highest trust for a



particular event. It can detect fake event locations, source locations, and event times as well as revoke messages from malicious vehicles. However, this model is not evaluated against a baseline. Study [36] embeds the trust certificate of a vehicle with the message that a receiver uses as a weight to evaluate the trust of the data. A vehicle that visits the event location either confirms or denies the event. The vehicle sends all stored feedback to an RSU to forward it to the Certificate Authority (CA) to update a vehicle's trust certificate. Later, vehicles receive updated trust certificates from the CA via an RSU. Thus, the approach suffers from communication overhead to frequently update trust certificates.

In [37], trust is computed from past experiences, neighbouring vehicle information, trust of the vehicle, and the packet delivery ratio. This approach has a trust manager, route manager, and decision manager. The trust manager finds the path trust and calculates the required time to forward a message to the destination. The decision manager informs a nearby RSU if the vehicle does not want to participate in packet forwarding. This model selects a path with the highest trust and lowest delay. The approach considers the packet delivery ratio, delay, and the number of routes. However, they only implement the trusted routing. In [38], a vehicle learns cognitively from the environment and develops contexts around an event to infer the trust. It defines a context which associates a set of interrelated concepts (for example vehicle, evaluation, event). This framework considers experience, opinion, and role for the trust evaluation. For outlier detection, time, speed, and distance thresholds are used. Besides finding the trust level for every report, this approach also finds the confidence of the report. The framework is simulated in both rural and urban scenarios and compared against existing frameworks. However, malicious vehicles can bypass the outlier-based detection process and can send false messages within the acceptable threshold they set for this model. In [39], an RSU is solely responsible for the trust computation of vehicles, and it collects recommendations and feedback from vehicles. Besides this, the RSU creates, manages, and merges clusters for the VANET. The scheme is robust against thwarting Sybil and wormhole attacks. The RSU also identifies malicious vehicles and prevents them joining another cluster. Though they maintain trustworthy clusters, this requires considerable dissemination and cluster management at the RSUs which demands significant computational effort.

### III. PROPOSED RSU ASSESSMENT METHOD AND DRIVER BEHAVIOUR MODEL

The proposed RSU assessment method is used only to assign RSU reward and punishment to drivers who are involved in disputes relating to untrue attack dissemination in the network. This is an extension to the trust framework described in [6]. The Markov model is used for behavioural analysis of drivers with this trust framework.

#### A. Sender – Side Trust Framework

In [6], a trust management framework is presented where a Tamper Proof Device (TPD) is fitted to each regular vehicle providing trust-based access control to the VANET. This framework considers regular vehicles, along with police,

ambulance, and fire service vehicles. The main components of the framework are the vehicles, RSUs, and the Trust Authority (TA). RSUs send incident data to the TA for storage. Vehicles take different roles based on their activities in the network. When a vehicle announces a message, then it is a sender vehicle. When a vehicle receives a message, it is called a receiver vehicle. When a vehicle notices an announcement is invalid, it can become an untrue attack reporter. However, this report can be malicious as well for which the framework arranges some punishment upon an RSU ruling. An RSU collaborates with the vehicles which are visiting the event location near the time to decide on the validity of the event. The vehicles which send feedback when collaboration is running are called clarifiers.

The following equations define the trust thresholds to achieve access control. Equation (1) confirms the trust score of a driver stays in the range of 0.05 to 0.9 irrespective of trust adjustments. Equation (2) relates to access-blocking of a driver/vehicle. Equation (3) regulates the message relaying ability and Equation (4) determines ability of regular vehicles to make announcements.

$$T_i = \begin{cases} 0.05, & T_i < 0.05 \\ 0.9, & T_i > 0.9 \\ T_i, & 0.05 < T_i \leq 0.9 \end{cases} \quad (1)$$

$$T_i = \{Blacklist. \quad T \leq 0.05\} \quad (2)$$

$$Message \ Relaying \ Ability = \begin{cases} False, & 0.05 \leq T < 0.25 \\ True, & T \geq 0.25 \end{cases} \quad (3)$$

$$Message \ Generation \ Ability = \begin{cases} Limited, & 0.05 \leq T < 0.5 \\ All, & T \geq 0.5 \end{cases} \quad (4)$$

Within this framework, regular vehicles are classified as *access-blocked* ( $T = 0.05$ ), *not trusted* ( $0.05 < T \leq 0.25$ ), *lowly trusted* ( $0.25 < T < 0.5$ ), *trusted* ( $0.5 \leq T < 0.8$ ), and *highly trusted* ( $0.8 < T \leq 0.9$ ). The trust of official vehicles is  $T = 1.0$  which is higher than the maximum trust of a regular vehicle ( $T=0.9$ ). A set of rules are employed for governing the actions of regular vehicles [6].

1) *Trust based access control for message announcements*: It is assumed each driver can announce an event if it is seen in the dashboard. It is dynamically updated based on the driver's trust score. Messages are organized into classes and each class is associated with a range of trust scores for access control. Vehicles must achieve a particular trust score to announce messages of a certain class. The framework rewards trustworthy announcements from the TPD after expiry of a withhold timer and optionally penalizes a driver if a driver delays beyond an acceptable limit. The TPD updates trust in relation to announcements, reporting, clarifying, relaying, and beaconing besides adjusting trust with RSU rewards and punishments.

2) *Functional diagram of the framework*: Assume, a trusted sender sends an announcement based on what he/she observes on a road which receivers receive and relay. The event is reported (opposite event) by a reporter after he/she thinks that the event has not occurred at the said location. An RSU upon reception of the report starts collaboration to decide

on the truthfulness of the event. Then it informs the TA of its decision and sends fixed rewards (0.1) / punishments (0.1) to the respective drivers based on the decision. The TPD of the respective drivers combines the RSU assessment with the driver's current trust. Additionally, the TA decides on whether blacklisting of a driver is necessary. This decision is conveyed via an RSU and the driver's TPD implements it. The functionality is shown in Fig. 1.

3) *RSU untrue message detection*: When a reporter reports an untrue attack, an RSU resolves the issue using a sum of weighted feedback calculation. This feedback data are collected from clarifier vehicles. However, when an official vehicle sends feedback, an RSU directly uses this to decide on the dispute. The TA also maintains a driver profile database consisting of the recent records from disputed decisions. A decision results in either a reward or punishment for a driver which are saved into this list. The untrue message detection mechanism is shown in Fig. 2.

In [6], the untrue detection process executes at RSUs to allocate the fixed reward and punishment without considering the severity of incident, driver past behaviour, and RSU confidence in the sender or reporter. Thus, the reward and punishment scheme lacks a sophisticated model to assess the appropriate magnitude of the reward or punishment. These parameters are important to consider as they are related to the event and the driver. They also vary from one event to another, from one driver to another, and the collected feedback. A fuzzy logic-based reward and punishment scheme is a good fit as these parameters are uncertain and inexact, although the reward or punishment should be based on the severity level of the incident. Also, fuzzy logic can approximately imitate the human-level decision making. The fuzzy logic based RSU controller can account for various factors and assign a justified level of reward or punishment for a given driver.

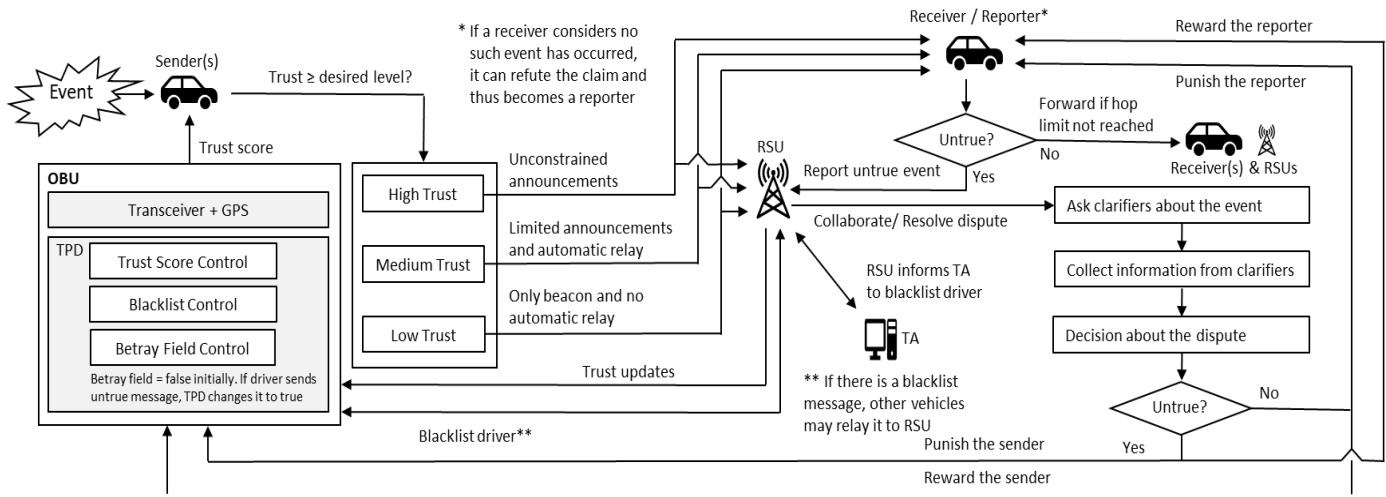


Fig. 1. Functional diagram of the trust framework [6].

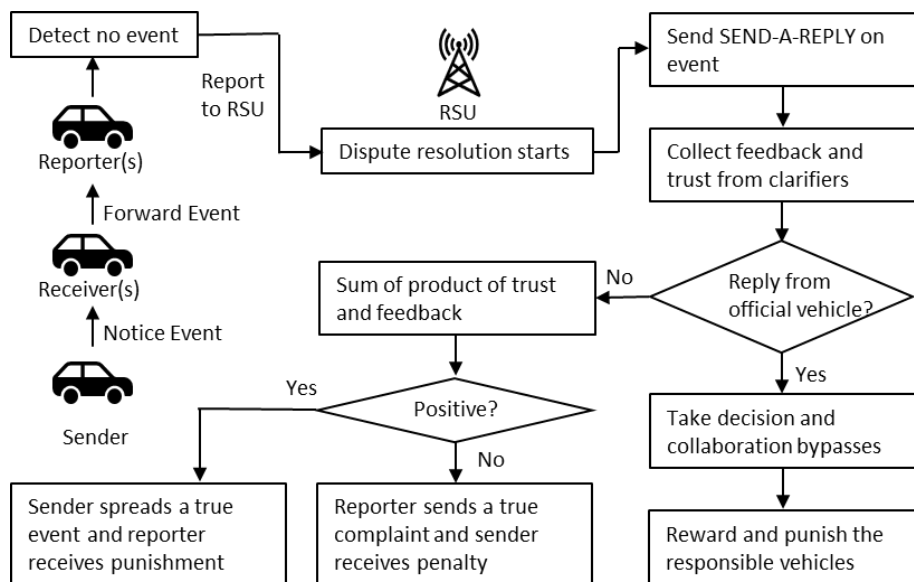


Fig. 2. RSU steps for untrue message detection.

**B. Overview of the Proposed Fuzzy RSU Reward or Punishment Assessment Scheme**

Fig. 3 depicts the proposed fuzzy RSU controller for determining reward or punishment. It starts from the left-hand side where it collects three inputs which are driver past behaviour, confidence in the sender or reporter and severity of the incident. This involves some form of pre-processing of input data to feed into the fuzzy controller. Then these inputs are handed over to the fuzzifier to produce input fuzzy sets. These sets are delivered to the fuzzy inference module which evaluates the fuzzy rules on the input fuzzy sets to produce the output fuzzy sets. These sets are then transferred to the defuzzifier module to generate the crisp number as output variables which is sent to the respective drivers as the level of reward or punishment for their action. A disputed decision at an RSU invokes the execution of this function to calculate the extent of reward or punishment for a conflicted announcement.

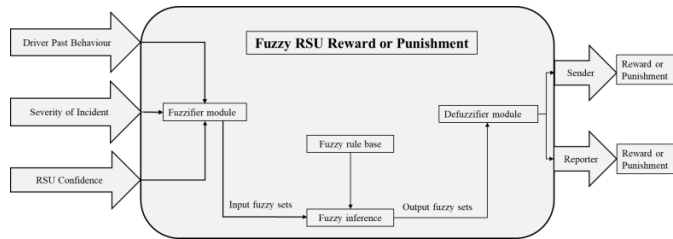


Fig. 3. A block diagram of the proposed fuzzy logic based RSU controller.

1) *Fuzzification*: Fuzzification finds the degree of membership for each input to the fuzzy sets (one or more linguistic variables) using a membership function. To find the degree of belonging, first the shape of the membership functions for every input are defined. Then the degree of belonging to the fuzzy sets are determined for each input. Membership functions are defined intuitively with the help of linguistic variables as shown in Table I.

TABLE I. INPUT FUZZY SETS

Input Parameters	Fuzzy sets
Driver Past Behaviour (DPB)	Good (G), Neutral (N), and Bad (B)
Severity of the Incident (SI)	Not Severe (NS), Less Severe (LS), and High Severe (HS)
RSU Confidence (RCS)	Low (L), Medium (M), and High (H)
Reward/Punishment	Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH)

a) *Driver Past Behaviour (DPB)*: The RSU uses a membership function to convert each input to the degree of belonging to the fuzzy sets. RSUs always send data concerning the rewarded and punished drivers to the TA. An RSU asks for DPB data from the TA. Let, NoP and NoR be the recorded number of rewards and punishments for the concerned drivers from their previous disputed events. When the TA sends NoP and NoR data to a dispute resolver RSU, then it estimates the ratio of NoP/(NoR+ NoP) for the relevant drivers. The RSU feeds this data directly into the fuzzifier to get a degree of belonging of the DPB to each from the set:

{“Good”, “Medium”, “Bad”}. The DPB ranges from 0 to 1 and each DPB value is separated by 0.1. For example, if a driver record contains 4 punishments out of the 10 most recent records, then the DPB is 0.4. The fuzzification returns the fuzzy value as {Good: 0.24, Medium: 0.76, Bad:0}. Fig. 4 shows the membership function for driver past behaviour.

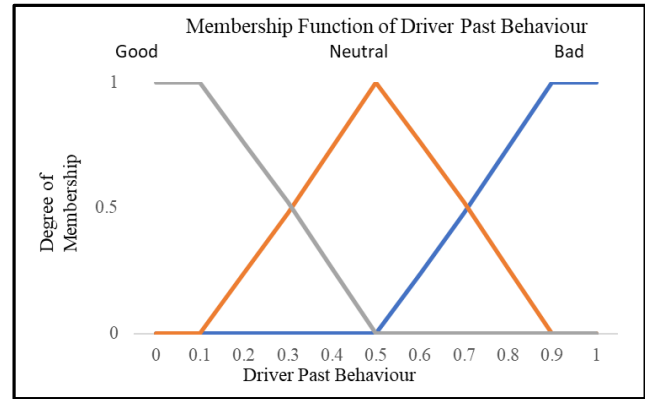


Fig. 4. Membership function for driver past behaviour.

b) *Severity of Incident (SI)*: The list of potential events is shown in Table II for this fuzzy controller. This is just an example list of possible events. In this Table, the event's name, and its severity (assumed impact on human lives) are shown.

TABLE II. POSSIBLE EVENT LIST

Incident Name	SEVERITY LEVEL (LOWEST TO HIGHEST)
Road Clear	0
Debris or Road Spillage (Oil or Muds or Sands)	1
Illegal Waste Dumping	2
Poor Conditioned Road	3
Minor Road Defect (Faded Sign) or Malfunctioning Traffic Element	4
Stranded or Abandoned Vehicle or Obstacle or No Obstacle	5
Major Road Defect (Pothole, Illegal Sign)	6
Diversion or Road Maintenance	7
Severe Weather (Snowy Road or Poor Visibility Due to Fog etc) or Environmental Incident	8
Flood or Fallen Tree on Road	9
Congestion	10
Traffic jam	11
Accident	12

Every RSU stores a copy of this table. When there is a dispute, the RSU looks up the severity level from the table to feed into the fuzzifier. Three fuzzy sets {“Not Severe”, “Less Severe”, and “High Severe”} are used for this input. When the SI is inputted, the fuzzification returns the fuzzy value as {Not Severe: 0.18, Less Severe: 0.82, High Severe: 0}. Fig. 5 shows the membership function for the severity of incident.

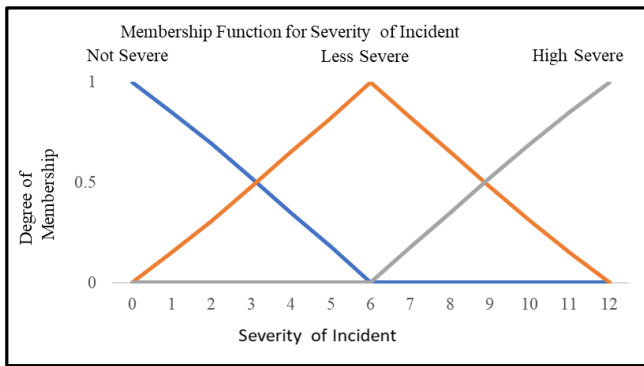


Fig. 5. Membership function for severity of incident.

c) *RSU Confidence in the Sender or Reporter*: An RSU obtains a confidence score from the received feedback using the ratio of feedback that supports the sender’s event to the sum of feedback which supports and contradicts the announcement. This is the RSU’s confidence in the sender. Similarly, the RSU confidence in the reporter is defined as the ratio of feedback that supports the reporter’s report to the sum of the feedback which both supports and contradicts the reporter’s report. Three fuzzy sets are defined for the RSU confidence which are {“Low”, “Medium”, and “High”}. The RSU confidence in the sender or reporter may or may not differ based on the feedback. The fuzzification returns the fuzzy value as {Low: 0, Medium: 0.33, High:0.67} for RSU confidence. Fig. 6 shows the membership function for RSU confidence in the sender or reporter.

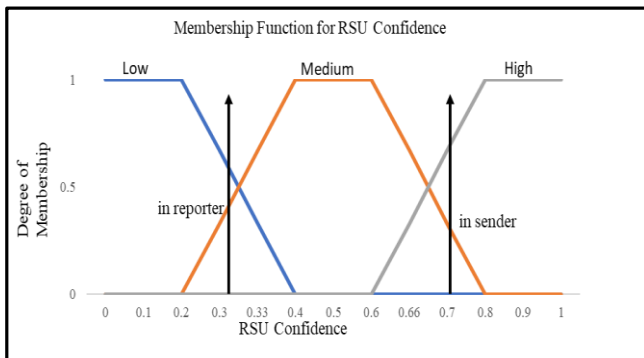


Fig. 6. Membership function for RSU confidence.

2) *Fuzzy rules for reward and punishment*: There is a separate set of rules for reward and punishment. Table III shows the set of rules used for rewarding whereas Table IV is used for punishing drivers. The reason for maintaining two sets of rules is that for one situation the reward may be smaller, but the punishment should be higher. Let output membership be OM. As each input has three fuzzy sets, thus the total number of rules is  $3*3*3=27$  which are given next. The first rule from Table III says as “if the (Driver Past Behaviour (DPB) is Good) AND (Severity of Incident (SI) is Not Severe (NS)) AND (RSU Confidence (RC) is Low), then the Reward is Low”. This explanation goes to other rules as well.

TABLE III. FUZZY RULES USED FOR REWARD

Rules	DPB	SI	RC	R
1	Good	Not Severe	Low	Low
2	Good	Not Severe	Medium	Medium
3	Good	Not Severe	High	High
4	Good	Low Severe	Low	Medium
5	Good	Low Severe	Medium	High
6	Good	Low Severe	High	Very High
7	Good	High Severe	Low	High
8	Good	High Severe	Medium	Very High
9	Good	High Severe	High	Very High
10	Neutral	Not Severe	Low	Low
11	Neutral	Not Severe	Medium	Low
12	Neutral	Not Severe	High	Medium
13	Neutral	Low Severe	Low	Low
14	Neutral	Low Severe	Medium	Medium
15	Neutral	Low Severe	High	High
16	Neutral	High Severe	Low	Medium
17	Neutral	High Severe	Medium	High
18	Neutral	High Severe	High	Very High
19	Bad	Not Severe	Low	Very Low
20	Bad	Not Severe	Medium	Very Low
21	Bad	Not Severe	High	Low
22	Bad	Low Severe	Low	Very Low
23	Bad	Low Severe	Medium	Low
24	Bad	Low Severe	High	Medium
25	Bad	High Severe	Low	Low
26	Bad	High Severe	Medium	Medium
27	Bad	High Severe	High	High

TABLE IV. FUZZY RULES USED FOR PUNISHMENT

Rules	DPB	SI	RC	P
1	Good	Not Severe	Low	Very Low
2	Good	Not Severe	Medium	Very Low
3	Good	Not Severe	High	Low
4	Good	Low Severe	Low	Low
5	Good	Low Severe	Medium	Low
6	Good	Low Severe	High	Medium
7	Good	High Severe	Low	Medium
8	Good	High Severe	Medium	High
9	Good	High Severe	High	High
10	Neutral	Not Severe	Low	Low
11	Neutral	Not Severe	Medium	Low
12	Neutral	Not Severe	High	Low
13	Neutral	Low Severe	Low	Low
14	Neutral	Low Severe	Medium	Medium
15	Neutral	Low Severe	High	Medium
16	Neutral	High Severe	Low	Medium
17	Neutral	High Severe	Medium	High
18	Neutral	High Severe	High	Very High
19	Bad	Not Severe	Low	Very Low
20	Bad	Not Severe	Medium	Low
21	Bad	Not Severe	High	Low
22	Bad	Low Severe	Low	Low
23	Bad	Low Severe	Medium	Medium
24	Bad	Low Severe	High	High
25	Bad	High Severe	Low	Very High
26	Bad	High Severe	Medium	Very High
27	Bad	High Severe	High	Very High

3) *Fuzzy inference:* Human decision making can be approximated by using fuzzy inference. Fuzzy Inference produces fuzzy output sets from the input fuzzy sets. During the fuzzy inference, each rule executes sequentially to obtain the desired output fuzzy set. A rule executes when its antecedent is satisfied. The antecedent of each rule is formed using Fuzzy AND, Fuzzy OR and Fuzzy NOT. The Fuzzy AND and Fuzzy OR are used as fuzzy logical operators. Fuzzy AND returns the minimum of all membership values from the antecedent part whereas a Fuzzy OR returns the maximum to clip or bound the height of output membership function. This means the output of the antecedent define the corresponding degree of membership value of the consequent part of each rule. Fig. 7 shows the output membership function of the reward/punishment where the reward is 0.08 and the punishment is 0.03.

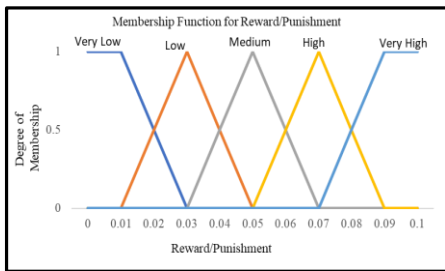


Fig. 7. Output membership functions for reward and punishment.

4) *Aggregation:* In this step, all outputs from the fuzzy inference are combined to get one aggregated fuzzy output set which is fed into the defuzzifier module to get the fuzzy reward and punishment. During aggregation, all similar output fuzzy sets are merged into one and their resultant fuzzy set has the maximum consequent from all similar output fuzzy sets. For example, if three rules produce **Low** output fuzzy set with the degree of membership are 0.05, 0.064, and 0.021, then the aggregation combines these into one **Low** output fuzzy set with the degree of membership equals 0.064.

5) *Defuzzification:* A defuzzification method takes the aggregated output fuzzy membership function and produces one crisp number which is the desired output from this system. Centre of Gravity (COG) is the most widely accepted defuzzification method to find the final defuzzified value. It is the final step of the fuzzy system. The most widely defuzzification method of Mamdani inference is the centroid technique. It delivers a point where a vertical line divides the aggregated output fuzzy set into two equal masses. This method finds a point which represents the COG of a fuzzy set, A, on the interval [a, b]. Here,  $\mu$  denotes the degree of membership. A reasonable estimation can be obtained by sampling a set of points. This is expressed as in Equation (5).

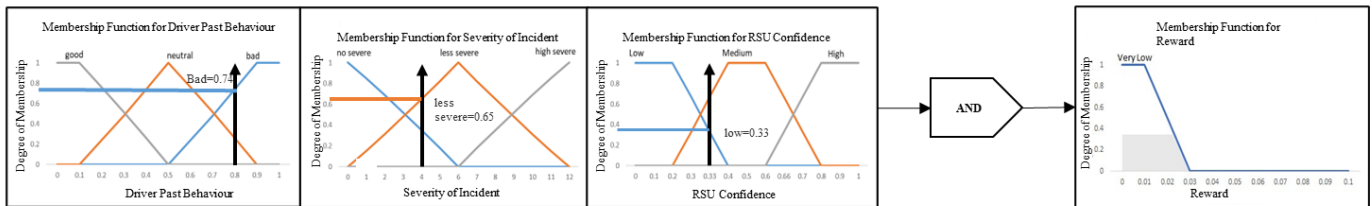
$$COG = \frac{\int_a^b \mu_A(x) x dx}{\int_a^b \mu_A(x) dx} \quad (5)$$

6) An Example Fuzzy Inference for reward

a) *Fuzzy Inference:* In Fig. 8, the truncated execution of two rules for calculating fuzzy reward is shown as they are selected during the fuzzy inference. The execution of other rules is deleted deliberately to save space. The antecedent part of the rules is evaluated first to generate an output from each rule with the height defined by the min or Fuzzy AND operation of the antecedents. The DPB is 0.8, SI is 4, and the RSU confidence is 0.33 for example fuzzy inference. Similarly, fuzzy punishment is determined using the rules from Table IV.

b) *Redundant rule reduction for reward:* When multiple rules produce the same output fuzzy set with different values, they can be combined into one by taking the maximum of all consequent values for the same output fuzzy set; As the rules 10, 11, 13, and 23 have Low output fuzzy set, so taking the maximum gives us Rule 23 with 0.65 as the membership degree for the Low output fuzzy set. As there is only one Medium fuzzy set, it is included directly. Also, Rules 19, 20, and 22 have the Very Low output fuzzy set, thus the maximum consequent value from these three rules is Rule 20 to include in the selected group for aggregation. This situation is depicted in Fig. 9.

R-22



R-23

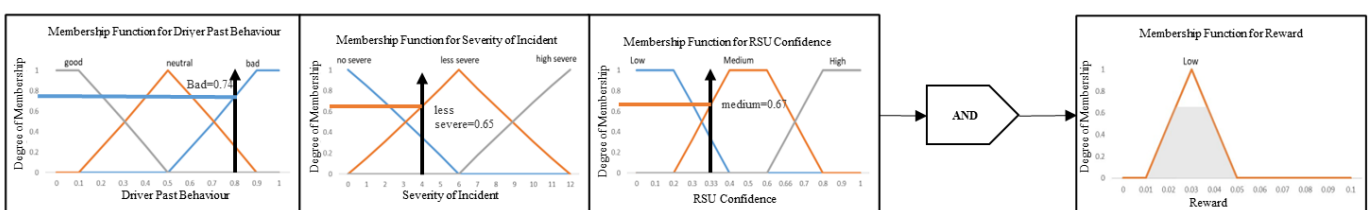


Fig. 8. Fuzzy rule inference for reward assessment.



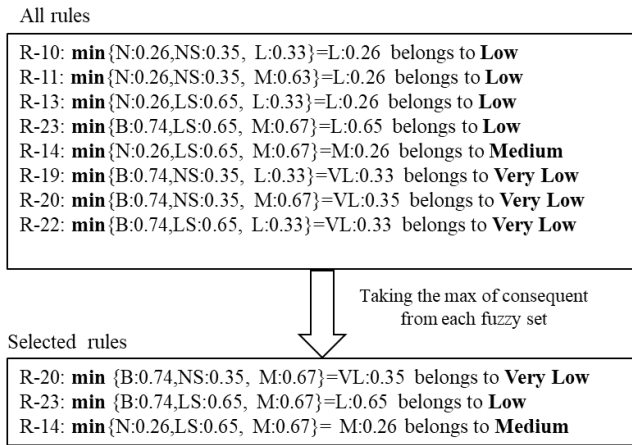


Fig. 9. Redundant rules reduction for reward.

c) *Aggregation of the consequents for reward:* The aggregation is applied to the selected rules which merges them to get the combined output membership function. In this step, only the output fuzzy sets with the highest degree of membership are used where all the output fuzzy sets with a lower value are inclusively covered. This is a combined fuzzy set as depicted in Fig. 10.

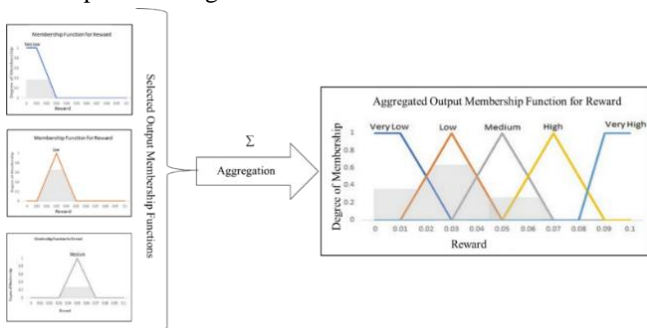


Fig. 10. Aggregated output membership for reward assessment.

d) *Defuzzification for reward:* Fig. 11 shows the assessed reward from the centroid defuzzification method. First, the area is sliced equally as shown in Fig. 11. Then the reward of 0.030014 is obtained as shown with a green arrow on the x-axis.

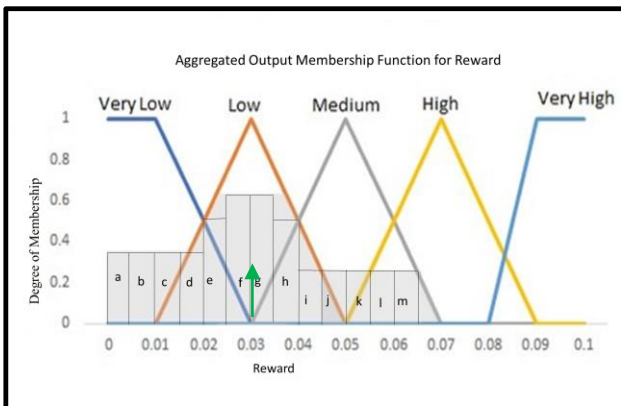


Fig. 11. Defuzzified reward for the example case.

Alternatively, from the “good” state, a driver can improve trust to move into the “very good” state to become a highly trusted vehicle. Once a driver is in the “very good” trust state, it is harder to lose trust as he/she only announces untrue messages with 0.1 probability. As such, the model captures the philosophy that good drivers tend to remain so, and vice versa unless they are encouraged to modify their behaviour. For consecutive untrue message announcements, a driver’s trust score is reduced. In this case, he/she may be moved to the “good” or “normal” state. It is even possible to move into the “bad” or “very bad” state when he turns severely malicious. In this way, a mal-intent driver loses his/her trust and may be access-blocked in the network from where he/she cannot participate in any communication. When a vehicle is access-blocked, an external procedure is assumed to enable him/her to be reset to the “normal” trust state, if permitted.

A clarifier is a vehicle which sends feedback in response to an RSU query. This feedback is consistent with the driver behaviour model. This allows the behaviour of clarifiers to be programmed similarly to the probabilities defined for different trust states of the sender and/or reporter drivers. As the trust model does not evaluate a clarifier’s feedback, their behaviour analysis is not considered as important as the sender or reporter information.

### C. Markov Chain Driver Behaviour Model

Driver announcements are only randomly reported by some reporters with the attack generation probability is set to 0.4 in the analysis of the current model [6]. In the series of experiments, a driver’s behaviour is not modelled to see at what situation they are sending more trustworthy or malicious messages. The disputes only arise from the reporter’s untrue attack messages which are generated randomly when the probability function returns true. This is why a model is developed which can control the message announcement behaviour from the driver. To this end, Markov-chain state transition model is created which can provide driver behaviour modelling and control message announcements. The proposed driver behaviour model is defined with some fixed states and from each states announcement probability for both trustworthiness and maliciousness are defined. There are some fixed conditions to switch between the states of this model.

The trust states of the proposed Markov chain model are defined with drivers lying probabilities to examine their honesty or lying behaviour. These states are defined based on the different trust thresholds set for the framework. Trust states are ordered according to the increasing trust values. Thus, a driver who wants to reach a higher trust state must achieve a higher trust value by announcing only trustworthy messages. A driver switches to another state when its trust score falls outside the range of trust scores for the current state. It is believed that a driver with a higher trust state possess the higher probability to announce more trustworthy messages than those with a lower trust state. With this model, acceptable behaviour means announcing trustworthy messages whereas the unacceptable behaviour means announcing untrue messages. When a trustworthy message is announced, a driver improves the trust score from it. If another driver sends a report about it and the sender driver wins the dispute, then RSU reward is added with the current trust. As a result, the

sender driver possibly makes a transition to another state which is associated with higher trust scores than the current one. In contrast, a driver loses trust score from the announcement of an untrue message when another reporter sends an untrue attack about it and the message is proved malicious by an RSU. Whether an announcement would be trustworthy or untrue, it is directly related to the driver behaviour. Hence, these activities are modelled with the proposed Markov chain-based state transition diagram by setting the probabilistic distribution to control untrue and trustworthy message announcements from each state. From each state, a driver earns rewards from the announcement, clarifying, reporting, forwarding and gets either reward or punishment from an RSU if there is a dispute relating to his/her announcement.

The proposed Markov model has six different trust states out of which one is the access-blocked state. A driver reaches this state when he/she is blacklisted, and his/her trust becomes 0.05. Other states are associated with different ranges of trust values. The six trust states are: “very good”, “good”, “normal”, “bad”, “very bad” and “access-blocked”. The probabilities of sending trustworthy and untrue messages from these states are set as shown in Table V which can be configured with different values to simulate the variation in driver behaviour. Table VI lists the probability of sending untrue attacks in the different trust states which defines the behaviour of the reporter drivers. These values are selected such that drivers with higher trust states send less untrue messages and reports than in the lower trust states. In a real-world scenario, a driver can react differently at different times which can be modelled with a Markov chain-based driver behaviour model using a different probabilistic distribution.

TABLE V. DRIVER’S ANNOUNCEMENT LYING PROBABILITY

Trust States	Probability of Announcing Trustworthy Message	Probability of Announcing Malicious Message
“very good”	0.8	0.2
”good”	0.6	0.4
”normal”	0.4	0.6
“bad”	0.2	0.8
“very bad”	0.1	0.9
“access blocked”	0	0

TABLE VI. REPORTER’S UNTRUE ATTACK REPORTING PROBABILITY

Trust States	Probability of Reporting an Untrue Attack	Probability of Not Reporting an Untrue Attack
“very good”	0.1	0.9
”good”	0.3	0.7
”normal”	0.5	0.5
“bad”	0.7	0.3
“very bad”	0.9	0.1
“access-blocked”	0	0

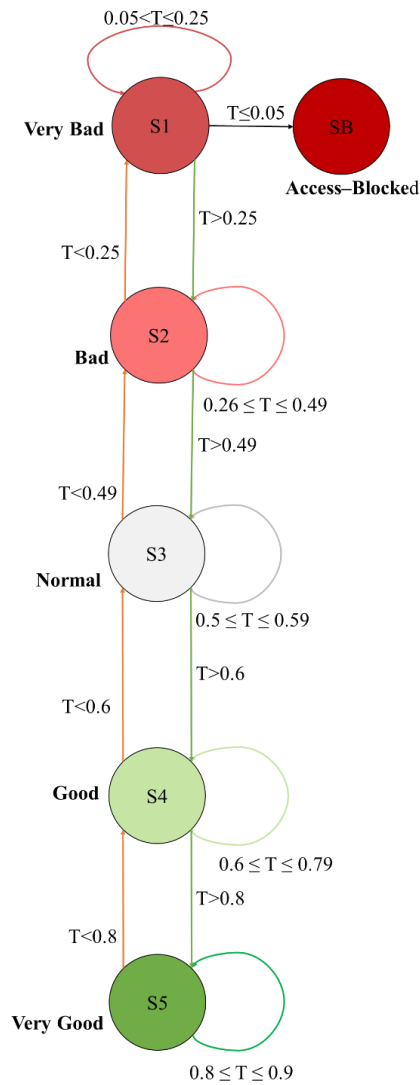


Fig. 12. Markov-chain behavioural model (state transition diagram).

With these trust states, a Markovian state transition-based driver behaviour model is presented, which is consistent with the trust framework described in Subsection III.A. A diagram of this model is shown in Fig. 12. It has fixed trust states, and each state is associated with a range of trust scores. A driver remains in a given state when his/her trust belongs to the range of trust values related to that state. With this model, a driver starts his/her journey from the “normal” state with a trust value equal to 0.5. From this state, a driver sends some announcements and relays events from others.

This model covers the announcement lying behaviour of drivers. Thus, from a “normal” state, a driver can build trust to reach the “good” state if he/she continues announcing trustworthy messages in the network. Also, he/she can lose trust by announcing untrue messages to reach the “bad” state from the “normal” state. He/she can even move to the “very bad” trust state if most of the announcements are untrue. In the worst case, the driver may be access-blocked if his/her trust score reaches 0.05.

#### IV. IMPLEMENTATION

First, Mamdani type fuzzy inference is implemented in MATLAB 2022 for RSU reward and punishment assessment. This provides a built-in fuzzy logic designer app where three inputs are created, their input membership functions, and corresponding fuzzy sets. After that, two different set of rules are entered into the rule editor of, and all the rules are given equal weight. As this is a two-output fuzzy system, two output membership functions and corresponding fuzzy sets are created. The fuzzy OR operator is used for punishment and the fuzzy AND is applied to the reward assessment. There are three fuzzy sets for each input and five fuzzy sets for each output. During the fuzzy inference for each dispute, all twenty seven rules are evaluated individually to produce the fuzzy output sets for each output. The aggregation applies on these output fuzzy sets and then the centroid method is applied on the combined fuzzy sets to return the desired fuzzy reward and punishment. These output values from MATLAB are directly processed and inserted into two different lists in the OMNeT++ to be used with the proposed model. There are eleven possible values of DBP. Hence, for each DBP value, all possible values of SI and RSU confidence are considered. In this way, different combinations of input values are used with the fuzzy system. For each DPB, a list of values is produced, and a different data structure in OMNeT++ is created to enable faster searching for different combinations of input values.

When a dispute decision is ready, an RSU asks for the DPB data from the TA. As the TA maintains a list of past records for all drivers, it can serve the query readily. After that, the RSU calculates the DPB for the relevant drivers. The RSU also calculates a confidence score of the disputing drivers from the collected feedback. Additionally, the RSU determines the severity level of event. The RSU then looks up the corresponding fuzzy reward and fuzzy punishment from the list. These values are directly used in the reward and punishment messages which the RSU announces and forwards to nearby RSUs to announce, too. In this way, each respective driver/vehicle receives the fuzzy RSU reward and punishment.

The following set of experiments use the Markov chain-based driver behaviour model which is implemented inside the TPD of every regular vehicle. This model governs the driver's announcement behaviour by setting the probability of sending trustworthy and untrue messages based on the behaviour state.

#### V. ANALYSIS AND VALIDATION OF THE MARKOV CHAIN-DRIVER BEHAVIOUR MODEL

##### A. Simulation Setup

A set of experiments has been carried out to evaluate the behaviour of sender or reporter drivers by changing their lying probability to observe the proportion of trustworthy and untrue messages generated from different trust states over the simulation period. The trust framework, the fuzzy reward and punishment mechanism, and the Markov state transition model are implemented in Veins [40] which comprises OMNeT++ [41] and SUMO [42]. It is an open-source framework which enables online communication between OMNeT++ and SUMO when the simulation is running. The participating

vehicles run for 5000 simulation seconds (s) on a fixed circular route in the Erlangen city map shown in Fig. 13. 100 vehicles are added at the start of the simulation and their numbers are kept constant throughout the experiment. Vehicles undergo a warm-up period where they move without announcing any event. When the warm-up period has elapsed, a fixed sender driver announces messages periodically at 1000s periodic intervals for each event type starting from the 500s. The simulation includes multiple types of event announcement from the same driver of V[0] for behavioural analysis. The events are scheduled as an accident message at 500s, a debris message at 700s, a road defect message at 900s, a traffic element problem message at 1100s and a tree on the road message at 1300s. Reporters deterministically send untrue attack reports based on the probabilistic distribution defined in Table VI.

As it is required to model the behavioural change of these reporters as well, their trusts are shown in Fig. 15 to 20 beside the sender driver. In this way, a series of experiments are conducted with different initial trust distributions and then the trust evolution is observed to examine the distinctive driver behaviour. A fixed reward and punishment mechanism is used from the disputes to update the trust of drivers so the result can differentiate their behaviour, whether they lie or not and in what circumstances they lie. Other rewards and punishments within the trust framework are not enabled for this analysis of driver behaviour.

In this series of experiments, drivers can send untrue attacks even when their trust score is less than 0.5 which was not allowed with the trust model presented in [6]. If a driver can send a message from a particular trust state, then he/she is allowed to send an untrue attack version of the originated message. The RSUs employ a 120-second collaboration timer to determine the validity of a dispute from the clarifier feedback. Thus, the verification time delays the reception of rewards and punishments from an RSU. Also, RSU reward is disseminated in one message and RSU punishment is sent in another message to the driver which also adds an additional delay besides their availability to an RSU and wireless collisions. Thus, the collaboration timer and a vehicle's availability, delays the reception of reward or punishment at the vehicles concerned. Table VII lists the parameters for the experiments.

There are two sets of experiments conducted for examining driver behaviour model. In the first set of experiments, clarifiers send opinion based on the witness and a probability distribution. If a driver with a "very high" trust state generates an event, then the clarifiers send positive opinions with 0.8 probability and negative opinions with 0.2 probability. For the "good" trust state, clarifiers send positive opinions to 60% of cases and negative opinions to 40% of cases. A message from a "normal" trust state originating from a driver gets 40% positive and 60% negative opinions. From the "bad" state, clarifiers deny announcements 80% of the time and support only 20% of the time. From the "very bad" state, clarifiers deny announcements 90% of the time and support only 20% of the time. This distribution can be changed as needed to model the variation in a sender or reporter driver's behaviour. In the second set of experiments,

clarifiers send feedback based on the probability distribution of their trust states as shown in Table VIII and the reporters send report based on the Table VI.

TABLE VII. SIMULATION PARAMETERS

Parameters	Values
Fuzzy reward and punishment	Varied
Fixed reward and punishment	0.1
Data Collection Nature	1. When all features enabled 2. When only RSU judgement applied
Simulation Period	5000s
Warm-up Period	500s
Announcement Interval	1000s
Initial Trust	Uniform distribution (0.5-0.6)
Number of Vehicles	100
Multiple types of Events Generated	Yes
Number of RSUs	12
Number of TA	1
Attacker Model	Untrue and Inconsistent Behaviour
Untrue Attack Generation	Based on the message class
Announcement Reward	Maximum of 0.8 (0.1 to 0.8 based on delay and distance)
Clarifier Reward	Maximum of 0.8
Relaying Reward	0.002
Collaboration Timer	120s

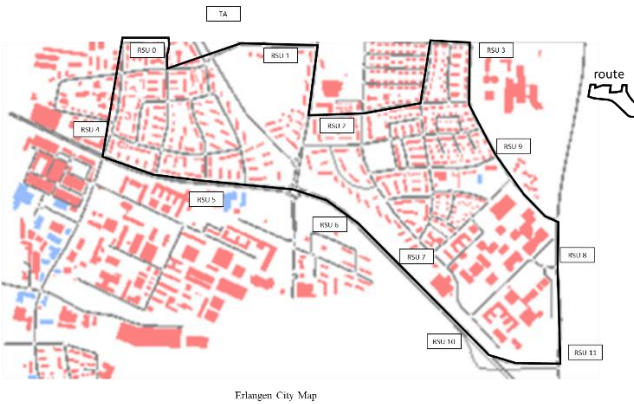


Fig. 13. Erlangen city map from [40].

**B. Behavioural Analysis of the Sender and Reporter Drivers**

1) *Uniform Trust Distribution (0.4 to 0.5):* In this experiment, all vehicles are inserted, and drivers are assigned their initial trust using a uniform distribution in the range of 0.4 to 0.5. Fig. 14 records the lying behaviour data from this experiment. The x-axis shows the simulation seconds, and the y-axis shows how trust score changes from the rewards and punishments. Though 100 drivers are present, the trust records of most drivers are not included in this chart for simplicity as their trust remains constant.

a) *Results:* There is an accident message scheduled from V0 which is not announced as the trust of the driver is insufficient. This is why a change in the trust data only commences from 700s when V[0] announces a debris message. As the trust of V[0] is low, driver has a higher chance to lie to others which is modelled using a probabilistic distribution. As the driver of V[0] lies, the drivers of V[2] and V[3] improve their trust by sending untrue attacks and they win against the driver of V[0]. This is visible from the chart. The other two drivers do not participate in the reporting process and hence their trust remains constant over the simulation period. Also, V[5] wins one dispute over V[0] which is indicated by a trust increment at about 3600s. It is seen that the announcement of trustworthy messages varies based on a driver’s trust state.

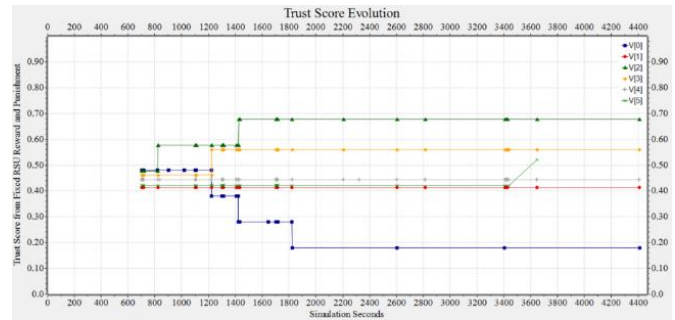


Fig. 14. Behavioural analysis of the drivers with trust (0.4-0.5).

2) *Fixed trust score of 0.9:* In this experiment, all drivers start from a very high trust state with a trust score of 0.9. Fig. 15 records the lying behaviour data from this experiment. The driver of V[0] is set to send 90% trustworthy and 10% of malicious announcements from this state.

a) *Results:* It is seen very few announcements are reported from V[1] and V[5] as they are also assigned “very good” trust states though their malicious probability is 0.2. This results in the constant trust score of the driver of V[0] while some reporters send untrue attacks maliciously which are disproved at RSUs. Hence, some reporters receive RSU punishments at different times during the latter part of the simulation. The drivers of V[1] and V[2] send only untrue attacks for which their trust is reduced. Thus, as configured, with a higher trust state there are fewer untrusted messages announced. Additionally, reporter drivers send fewer untrue attacks when their trust scores and corresponding trust states are higher.

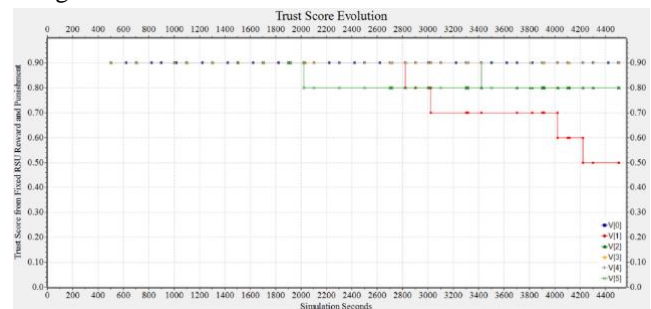


Fig. 15. Behavioural analysis of the drivers with trust=0.9.



C. Behavioural Analysis of Sender with Fixed Trust (0.6) of Reporter and Clarifier

1) *Simulation setup:* The set of parameters are same as they are listed in Table VII. 100 vehicles are added and then they elapse a warm-up period. One sender driver of V[0] sends message periodically and five reporters from V[0],...,V[5] send reports based on the probability distribution defined in Table VI. Table VIII lists the feedback generation probability of clarifier vehicles. In the next two experiments, clarifiers send feedback based on the probability distribution of their trust states. Also, the reporters send report based on the probability distribution of their trust states. After that their behaviour are captured in Fig. 16 and Fig. 17.

TABLE VIII. CLARIFIER’S FEEDBACK PROBABILITY

Trust States	Probability of Sending Positive Feedback	Probability of Sending Negative Feedback
“very good”	0.8	0.2
”good”	0.6	0.4
”normal”	0.4	0.6
“bad”	0.2	0.8
“very bad”	0.1	0.9
“access blocked”	0	0

2) *With sender driver’s trust of 0.3:* Fig. 16 shows the trust score evolution of six vehicles. In this experiment, the trust of sender driver is set to 0.3, the trust of the reporter and the clarifier is set to 0.6. Clarifiers send opinion when an RSU asks based on their probability distribution of trust states. As, the trust score of the reporter and clarifier belong to the “Good” trust state. With these settings, reporter vehicles send untrue attacks with only 30% of cases and clarifiers send positive opinion in 60% of cases when they observe event on road. They also send negative feedback with 0.4 probability if they do not see the event on the said location. In this way, their communication is achieved.

a) *Results:* Until first 1400s, there is no dispute, and no trust change observes. After that, there are many reports announced for which the driver of V[0] only wins. As the reporters sends report maliciously. The reporter driver of V[5] loses all disputes which reduces trust to 0.2 at 2400s. The driver of V[3] does not report any announcements from V[0] until 2800s as seen from the chart. After this time, V[3] sends many reports which are proved false to RSU, so the trust is reduced to 0.2 at 4030s. Other reporters excluding V[4] occasionally sends untrue attacks and they also lose the disputes to V[0]. In this way, V[0] builds trust as always it announces trustworthy messages and some reporters being malicious lose trust. In Fig. 16, the sender driver slowly improves trust from only the RSU rewards, and the malicious reporters receive only RSU punishments as their reports are proved false by RSUs. As the sender is trustworthy throughout the simulation, all reporters receive RSU punishments which reduces their trust score, and their trust state moves from “normal” to “bad” and then “very bad” as a consequence.

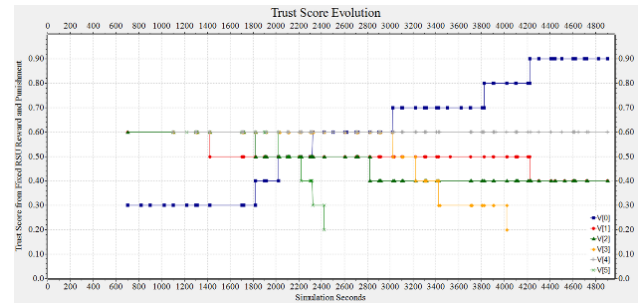


Fig. 16. Behaviour analysis of driver when trust score is 0.3.

3) *With sender driver’s trust of 0.7:* In this experiment, sender driver starts with 0.7 trust score and from “normal” trust state whereas the clarifier’s and reporter’s trust state are same to the previous experiment. They both start with the “Good” trust state.

a) *Results:* In this experiment, the driver of V[0] only builds trust as always send trustworthy announcements. Reporter drivers V[2], V[5], and V[3] send reports maliciously for which they lose all disputes. These are noticed by the trust decrements in Fig. 17. Reporter V[4] does not send any report and V[1] sends only one untrue report for which it receives the RSU punishment. When a reporter sends a malicious report and receives RSU punishment, then subsequently it sends more report maliciously as their trust states moves toward “bad” state. As the sender driver reaches “Good” trust state early in Fig. 17, it only announces trustworthy messages and when reporters send false reports, they receive RSU punishments. As they move from “Normal” to “Bad” states the reporters send more false reports and hence they receive more RSU punishments.

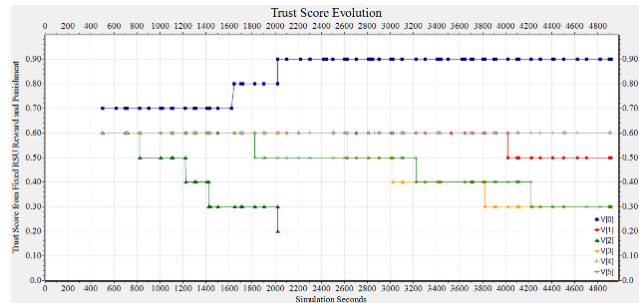


Fig. 17. Behaviour analysis of driver when trust score is 0.7.

VI. PERFORMANCE COMPARISON OF THE PROPOSED FUZZY JUDGEMENT VS. FIXED RSU JUDGEMENT

A. Performance Comparison Using Only RSU Reward and Punishment

1) *Simulation setup:* The fuzzy reward or punishment method is applied when dispute decisions are ready at RSUs. Hence, the comparison is made between the fuzzy vs fixed reward and punishment schemes. To this end, a series of experiments is conducted to evaluate their performance. When the warm-up period has elapsed, a fixed sender driver of V[0] announces messages periodically at 1000s periodic intervals for each event type starting from the 500s. In this set of

experiments, multiple types of event announcement are considered from the same driver V[0] for this comparison which is announced similarly in the behaviour analysis. When they are announced, a fixed set of reporter drivers of vehicles V[1], V[2], V[3], V[4], and V[5] deterministically sends untrue attack reports after their reception. The trust data is recorded separately for both the fuzzy and fixed systems. The trust framework has other TPD rewards and punishments which are omitted for differentiating these assessment results since fuzzy logic is only used to improve the RSU reward and punishment mechanism. Updates to trust from the fuzzy and fixed reward and punishment schemes are shown on graphs to compare them. After this, two trust density distributions are presented for each scheme. One shows the initial trust data, and the other provides the trust data when the simulation ends.

2) *Scenario 1 – Trust Updates from the Fuzzy RSU:* Fig. 18 shows the trust score evolution for six vehicles only. Trust is updated only from RSU judgements. The x-axis represents simulation seconds, and the y-axis shows the updated trust from the fuzzy RSU unit. During this experiment, the driver of V[0] sends scheduled events periodically. The initial trusts are assigned from a uniform distribution with the range of 0.5 to 0.6. The driver of V[0] starts with a “normal” trust state which governs his/her behaviour in message announcements. This state is configured to send more malicious messages than the trustworthy messages in the state transition model.

a) *Results:* It is seen that V[0] builds trust from the fuzzy rewards as it announces only trustworthy messages while the reporters get fuzzy punishments which reduces their trust as the simulation progresses. First, V[0] moves to “Good” state and then to “Very Good” states. V[0] reaches the maximum trust at about 1800s with “Very Good” state. Alternatively, reporters in this experiment send untrue reports and move from the “normal” to the “bad” trust state. For example, the driver of V[2] always sends false reports and receives RSU punishments. His/her trust score plunges to the lowest value of 0.34 at 2900s due to being malicious. It is noticeable that the first reward of V[0] is highest as the driver has no punishment records in the DBP whereas the latter judgements are not seen as high as the first one. Since, some latter rewards are from the disputes relating to the less severe announcements. Alternatively, the fuzzy RSU punishments are not very harsh initially which is seen in the reporter vehicles V[1] and V[5]’s punishments. They increase slightly in the later punishments where the severity of incident, punishment records in the DPB, and RSU confidence influence the outcome. In later disputes, event severity levels are different which vary the punishment. Hence, the rewards / punishments vary throughout the experiment whereas in the fixed reward scheme trust increments / decrements are fixed irrespective of mitigating factors. So, with the fuzzy scheme, a driver has more chances to improve trust scores from subsequent announcements and trustworthy reporting. This way their network participation lifespan is extended. Fig. 19 depicts the trust scores of all vehicles which participated in this experiment. It is noticeable from this figure that the trust

scores of most vehicles are unchanged throughout the simulation as they do not report or announce any messages and there is no forwarding or clarifying reward for others.

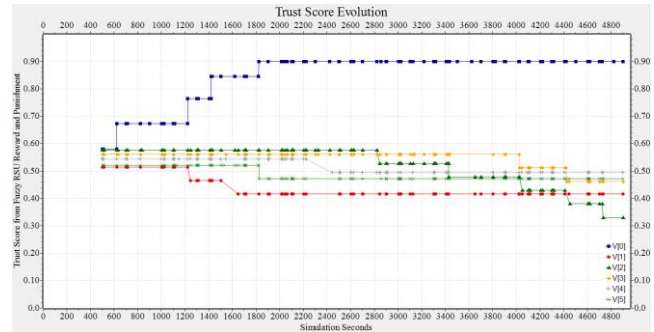


Fig. 18. Trust score evolution of six vehicles from the fuzzy reward and punishment.

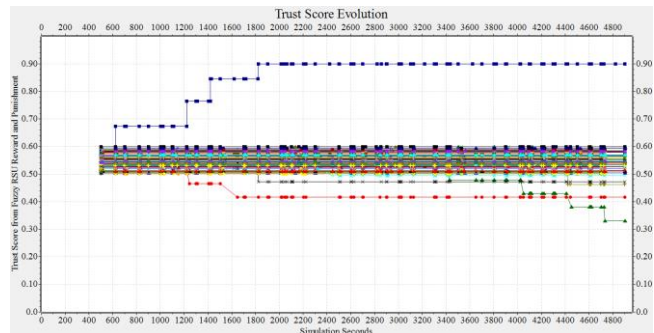


Fig. 19. Trust score evolution of all vehicles with the fuzzy reward and punishment.

Fig. 20 shows the trust score density distribution of vehicles collected at the beginning and at the end of the simulation. The initial trust score of all vehicles is between 0.5 and 0.6. The right-side chart shows that V[0] reaches 0.9 which is marked by a dot. Most vehicles do not see any trust score alterations apart from three vehicles which are the reporters in this experiment. This is because general vehicles do not engage in any disputes from which they can earn or lose trust. Additionally, they are not given any reward from the forwarding or other activities. The long gap in the right chart means no vehicle other than V[0] achieves this score due to the experimental design and this result is as expected. Also, the driver behaviour model governs their honest and dishonest announcements. It is seen with the fuzzy system, the magnitude of reward and punishment are more nuanced than the fixed system so vehicles have more time to correct their future behaviour and resume normal operation. The blacklisting of a vehicle or reaching the highest trust is also delayed when using the fuzzy system. Even so, in the fuzzy system when only RSU rewards and punishments are given, the sender vehicle still reaches 0.9 trust. The reporter vehicle reaches a low trust score though it has some trust left to carry out further communication and it could choose to correct its behaviour and achieve good trust score in due course. Overall, with the fuzzy system the trust scores are more stable than the fixed system in the sense that when trust is gained or lost it does not change dramatically. Additionally, the fuzzy system considers environmental dynamics for fuzzy judgements, e.g.,

event severity, driver past behaviour and confidence score which is appropriate when reviewing disputes.

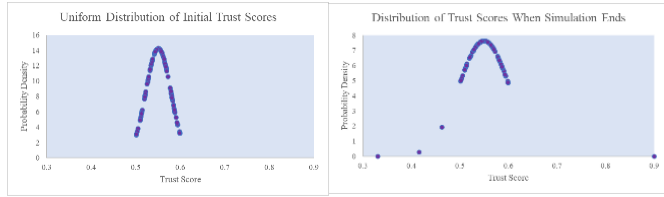


Fig. 20. Distribution of trust scores at the start and the end.

3) Scenario 2 – Trust Updates from the Fixed RSU: The next experiment measures the trust score of vehicles only from the fixed RSU reward and punishment mechanism. In Fig. 21, simulation time is on the x-axis and the y-axis shows the trust score. This is conducted with the set of parameters defined in Table V, but the RSU reward and punishment is fixed (0.1) for every driver.

a) Results: V[0] sends a malicious message initially and receives an RSU punishment that reduces its trust below 0.5. From this stage, it is configured to send more malicious messages 80% of time. Thus, its trust subsequently decreases from RSU punishments. When its trust score belongs to the “very bad” state, it sends all malicious messages. In this way, its trust is reduced to 0.05 which meets the condition to block its access. Alternatively, the reports from V[1] wins all disputes and hence its characteristic shows an upward trend. Also, V[4] and V[5] win two other disputes over V[0] and hence receive RSU rewards. It should be noted that there are no events after the 4400 seconds. It is seen that trust adjustments are faster in the fixed RSU judgement system as it assigns a higher amount (0.1) irrespective of event type and driver behaviour compared to the fuzzy system which provides a value in the range 0.01 to 0.1 based on the evaluation result. When only RSU rewards and punishments are given, in the fixed system vehicle V[0] is access-blocked. This is due to the RSU decisions about the announcement being untrue along with the magnitude of the penalty. Fig. 22 shows the trust scores of all vehicles in this experiment. In this figure most of the vehicles do not change their trust score as they do not participate in any reporting or announcement. Besides, they are not given any reward for clarifying and forwarding.

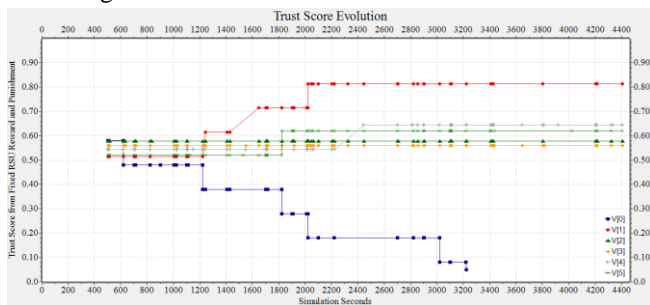


Fig. 21. Trust score evolution from fixed reward and punishment.

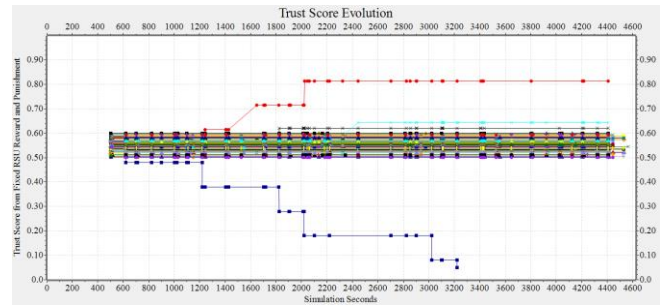


Fig. 22. Trust score evolution with fixed reward and punishment.

Fig. 23 shows the initial trust and the final trust distribution in two density curves. The first density chart shows the trust scores of all vehicles generated from a uniform distribution. However, the right-hand chart plots the trust scores of all vehicles when the simulation ends. As expected, in the second chart, the trust of most vehicles is unchanged as they do not engage in any disputes from which their trust can change. The right-hand chart confirms some vehicles with positive behaviour build their trust from truthfully reporting activities whereas the sender V0 is access-blocked, leaving its trust at 0.05. With this fixed RSU judgement, vehicles have less opportunity to modify their behaviour and vehicle access-blocking is more likely as shown in the right chart in Fig. 21.

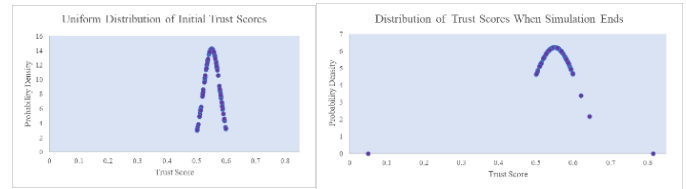


Fig. 23. Distribution of trust scores at the beginning and the end.

## VII. DISCUSSION

The trust model with the fuzzy reward or punishment assessment scheme controls the broadcasting of messages at the sender side based on the trust score of drivers / vehicles so a receiver driver / vehicle can believe in a message instantly and does not need to take any further action. By regulating the ability to broadcast, malicious vehicles, once identified, are unable to continue to broadcast messages. Though, blacklisting is present in most existing approaches it requires the trust score to reach zero. Therefore, a malicious vehicle can create many hazardous problems before being blacklisted. Furthermore, driver decision times (response times) are reduced as trust does not need to be verified on a per message basis. This also reduces the communication overhead. It uses the RSU for ruling on a dispute when needed using clarifier feedback, rather than approaches which gather direct and/or indirect trust or opinions from surrounding neighbours, which may include false recommendations from malicious vehicles. However, the application of fuzzy reward or punishment assessment is only limited to the dispute resolution process at the RSU. Additionally, it requires presence of clarifier vehicles to send feedback to assist in the resolution of disputes.



### VIII. CONCLUSION AND FUTURE WORK

In this paper, a Mamdani fuzzy logic based RSU reward and punishment assessment scheme is presented. This application considers event severity, driver past behaviour and RSU confidence (calculated from the feedback of the clarifier vehicles) to determine an appropriate level of reward or punishment for the drivers involved. The reward and punishment mechanism uses a different set of rules to assess the output. The fuzzy RSU reward or punishment assessment scheme is an extension of the fixed RSU judgement mechanism in the previous sender-side trust framework [6]. The RSU ruling is only needed when there is a dispute (when both an event and opposite event exist) in the network. The fuzzy RSU controller is invoked only when it receives untrue attack reports, which is expected to be occasional. A Markov-chain based driver behaviour model is also included to control the announcement behaviour of driver when conducting the series of experiments.

The fuzzy approach is compared against a fixed reward and punishment scheme. Trust evolution timelines are provided in each case along with trust density distribution curves when only the RSU mechanism is active. The results suggest the fuzzy system achieves a more stable trust environment. This assessment also employs a Markov-chain based driver behaviour model whereby good drivers are assumed to behave in a positive manner more generally, and vice versa. This allows the nuanced fuzzy controller decisions to encourage drivers to behave better, and to provide fairer allocation of rewards and punishments based on several factors. However, in the future other inputs to the fuzzy controller could be considered.

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# Investigating the User Experience and Evaluating Usability Issues in AI-Enabled Learning Mobile Apps: An Analysis of User Reviews

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**Abstract**—Integrating artificial intelligence (AI) has become crucial in modern mobile application development. However, the current integration of AI in mobile learning applications presents several challenges regarding mobile app usability. This study aims to identify critical usability issues of AI-enabled mobile learning apps by analyzing user reviews. We conducted a qualitative and content analysis of user reviews for two groups of AI apps from the education category - language learning apps and educational support apps. Our findings reveal that while users generally report positive experiences, several AI-related usability issues impact user satisfaction, effectiveness, and efficiency. These challenges include AI-related functionality issues, performance, bias, explanation, and ineffective Features. To enhance user experience and learning outcomes, developers must improve AI technology and adapt learning methodologies to meet users' diverse demands and preferences while addressing these issues. By overcoming these challenges, AI-powered mobile learning apps can continue to evolve and provide users with engaging and personalized learning experiences.

**Keywords**—Human-Computer Interaction (HCI); Artificial Intelligence (AI); user reviews; AI-Enabled Mobile Apps; usability

## I. INTRODUCTION

There is a growing demand for mobile apps incorporating artificial intelligence (AI) as more people use them to enhance their daily lives. The size of the AI apps market is expected to expand rapidly in the coming years [1]. By incorporating AI into mobile apps, programmers can introduce cognitive and logical characteristics that lead to a diverse selection of smartphone applications. [2]. Implementing AI technology is prevalent across various facets of human existence, particularly within the field of education [3].

Mobile learning applications incorporating AI provide a sophisticated educational atmosphere, progressive pedagogical techniques, and easily accessible platforms for learners [4]. Recent studies have noted the positive impact of AI-based in English education [5]. The increasing trend of mobile assisting language learning apps has resulted in the utilization of AI-powered speaking applications equipped with speech evaluation mechanisms to facilitate English as a foreign language (EFL) speaking exercises [6]. Besides, the current wave of artificial intelligence is already impacting the management and domination of math education apps [7].

However, AI systems must demonstrate effectiveness and efficiency while ensuring user satisfaction. This is crucial

because usability strongly influences the success and quality of software [8]. Therefore, to evaluate the usability issues in AI-enabled learning mobile apps, this research will utilize usability key factors such as user satisfaction, efficiency, and effectiveness, commonly considered when assessing mobile apps [9] [10].

The rapid expansion of mobile devices has resulted in an upsurge in mobile applications accompanied by user reviews [11]. In mobile app marketplaces like the Apple Store and Google Play, users can rate apps and post reviews about adding a feature, reporting an issue, and their experiences using them. These reviews can be rich sources of information for developing future software versions [12]. In other words, developers can improve software quality and identify missing features by analyzing user reviews [11]. The previous study has shown that these reviews possess information related to user usability [13]. Thus, analyzing app reviews is a helpful way to identify any usability problems that users might face and to reveal any looked-for improvements [14]. Groen et al. [15] discovered that these app reviews have the ability to discover quality features directly affecting users.

Despite the wide adoption of AI-enabled learning mobile apps, there is still a need to better understand the specific usability issues associated with these apps. The purpose of this study is to address this gap. Additionally, while several studies [11] [14] [16] [17] [18] analyzed user reviews to detect usability issues to enhance software quality, there is insufficient research regarding the specific examination of AI-enabled learning apps. This is an area that our study aims to investigate and address.

In response to the identified gaps, this research makes notable contributions to the field of AI-enabled mobile learning apps. Through a comprehensive analysis of user reviews focusing on user experience and usability issues, our study offers a robust understanding that can assist app developers and designers in improving the design and development of AI-enabled mobile learning apps. Understanding user perspectives can address usability issues, improve user satisfaction, increase effectiveness, and enhance efficiency in mobile learning experiences. The research findings also contribute to the broader understanding of AI in education, highlighting the challenges and opportunities associated with AI integration in mobile learning apps, thus facilitating their wider acceptance and use among learners and educators.

This study aims to perform a thorough usability evaluation

of AI-enabled mobile learning apps, following ISO 9241 standards [9] [10], measuring effectiveness, efficiency, and satisfaction. The primary objective is to identify potential usability issues affecting user satisfaction, effectiveness, and efficiency. Additionally, to identify the primary challenges and deficiencies that AI-enabled learning applications encounter in delivering satisfactory performance. This study provides valuable information for application developers and designers to improve app usability by analyzing user reviews of various AI-enabled mobile applications in the education category. The findings help identify the apps with significant problems and weaknesses, showing where improvements should be focused. Based on these goals, this research aims to answer the following research questions:

**RQ1:** How is the user experience with AI-enabled mobile learning apps?

**RQ2:** To what extent do usability issues impact user satisfaction, effectiveness, and efficiency in AI-enabled mobile learning apps?

**RQ3:** What are the most prevalent usability issues related to AI in AI-enabled mobile learning apps?

The responses to the research questions mentioned above will offer crucial insights into the most prevalent usability issues related to AI-enabled mobile applications for language learning and educational support. These insights can be leveraged to identify areas that require improvement and formulate effective strategies to enhance the usability of these apps. Ultimately, this research aims to improve the usability of AI-enabled mobile learning apps, thereby enhancing user satisfaction, effectiveness, and efficiency.

The paper is organized as follows: Section II presents usability evaluation in mobile applications, and leverages user reviews for detecting usability issues in diverse mobile applications. Then, Section III explains and justifies the research methodology utilized in this study. Section IV presents the results, while Section V engages in the discussion of the results. Section VI focuses on addressing potential threats to validity. Finally, Section VII concludes the paper and discusses future work.

## II. RELATED WORK

This section highlights the most usability evaluation in mobile apps and the utilization of user reviews to detect usability problems in mobile apps.

### A. Usability Evaluation in Mobile Application

Many studies have conducted usability evaluations of mobile apps [15] [19] [20]. For instance, a systematic review by [19] showed a literature review on a comprehensive examination of the usability of mobile apps. They found that the definition of ISO 9241-11 has been mostly used in HCI, followed by ISO 25010 definition. Furthermore, they discovered that efficiency, satisfaction, and effectiveness were the most frequent attributes. Another systematic study by Sunardi et al. [20] introduced a literature review of the most usability evaluations. They observed that satisfaction, efficiency, and effectiveness are the most well-known usability evaluations. Another systematic review by [21] discussed mobile app

usability in different mobile app categories. They identified frequent usability for mobile applications and required design features for a particular mobile application category. Another study by [22] proposed a model that aims to employ opinion mining to evaluate the subjective usability of the software automatically. This model is centered on three crucial quality factors of usability: effectiveness, efficiency, and satisfaction. Moreover, Alhejji et al. [23] completed a comprehensive analysis, assessment, and comparison of the usability of mobile banking apps, considering both iOS and Android platforms in Saudi Arabia. The researchers evaluated usability based on effectiveness, efficiency, and satisfaction, as defined by ISO 9241.

### B. Leveraging user Reviews for Detecting Usability Issues in Diverse Mobile Applications

Previous studies used user reviews to extract valuable information [11] [14] [16] [17]. Felwah and Rita [14] analyzed 1236 reviews from 106 mental health apps to detect usability issues. They categorized usability issues into six groups, finding that the results could offer app developers valuable design advice to enhance the usability of mental health apps. The further study analyzed [16] user reviews in stroke caregiving applications to identify usability problems. They found some usability issues such as errors, efficiency, and effectiveness because of the misunderstanding of the user needs of app developers. The authors categorized the user reviews as negative or neutral using the usability evaluation criteria of Nielsen and Bevan, as well as considering the extent of the user experience. In addition, another work by [17] reviewed mobile applications created for the COVID-19 pandemic. The writers gathered feedback from users in the form of ratings and reviews as well as information on the objectives and features of the app. The review's results emphasized the need for new application development and further improvement, revealing design features like ease to use, cultural sensitivity, usefulness, privacy, responsiveness, security, flexibility, support, performance, and reliability. Another work by Pawel and Anna [11] investigated the potential of user reviews to extract usability and user experience problems in WhatsApp. They identified seven usability factors that were connected to the issues that were reported. Using different dictionary sources, they used a sentiment analysis by grouping all the negative and positive words from the user reviews. Another research study by [24] proposed employing machine learning (ML) techniques to ascertain users' perspectives. Furthermore, they utilized and compared the effectiveness of five different ML classifier algorithms. Lastly, [18] explored user reviews and discovered novel usability issues associated with disaster applications by adapting a pre-existing usability framework. The existing research on usability in mobile app user reviews has been extensive. However, the usability of AI-enabled mobile applications for language learning and educational support has received limited attention in previous research. Therefore, this study aims to analyze user reviews and uncover potential usability issues associated with AI mobile applications in this specific domain.

## III. METHODOLOGY

Our motivation is to empirically evaluate usability issues in AI-enabled mobile applications designed for language learning

TABLE I. APP'S STATISTICS

App Group	App Name	Number of Reviews
Language Learning	ELSA: Learn And Speak English	45,576
	Duolingo: language lessons	276,819
	Cake - Learn English & Korean	80,309
Educational Support	Socratic by Google	5,789
	Microsoft Math Solver	3,651
	Symbolab: Math Problem Solver	1,248
	Photomath	22,1559

and educational support. To accomplish this, we have devised an approach comprising six steps, which we will refer to as A, B, C, D, E, and F, as shown in Fig. 1. This section provides a detailed description of each step.

#### A. Identifying AI Mobile Apps Designed for Self-Education

Our objective is to assess the usability issues in mobile applications designed for language learning and educational support using AI. To achieve this, we have identified a specific subset selection criteria to filter out the relevant apps. These selection criteria are outlined below.

- **Initial Selected Apps:** We selected the top 100 worldwide downloaded mobile applications in the education category. We sourced this information from the ranking lists on data.ai<sup>1</sup>. This selection aimed to include the widely used apps in our study.
- **AI-Enabled Mobile Apps:** Then, we manually investigated the description of each initialed selected top 100 apps in the education category to ensure whether an app uses AI features, as shown in Fig. 2.
- **Number of App Reviews:** We excluded apps with reviews less than 1000.

This study identified mobile applications in the education category that explicitly incorporated AI technology. we aimed to investigate the usability issues associated with apps that used AI for educational purposes. After reviewing the top 100 apps in the education category based on the selection criteria, we found that only thirteen apps met our selection criteria. Since most of our study heavily relies on user reviews, we want to ensure these apps have sufficient user reviews. Therefore, we discarded apps with reviews of less than 1000. Additionally, we excluded apps unrelated to language learning and educational support to ensure our analysis focused on relevant apps. As a result, this allowed us to filter out seven AI-enabled mobile applications, namely: *ELSA: Learn And Speak English*, *Duolingo: language lessons*, *Cake - Learn English & Korean*, *Socratic by Google*, *Microsoft Math Solver*, *Symbolab: Math Problem Solver* and *Photomath*. Although these apps belong to the same category, they serve different purposes. Consequently, we classified them into two groups - language learning and educational support, as shown in the Table I.

<sup>1</sup><https://www.data.ai/>

#### B. Data Collection and Cleaning

After identifying seven AI mobile applications for learning languages and educational support, we collected all available app reviews for these apps from Google Play Store. To do so, we utilized *Google-Play-Scraper*<sup>2</sup> using Python to crawl user reviews for each app. We collected **634,951** user reviews for all seven apps between March 2022 and March 2023. However, we found that the initial data contained irrelevant and noisy information, such as short sentences, emojis, and non-English reviews, which could be problematic when answering our research questions. Therefore, we used Natural Language Processing (NLP) libraries to make our results more reliable by removing all irrelevant and noisy data. We utilized the following cleaning criteria to filter out irrelevant reviews:

- 1) Blank content.
- 2) Emojis-only content.
- 3) Emojis and numbers from the content.
- 4) Duplication content.
- 5) Non-English.
- 6) Less than two words.

As a result, we exclude 189,491 irrelevant app reviews with the remaining **445,460** relevant reviews.

#### C. Sentiment Analysis

We conducted sentiment analysis to filter out reviews to positive, negative, and neutral as it offers advantages in identifying usability [25]. To determine the sentiment of each review sentence, we utilized a domain-specific sentiment analysis tool, SentiStrength-SE [26], specifically designed for analyzing text in software engineering, including analyzing user reviews [27]. The SentiStrength-SE algorithm evaluates each word individually and assigns a score to indicate its sentiment. The tool allocated numerical values to positive and negative words, ranging from +1 to +5 for positive and -1 to -5 for negative [28]. The polarity of sentiment, as determined by its value, can be categorized as negative when the value is less than 0, positive when the value is greater than 0, or neutral when the value is equal to 0. This classification allows for assessing the severity of the sentiment based on its proximity to 0. This approach, as described in [29], provides a framework for understanding the sentiment expressed in user reviews. To compute the overall sentiment score for each sentence, we determined the highest positive and negative scores and combined them [28]. By utilizing the SentiStrength-SE tool on **445,460** reviews, it filtered them based on three categories (Neutral = 163,142, Positive = 247,640, and **Negative = 34,678**). This process is beneficial for collecting candidate reviews for our evaluation in the next step and reduces the number of reviews that will be matched with usability factors: satisfaction, effectiveness, and efficiency [22].

#### D. Usability Keywords Filtering

The purpose of using usability keyword filtering in this step is to identify potential usability issues quantitatively by analyzing user reviews. However, the reviews we obtained contained mixed feedback, including positive, neutral, and negative opinions. We only analyzed the negative reviews since

<sup>2</sup><https://pypi.org/project/google-play-scraper/>

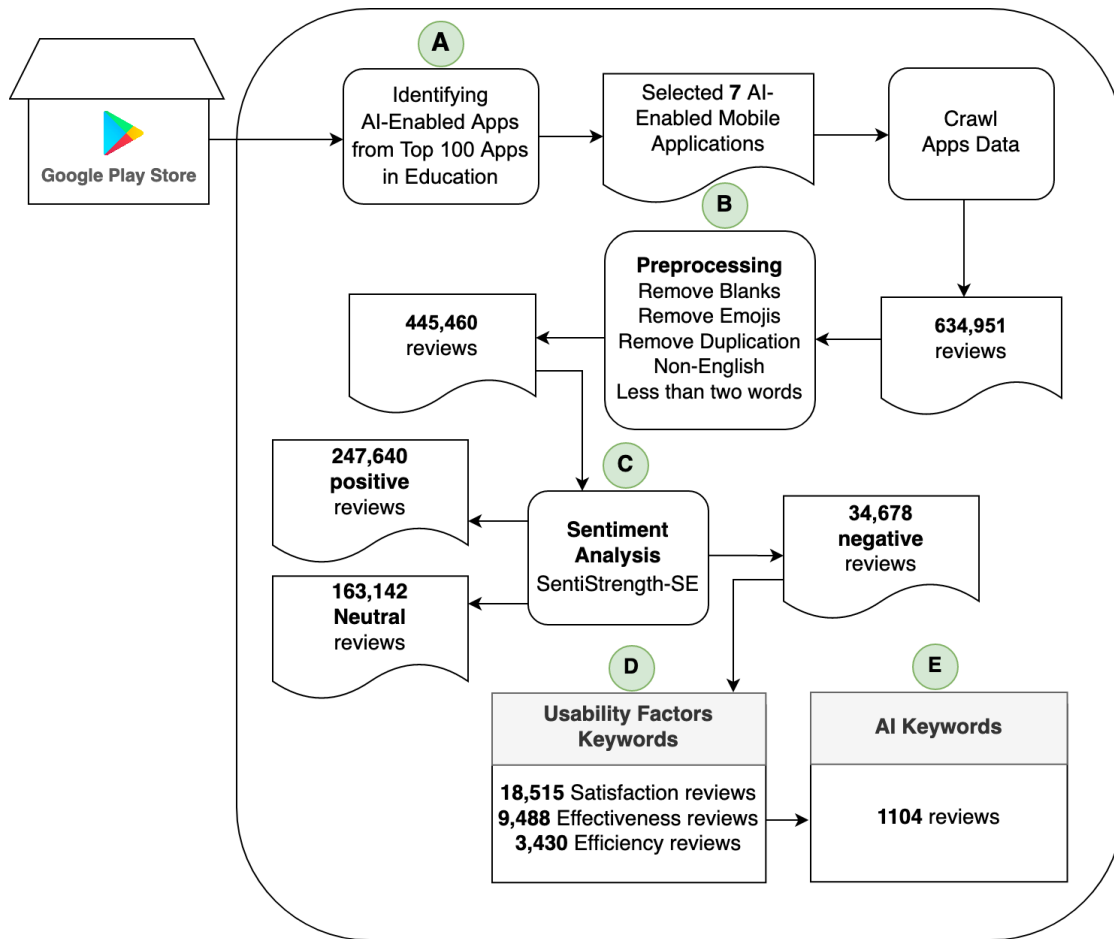


Fig. 1. Overview approach.

Our English learning app is powered by Artificial Intelligence (AI) that can quickly assess your fluency level and help you learn English, no matter what your native language is. ELSA has 7,100+ AI language learning activities and tools to help you speak in an...

Fig. 2. App's description.

we focused on examining the usability issues in AI-enabled mobile learning. As defined by ISO 9241-11, Usability refers to how effective and efficient a product is and the degree of user satisfaction after using it [30]. To better understand the usability issues associated with these apps, we constructed three negative polarity lexicons based on satisfaction, effectiveness, and efficiency keywords. These keywords were identified by conducting a thorough examination of relevant studies [23] [11], as shown in Fig. 3. We labeled the app reviews using a Python script that employs the NLTK library, which considers lemmatization and stemming. For example, the word “crashed” can be lemmatized to “crash,” and “disappointing” can be stemmed to “disappoint”. Using these techniques, we could identify and classify specific usability issues more effectively, leading to more accurate results. Next, we calculated the count and frequency of negative reviews of each usability factor [9]. This resulted in 18,515 reviews related to satisfaction, 9,488 reviews on effectiveness, and 3,430 on efficiency. We then

determined the overall usability score for each app review by adding the negative satisfaction, effectiveness, and efficiency scores together [10] [30]. We evaluated the usability issues of AI-enabled mobile apps for language learning and educational support by comparing the usability scores. Then, we identified which apps had the most usability issues and which had minor ones.

#### E. AI Keywords Filtering

After identifying usability issues from the previous step, we combined the results of 28,948 relevant negative usability reviews to filter out reviews based on AI terms [31], as shown in Fig. 4, to find only AI-related reviews. To achieve this, we developed another Python script that employs the NLTK library, which considers lemmatization and stemming, as before. This allows for more effective identification and classification of specific AI-related usability issues, ensuring more accurate results. For example, “speech recognition” can be lemmatized

to “speech recognize”, and the word “voice recognition” can be stemmed to “voic recognit” The filtered result was 1104 AI-related reviews out of 28,948. We then randomly selected AI-related reviews based on their rating [25], resulting in 221 reviews. Then, quantitative data analysis was used to examine the most prevalent usability issues related to AI in AI-enabled mobile apps for language learning and educational support. The qualitative content analysis approach enabled identifying and examining how these usability issues are reflected in user experiences. We performed a thematic analysis of the data using Excel software. Based on the steps outlined in Fig. 5, we conducted a manual analysis of the sample AI-related reviews [32]:

1. Randomly select 221 AI reviews based on the rating criteria.
2. Conduct a comprehensive reading of all 221 selected reviews to gain a deep understanding of the data.
3. Identify and note any patterns or ideas that emerge from the reviews.
4. Generate initial codes from the patterns and ideas identified in the reviews.
5. Review the codes to identify overarching themes and sub-themes that capture the essence of the data.
6. Refine the results by reviewing and comparing the themes to the original data to ensure they accurately reflect the content and context of the reviews.
7. Define and label each theme and sub-theme to make it clear and understandable.
8. Provide quotes from the reviews to illustrate each theme and sub-themes.

We coded the sample reviews manually after reading them multiple times to familiarize themselves with the information. We assigned codes to significant phrases and sentences relevant to AI-related issues [32]. Additionally, as the research progressed, we modified the codes to represent the substance and context of the information accurately. Then, we analyzed the codes to identify recurring themes and sub-themes [33]. We appropriately labeled the data to reflect the content and context of the information. To uphold the accuracy and reliability of the analysis, we conducted various tests and inspections, including reviewing the coding strategy and checking inter-coder reliability with a second researcher. We addressed any inconsistencies or misunderstandings through discussion and agreement. We systematically conducted the manual analysis process, ensuring the findings’ validity and reliability. The analysis followed the guidelines provided by [34].

#### IV. RESULTS

Our evaluation examined the impact of usability issues on using AI-enabled mobile learning apps and their impact on user satisfaction, effectiveness, and efficiency. The usability issues are crucial to explore, as they can influence user behavior and affect the overall performance of educational apps. By analyzing user reviews of various AI-enabled mobile apps for learning languages and educational support, this study aims to illuminate the possible challenges or concerns that users encounter while using these apps and assess how these issues affect the user experience.

**RQ1:** How is the user experience with AI-enabled mobile learning apps?

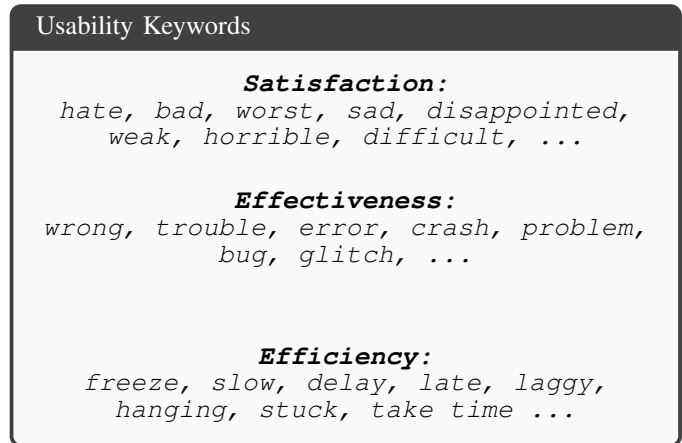


Fig. 3. Negative usability keywords.

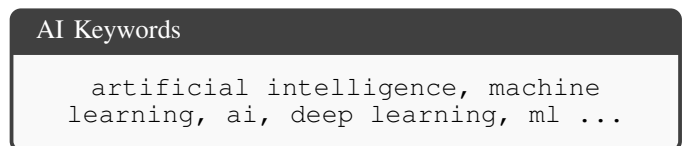


Fig. 4. Keywords related to AI.

**RQ1 Rational:** This question aims to determine the overall sentiment of user reviews towards AI-enabled mobile learning apps. The sentiment analysis will provide insight into how users experience and perceive these types of apps, helping identify potential improvement areas. Understanding the sentiment of user reviews can assist developers and designers in creating better AI-enabled mobile learning apps that align with users’ needs and expectations.

**RQ1 Results:** As described in the methodology section, we conducted sentiment analysis to identify the sentiment expressed in user reviews. The sentiment analysis results for AI-enabled learning apps shown in Fig. 6 revealed that in the learning language app group Duolingo: language lessons had the highest number of reviews, totaling 213,307. However, the app received the highest negative reviews, with 21,441 users expressing dissatisfaction with its features. In addition, the app had 67,043 neutral reviews. ELSA Learn English, Get Fluent received 25,410 reviews, with 16,506 positive and only 797 negatives, resulting in a high percentage of positive reviews. The app also had 8,107 neutral reviews. Similarly, Cake - Learn English & Korean received 48,435 reviews, with 32,461 positive and 1,048 negative reviews, resulting in the highest positive review count in this category. The app also had 14,926 neutral reviews. The app also had 14,926 neutral reviews. Among the educational support app group, Socratic by Google received 3,744 reviews, with 1,940 being the highest positive, 217 negatives, and 1,587 natural reviews. Microsoft Math Solver and Symbolab: Math Problem Solver had fewer reviews, with 2,593 and 893 reviews, respectively. Symbolab: Math Problem Solver had the highest negative reviews, with 140 users expressing dissatisfaction with its features and 413 neutral reviews, followed by Microsoft Math Solver, with 240 negative reviews and 1147 natural reviews. Photomath



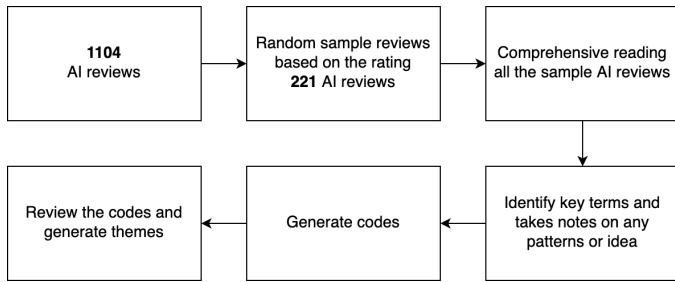
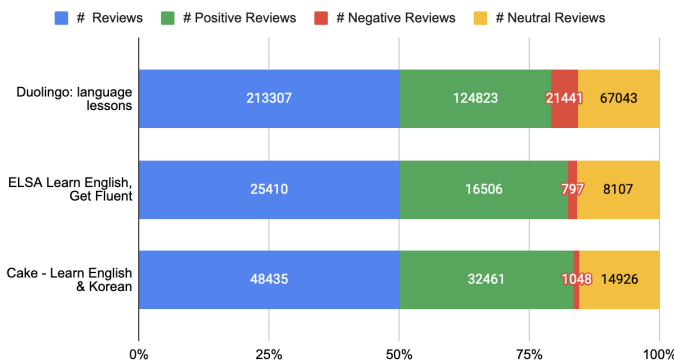
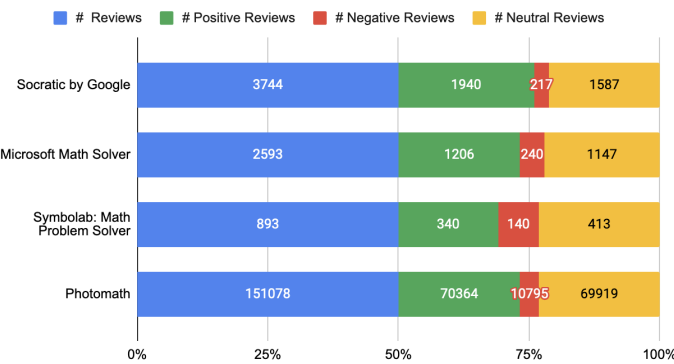


Fig. 5. A brief overview of our manual qualitative content analysis approach.

**RQ1 Summary.** This summary highlights that Duolingo had the highest number of negative reviews among language learning apps, while Cake - Learn English Korean had high percentages of positive reviews. Socratic by Google had the highest positive reviews among educational support apps, while Symbolab: Math Problem Solver had the highest negative reviews. Overall, the apps had more positive than negative reviews, with many neutral reviews.



(a) Language learning apps.



(b) Educational support apps.

Fig. 6. The user experience with the seven AI-enabled mobile learning apps.

received the highest number of reviews, with 70,364 positive, 10,795 negatives, and 69,919 neutral reviews, resulting in the second-highest positive reviews count alongside Microsoft Math Solver in this category. Overall, the AI-enabled mobile learning apps had more positive than negative reviews, with 247,640 positive reviews, 34,678 negative reviews, and 163,142 neutral reviews out of 445,460 total reviews.

**RQ2:** To what extent are the usability issues of using AI-enabled mobile learning apps impact user satisfaction, effectiveness, and efficiency?

**RQ2 Rational:** With the increasing prevalence of AI in mobile learning apps, it's essential to assess the impact of usability issues on user satisfaction, effectiveness, and efficiency. Investigating these factors can help identify potential problems and provide insights for developers and designers to improve these apps.

**RQ2 Results:** To address this question, we conducted a study that filtered out reviews based on usability factors described in the methodology section. After filtration, the word clouds of the app reviews show the most occurrences of negative usability keywords in Fig. 7. Our results in Table II indicate that usability issues impact user satisfaction, effectiveness, and efficiency in AI-enabled mobile learning apps. In the language learning apps category, ELSA Learn English and Get Fluent exhibited the highest dissatisfaction score at 61%, suggesting user discontent with the app. Duolingo: language lessons and Cake - Learn English & Korean showed quite similar dissatisfaction scores at 56% and 57%, respectively, indicating a close level of user satisfaction between the two apps. Notably, Cake - Learn English & Korean excelled with the lowest dissatisfaction scores in effectiveness and efficiency at 12% and 5%, respectively, suggesting that users find this app both effective and efficient for language learning. Both Duolingo: language lessons and ELSA Learn English and Get Fluent showed dissatisfaction scores in effectiveness at 33% and 23%, respectively. However, their efficiency dissatisfaction scores were 11% and 8%, respectively, suggesting these apps do not significantly impede users' learning efficiency. Moving to the educational support apps category, Symbolab: Math Problem Solver had the highest dissatisfaction score at 79%, indicating substantial user discontent. Microsoft Math Solver displayed a dissatisfaction score of 59% with a relatively high effectiveness dissatisfaction score of 24%. This suggests a moderate impact on user satisfaction, with a relatively lower efficiency dissatisfaction score of 6% compared to its higher effectiveness dissatisfaction score. Despite having the second highest dissatisfaction score at 63%, Socratic by Google presented low dissatisfaction scores for effectiveness and efficiency at 12% and 5%, respectively, suggesting a smaller impact on these areas. Photomath stands out with a relatively low overall dissatisfaction score of 48%, indicating better user satisfaction than other apps in this category. However, there is room for improvement as its effectiveness and efficiency dissatisfaction scores sit at 19% and 9%, respectively. Regarding the total usability score shown in Fig. 8, among the language learning apps, Duolingo: language lessons achieved the highest total usability score of 99%, indicating that users

encountered the most usability issues with this app, particularly regarding negative satisfaction and negative effectiveness. ELSA Learn English and Get Fluent obtained a total usability score of 93%, signifying significant usability issues related to satisfaction and effectiveness. On the other hand, Cake - Learn English & Korean obtained the lowest total usability score of 74%, suggesting that users encountered fewer usability issues with this app. In the educational support apps category, Symbolab: Math Problem Solver garnered the highest total usability score at 101%, indicating higher usability issues with this app compared to other apps in this category. Photomath received the lowest usability score of 75%, indicating moderate usability issues. Understanding the impact of usability issues in AI-enabled mobile learning apps can guide developers and designers in proactively identifying and resolving these problems. This process can enhance overall user satisfaction, effectiveness, and efficiency. The knowledge gained from addressing these issues will inform future improvements in the design and functionality of these apps, ultimately leading to more effective and gratifying learning experiences.

**RQ2 Summary.** The result showed notable usability issues with AI-enabled mobile learning apps. Among the language learning apps, Duolingo: language lessons had the highest usability issues score of 99%, while Symbolab: Math Problem Solver obtained the highest score of 101% among the educational support apps. Developers and designers can use this information to improve the overall usability of these apps.

**RQ3:** What are the most prevalent usability issues in AI-enabled mobile learning apps?

**RQ3 Rational:** This question aims to pinpoint the most frequently encountered AI-related usability problems in mobile applications designed for language learning and educational support, as reported by users in their reviews. By gaining insight into these prevalent issues, developers and researchers can concentrate on enhancing the usability aspects tied to AI technology. This knowledge will aid in refining the overall user experience and satisfaction with these apps, ultimately providing significant benefits to learners and educators.

**RQ3 Results:** To answer this question, we conducted a thematic analysis as described in the methodology section. We applied the thematic analysis to the two apps group learning languages apps and educational support apps. The result of the analysis is shown in Table III and outlined below:

#### Learning Languages Apps Group:

**AI-related functionality issues:** This theme refers to problems users face with the artificial intelligence components in the app. These issues can directly affect the user experience and hinder their learning process. There are two sub-themes under this main theme:

**a. Voice recognition:** This highlights issues where the app fails to recognize or understand the user's voice accurately, leading to frustration and a poor learning experience. A user complained that *"the app became unstable, and AI doesn't care about recognizing anything. You can sing a song instead of the correct answer, and AI will accept it. Most of the time,*

*it freezes in the middle of the lesson, and the mic button gets stuck, among other issues. Don't buy their plan until they fix their app."* The issues related to voice recognition underline the importance of extensive testing and improvement of AI technology to ensure accuracy and effectiveness in aiding users' language acquisition journey.

**b. AI understanding of user input:** This deals with situations where the app's AI fails to understand or process the user's input accurately, resulting in irrelevant or incorrect content being presented to the user, limiting the learning experience's effectiveness. One user reported, *"It was a good tool to start learning a new language from scratch. But I find that the AI component doesn't work very well. It gives easy exercises for the same word right after I've already done a more challenging one. Also, I have to practice a lot of unnecessary stuff like names and cities. A lot of practices are highly redundant, so I think I waste a lot of time practicing easy and unnecessary stuff. Furthermore, I have no choice in what to practice. All in all, it's not the most efficient."* It is crucial to integrate AI technology into language learning apps for a fulfilling educational journey.

**AI Performance:** This theme refers to issues related to the app's performance and capabilities of the AI component. These issues can affect the overall effectiveness of the app in helping users learn a language. There are three sub-themes under this main theme:

**a. Learning methodology:** This includes issues where the AI's approach to teaching a language is deemed ineffective or flawed. Users might find the exercises repetitive, redundant, or not challenging enough, which may hinder their learning progress. One user states, *"The app is basically good but its AI is too bossy. Nobody needs to be mocked for missing lessons. People get busy sometimes, and constant reminders ain't cool. They just piss people off even more."* To guarantee a satisfactory user experience, developers must design AI language learning applications with stimulating activities and lucid explanations.

**b. AI-generated content:** This refers to issues with AI-generated content, such as inconsistencies, errors, or low-quality material. These problems can lead to confusion or a less engaging learning experience. One user points out, *"It's totally useless. It randomly recognizes or rejects what you're saying; there's no logic behind it. I've been using it for a while but have seen no improvement. It doesn't show you how to produce some sounds, just provides some useless text. It accepts incorrect input and randomly rejects correct input, creating an illusion of functionality. Additionally, it records all your voice data and stores it on their servers indefinitely. Even when you request deletion, the data remains."* Developers must ensure that the AI-generated content they produce is of high quality and accuracy, providing users with a positive learning experience. By focusing on improving AI-generated content, the app can better meet users' needs and enhance their language learning journey.

**Instant Feedback Issues:** This theme addresses problems that arise when the language learning app's AI does not offer sufficient, comprehensible guidance on the material being taught, resulting in user confusion and frustration. This main theme consists of a single sub-theme:

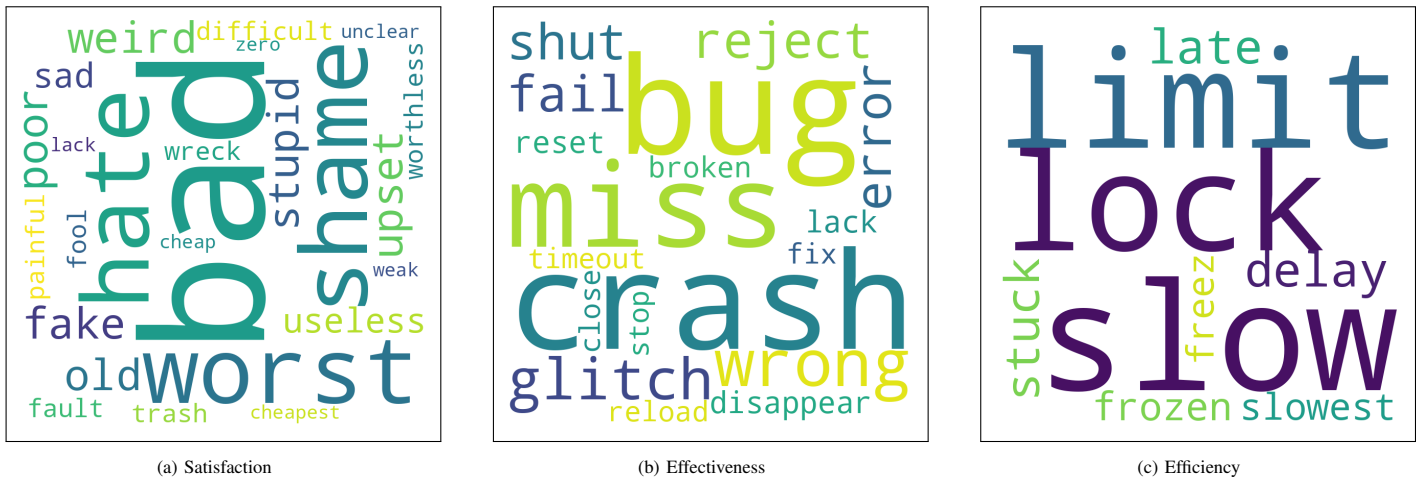


Fig. 7. The word clouds of app reviews display the most frequent occurrences of negative usability keywords.

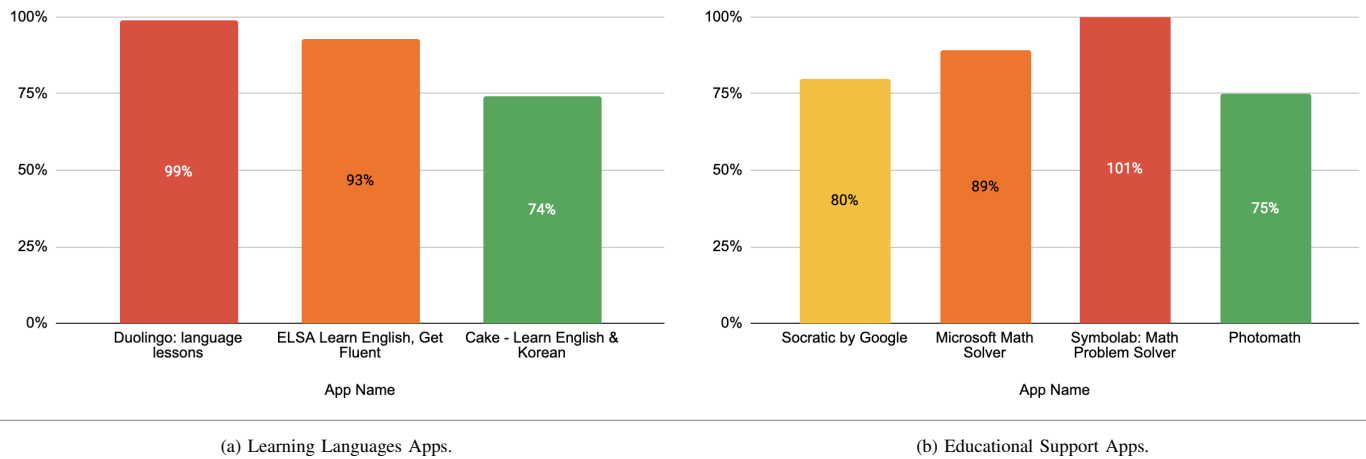


Fig. 8. The overall usability issues in the seven AI-Enabled mobile learning apps.

**a. Diverse challenges with AI-generated feedback:** This sub-theme pertains to situations where the app's generated content is unclear, confusing, or not provided, leading to an unsatisfactory learning experience. Without feedback, users might find it difficult to identify their errors and understand how to improve, which could impede their progress. For example, a user mentioned, "I am learning Ukrainian from a professional teacher along with using the app Many times I am taught something that contradicts what Duolingo says Very confusing. The two voices that read out the questions also mispronounce the words I know this because I have Google translate as well as actual Ukrainians telling me that its wrong My main issue is that it does not explain why the answer is what it is If I knew the rule maybe Id get the right answer Im just frustrated and needed to vent." It shows inaccurate or inconsistent feedback on users' pronunciation, leading to frustration and impeding their language learning progress. Addressing these concerns is crucial in enhancing the user experience and facilitating effective language learning.

**Educational Support Apps Group:**

**AI-related Functionality Issues:** This theme's main focus is on the difficulties users encounter when using the artificial intelligence elements included in the application. These challenges could reduce user satisfaction and prevent them from advancing academically. Resolving these issues could improve the efficiency and effectiveness of AI-based learning applications. The primary theme is divided into two subthemes:

**a. Inaccurate problem recognition:** Users report that the app fails to recognize problems, showing a different problem or failing to recognize specific symbols accurately. One user states, "Horrible All it can do is solve basic questions and I ended up getting in a row idk how ppl like this app but it acts like ai I take a picture of the question and then it shows a totally different problem I expect you to fix this monstrosity."

**b. Poor image recognition:** Users report issues with the app's image recognition capabilities, making it difficult to capture and solve problems accurately. A user shares, "This app is complete literal trash It cant even recognize an extremely simple variable equation system properly much less solve it Leave the image recognition to the big boys like"

TABLE II. THE ANALYSIS OF OCCURRENCE AND FREQUENCY OF NEGATIVE REVIEWS FOR EACH USABILITY FACTOR

App Name	App Group	Negative Reviews	Satisfaction (%)	Effectiveness (%)	Efficiency (%)	Total Usability (%)
Duolingo: language lessons		21441	56	33	11	99
ELSA Learn English, Get Fluent	Language Learning	797	61	23	8	93
Cake - Learn English & Korean		1048	57	12	5	74
Socratic by Google		217	63	12	5	80
Microsoft Math Solver	Educational Support	240	59	24	6	89
Symbolab: Math Problem Solver		140	79	15	8	101
Photomath		10795	48	19	9	75

Google and Microsoft, You're an embarrassment to society and to yourselves."

**c. Inability to solve complex problems:** Users mention that the app is limited in solving complex mathematical problems or specific algorithms. As one user mentions, "As long as this app does not solve the Gau Algorithm, it is worthless for me. Can't read matrix integrals or equations with more than one variable. Total trash."

**AI Performance:** This theme draws attention to concerns with the performance and capabilities of the app's AI component, such as flaws or inconsistencies that could reduce the app's overall usefulness in aiding users in learning or problem-solving. Improved user satisfaction and learning outcomes can result from higher AI performance. This overarching theme has two sub-themes:

**a. Inconsistent handwriting recognition:** Users find that the app struggles to recognize handwritten problems, leading to incorrect solutions accurately. One user shares, "Has a bit of trouble with handwriting recognition and larger, more complex problems, but those problems are to be expected from any algorithm."

**b. Limited language support:** Users report that the app cannot recognize or solve problems written in certain languages, limiting its usefulness for non-English speakers. A user complains, "Time-wasting app for Nepalese. Because it doesn't recognize the math problems properly which is written in Nepali language, so don't waste your valuable time, guys, in this app."

**Ineffective Features:** This theme highlights aspects of the app that are inadequate or ineffective in helping users achieve their educational goals. Developers can enhance their app's functionality by addressing these concerns and meeting user demands.

**a. Limited problem-solving capabilities:** Users find the app's ability to solve certain problems insufficient or lacking. One user complains, "This app is complete literal trash. It can't even recognize an extremely simple variable equation system properly, much less solve it."

**Instant Feedback Issues:**

This refers to situations where the AI-generated feedback is either delayed, unclear, or not provided, affecting the user experience and learning process. Addressing these issues is crucial for enhancing the user experience and promoting effective learning through the app. Improving the clarity and simplicity of AI-generated content can enhance the general user experience and the effectiveness of educational support apps.

**RQ3 Summary.** We identified several usability issues in AI-enabled mobile language learning and educational support apps. These issues include functionality problems related to AI, performance issues, ineffective features, and lack of instant feedback. Addressing these issues is essential to improve the effectiveness of the apps and enhance the overall user experience.

**a. Varied concerns with AI-generated feedback:** This underline specific example where the explanations or information provided by the AI is unclear, confusing, difficult to understand, or not presented at all. One user complained, "I am not happy with the new version the old version used to show each explanation in cost but now The AI Tutorial which was free in old version And now I have to buy in Photo math plus that saying is correct that old is gold old version is the worst now I wanted to solve one equation and wanted the AI Tutorial but now it says pay monthly or Anually education should be free I want the old version back." Addressing these concerns is crucial to improve the user experience and facilitating learning through these apps. Focusing on the clarity and simplicity of AI-generated feedback can help relieve these concerns, eventually enhancing user experience and the effectiveness of educational support apps.

Overall, during the analysis, we identified the most prevalent usability issues related to AI in AI-enabled mobile learning applications. These issues include voice and image recognition, AI understanding of user input, poor AI performance, instant feedback issues, ineffective features, and lack of clarity in AI-generated content. It is crucial to address these issues to enhance the usability of these apps, improve user experiences, and ultimately support the success of both learners and educators.

V. RESULTS DISCUSSION

Our evaluation of user reviews indicates that AI-enabled mobile learning apps generally provide a positive user experience, but several usability issues can affect user satisfaction, effectiveness, and efficiency. Below are some key takeaways from our analysis:

**Takeaway 1: Positive user experiences.** Most user reviews for the apps we analyzed were positive, with users praising them for their fun, easy-to-use interface, and short, engaging lessons. For example, one user of the Cake - Learn English Korean user wrote, "Love this app! It's been helping me a lot with learning Korean. It's fun, easy, and the lessons are short,

TABLE III. THEMATIC ANALYSIS RESULTS: AI-RELATED ISSUES IN AI-ENABLED MOBILE LEARNING APPS

App Group	Theme	Sub theme
Language Learning	AI-related functionality issues	a. Voice recognition b. AI understanding of user input
	AI Performance	a. Learning methodology b. AI-generated content
	Instant Feedback Issues	a. Varied concerns with AI-generated feedback
Educational Support Apps	AI-related functionality issues	a. Inaccurate problem recognition b. Poor image recognition c. Inability to solve complex problems
	AI Performance	a. Inconsistent handwriting recognition b. Limited language support
	Ineffective Features	a. Limited problem-solving capabilities
	Instant Feedback Issues	a. Varied concerns with AI-generated feedback

which is perfect for my busy schedule.” Another user of the Photomath app noted, “Really excellent mind-blowing capture information calculation step-by-step procedure brilliant app. Everyone must need this app.” These positive reviews suggest that AI-enabled mobile learning apps can be an effective and enjoyable way for users to learn new languages or receive educational support.

**Takeaway 2: AI-related usability issues.** Our analysis revealed several AI-related usability issues that can negatively impact user satisfaction, effectiveness, and efficiency. Some of the issues are voice recognition from learning apps and image recognition from educational support apps. For example, one user of the Duolingo app noted, “The voice recognition sometimes makes mistakes, which can be frustrating.” Addressing these issues will be critical for improving the future usability of AI-enabled mobile learning apps. Another example from one of the users of the Photomath app noted, “This app is complete literal trash It cant even recognize an extremely simple variable equation system properly much less solve it Leave the image recognition to the big boys like Google and Microsoft Youre an embarrassment to society and to yourselves.” Addressing these issues will be critical for improving the future usability of AI-enabled mobile learning apps.

**Takeaway 3: Diverse challenges in AI performance and accuracy.** Our analysis revealed that users reported various AI performance and accuracy issues in AI-enabled mobile learning apps. These challenges spanned from language understanding and voice recognition to problem-solving capabilities, image recognition, and inconsistent handwriting recognition. For instance, a user of the Photomath app observed, “Inaccurate problem recognition, poor image recognition, and inability to solve complex problems.” Moreover, there were issues with limited language support and speech recognition. These problems can adversely affect the learning experience and the effectiveness of the applications. It underscores the critical need for continuous development and improvement in AI technology to address these performance issues, thereby enhancing the user experience.

**Takeaway 4: Provide AI explanation.** With the advancement of AI, previous studies have developed tools and libraries that aim to explain the behavior and output of AI models [35]. This feature is essential, particularly from the user’s perspective. Our analysis shows that unexplained AI predictions contribute to users’ frustration and make it difficult for them to understand such predictions. For example, one user of the Socratic by Google app noted, “I wish there was a way to see how the AI is coming up with its solutions. Sometimes it’s not clear why it’s giving me the answer it is.” This user’s comment illustrates how users can become frustrated when the AI model does not explain its behavior when recognizing or rejecting user input. By providing AI explanation frameworks, developers can provide the AI output to the users and explain how and why the AI decided to make that output, which can increase user satisfaction.

**Takeaway 5: Reduce Bias in AI.** Even though the root cause of bias comes from the data itself [36], since data engineering is an essential step in machine learning, it also affects the model functionality and the degree of biased output. Addressing these biases is essential for improving AI-enabled mobile learning apps. For example, one user of the Duolingo app noted, “The app’s AI tends to favor certain accents and pronunciations over others, making it difficult for learners with different accents to get accurate feedback.” Another user of the ELSA app noted, “Please add british accent AI I want it so bad.” These examples highlight how biases in AI can negatively impact users’ experiences and learning outcomes. By addressing these biases, developers can create more inclusive and effective AI-enabled mobile learning apps.

**Takeaway 6: Addressing ineffective AI features.** Our analysis also identified several AI features that were deemed ineffective or flawed, such as limited problem-solving capabilities, limited language support, and repetitive or redundant exercises. For example, a user voiced dissatisfaction “The app’s problem-solving AI is quite limited and often fails to provide accurate solutions. It struggles with complex math equations and frequently gives incorrect answers ...” To mitigate these challenges and improve the user experience, it is necessary to

enhance the application's AI technology or refine the learning methodology.

Despite the generally positive assessments of AI-enabled mobile learning apps, our investigation has revealed critical findings that highlight areas for development. To improve user satisfaction, effectiveness, and efficiency, developers must address usability challenges related to AI performance, accuracy, bias, and explanation. By solving these issues, developers can create more effective and inclusive mobile learning apps that utilize AI to provide engaging and personalized learning experiences. Moreover, enhancing AI technology and adapting learning paradigms to meet users' diverse demands and preferences is essential. These measures will ensure that AI-powered mobile learning apps continue to evolve and offer students engaging learning opportunities.

## VI. THREATS TO VALIDITY

Evaluating the usability of AI-enabled mobile apps for language learning and educational support involves data gathering, filtering, and manual classification, which can be susceptible to various threats that may impact the results.

**Internal Validity** Regarding internal threats to our evaluation, one concern is the accuracy of the thematic analysis and the coding process, particularly in matching AI reviews with appropriate themes. This process is susceptible to human error and incorrect matches. To address this issue, we employed a rigorous thematic analysis approach in which two authors independently coded the reviews and established a code of agreement. The agreement was measured using a scale of 1 for strongly agree, 0 for neutral, and -1 for disagree. We only included reviews in our analysis that both authors strongly agreed on to minimize the potential for error and ensure the reliability of our findings.

**External Validity** Regarding external validity, our findings may need to be more generalizable. The data collection process only included mobile apps from the Android platform. Therefore, the results of this study may not apply to other mobile platforms, such as the Apple App Store.

## VII. CONCLUSION AND FUTURE WORK

In conclusion, AI-enabled mobile learning apps have shown great potential to provide users with effective learning experiences. However, addressing usability issues related to AI-related functionality, performance, bias, explanation, and ineffective features is crucial to enhancing user satisfaction, effectiveness, and efficiency. Developers must prioritize enhancing specific AI technologies and adapting learning methodologies to cater to users' diverse needs and preferences. By implementing these improvements, AI-powered mobile learning apps can become more inclusive and effective, leading to engaging and personalized learning experiences for users and fostering a promising future for AI-enabled mobile learning applications.

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# A Hybrid Method Based on Gravitational Search and Genetic Algorithms for Task Scheduling in Cloud Computing

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**Abstract**—Cloud computing has emerged as a novel technology that offers convenient and cost-effective access to a scalable pool of computing resources over the internet. Task scheduling plays a crucial role in optimizing the functionality of cloud services. However, inefficient scheduling practices can result in resource wastage or a decline in service quality due to under- or overloaded resources. To address this challenge, this research paper introduces a hybrid approach that combines gravitational search and genetic algorithms to tackle the task scheduling problem in cloud computing environments. The proposed method leverages the strengths of both gravitational search and genetic algorithms to achieve enhanced scheduling performance. By integrating the unique search capabilities of the gravitational search algorithm with the optimization and adaptation capabilities of the genetic algorithm, a more effective and efficient solution is achieved. The experimental results validate the superiority of the proposed method over existing approaches in terms of total cost optimization. The experimental evaluation demonstrates that the hybrid method outperforms previous scheduling methods in achieving optimal resource allocation and minimizing costs. The improved performance is attributed to the combined strengths of the gravitational search and genetic algorithms in effectively exploring and exploiting the solution space. These findings underscore the potential of the proposed hybrid method as a valuable tool for addressing the task scheduling problem in cloud computing, ultimately leading to improved resource utilization and enhanced service quality.

**Keywords**—Cloud computing; task scheduling; genetic algorithm; gravitational search algorithm

## I. INTRODUCTION

With the advent of cloud computing, most companies are moving their on-premises infrastructure to the cloud to efficiently provide network, storage, and computing services to their customers [1]. Different service models are available in this model, allowing users to access resources on demand [2]. The convergence of Internet of Things (IoT) [3, 4], artificial intelligence [5-7], differential equations [8], machine learning [9-12], smart grids [13], and Blockchain [14] has a profound impact on cloud computing, enabling enhanced connectivity, security, energy efficiency, data analytics, optimization, and intelligent decision-making capabilities, thereby revolutionizing the way resources are managed, services are delivered, and business operations are conducted in the digital era. The cloud paradigm requires a scheduling mechanism to provide on-demand access to cloud

resources and provision of the resources needed by users [15]. Typically, in cloud environments, a scheduler is employed to identify suitable solutions for assigning constrained resources among incoming applications or tasks in order to achieve scheduling objectives, such as energy consumption, response time, and reliability [16]. As most scheduling problems are either NP-hard or NP-complete, implementing optimal or suboptimal solutions over a minimum timeframe requires a considerable amount of time [17]. Therefore, there are currently no polynomial time-scheduling algorithms available for optimizing the scheduling of restricted resources in the present computing environments. Taillard [18] provided a simple example of the dilemma we are faced with, indicating that approximately 0.02 percent of the candidate solutions take 1 to 1.01 times the total time required to obtain the most optimal solution. It is clear from this example that identifying the optimal solution to a complex problem is extremely difficult.

With an increase in the number of cloud clients, scheduling becomes quite challenging. The first scheduling algorithms were designed for grid computing, and due to their efficiency, most of them were customized for use in distributed computing [19]. Cloud computing offers users the opportunity to make use of numerous virtual resources, making it impossible to assign tasks manually to each user [20]. Commercialization and virtualization have led to cloud computing being able to handle task scheduling complexity at the virtual machine level [21]. Hence, cloud computing relies on scheduling to allocate resources efficiently and effectively to each task. Currently, a wide variety of scheduling mechanisms are available, including dynamic, static, workflow, and cloud service scheduling [22]. The cloud maintains both internal and external resource demands, with specifications for response time, resource costs, storage, and bandwidth varying by task [23].

Previous studies on cloud computing task scheduling have identified several significant gaps. Firstly, these studies often failed to adequately consider the unique characteristics of cloud computing, such as dynamic resource allocation and multi-tenancy, resulting in an inability to capture the inherent complexity and scalability requirements of cloud environments. Secondly, the lack of standardized benchmarks and evaluation metrics hindered the consistent comparison and assessment of different scheduling approaches, emphasizing the need for a standardized

evaluation framework. Thirdly, the adaptability of scheduling algorithms to dynamic environments, including changing workloads and resource availability, was insufficiently addressed, leading to suboptimal resource utilization. Additionally, the diverse requirements of cloud tasks, such as varying resource demands and quality-of-service constraints, were often overlooked, resulting in inefficient allocation strategies and performance degradation. Lastly, the challenges associated with scaling scheduling algorithms to handle large-scale cloud environments were not adequately addressed, resulting in computational inefficiencies and scalability limitations. Addressing these gaps is crucial for developing effective and efficient task scheduling mechanisms in cloud computing.

While promising approaches have been developed to efficient cloud task scheduling, the problem remains NP-complete, implying its inherent complexity. This paper introduces a hybrid method that combines gravitational search and genetic algorithms to schedule multiple tasks within a cloud environment. By combining the strengths and capabilities of gravitational search and genetic algorithms, the paper seeks to overcome the limitations of previous approaches and provide a more effective solution. This hybridization allows for a more comprehensive exploration of the solution space and enhances the ability to find optimal task scheduling solutions. To assess the performance of the proposed algorithm, the paper conducts an experimental setup. The research provides a comparative analysis that showcases the advancements and improvements achieved by comparing the proposed algorithm with previous algorithms. Using several distributions to test the proposed algorithm adds value by providing insights into its performance trends and evaluating its effectiveness across different scenarios. The rest of the paper is structured as follows. Recent works on cloud task scheduling are reviewed in Section II. Section III describes the proposed algorithm. The simulation results are reported in Section IV. Section V concludes the paper.

## II. RELATED WORKS

Lin, et al. [24] proposed an algorithm for scheduling divisible tasks in cloud computing environments that takes into account bandwidth constraints. A novel non-linear programming solution is presented to the multi-task scheduling problem. In this model, the solution yields an efficient allocation strategy that estimates the appropriate number of tasks to be assigned to each virtual resource node. An optimized allocation scheme is used to develop a heuristic algorithm for scheduling loads, known as the bandwidth-aware task scheduling algorithm (BATS). The proposed algorithm outperforms fair-based task scheduling, bandwidth-only task scheduling, and computation-only task scheduling algorithms. Chen and Guo [25] developed a real-time task scheduling approach based on the PSO algorithm. Optimization objectives encompass the imbalance degree, deadline rate, makespan, and cost. Using a utility function, tasks are assigned to machines with high performance in order to maximize the profit of cloud service providers.

Zhao, et al. [26] propose a method for scheduling tasks that considers energy and deadlines for data-intensive

applications. As a first step, tasks are modeled as binary trees using a data correlation clustering approach. It takes into account the correlations generated from initial datasets as well as those generated from intermediate datasets. Thus, the global data transmission volume is substantially reduced, which contributes to a reduction in the rate of SLA violations. Second, using the determination of task requirement degree, a Tree-to-Tree task scheduling method is presented that enhances cloud system energy efficiency by minimizing the number of active machines, reducing data transmission time, and maximizing the utilization of its computing resources.

As a solution to cloud task scheduling problems, Li and Wang [27] proposed a multi-objective optimization algorithm based on the Analytic Network Process (ANP) framework. This algorithm was developed to overcome the weaknesses in mathematical analysis, limitations of optimization capabilities of conventional multi-objective optimization algorithms, and difficulty selecting Pareto optimal solutions in cloud task scheduling. First, they presented a theoretical analysis of cloud task scheduling based on matrix concepts. The improved NSGA-II multi-objective evolutionary algorithm has been applied to cloud task scheduling to search for the Pareto set among multi-objects by utilizing Gene Expression Programming (GEP). Lastly, the ANP model is coupled with the improved NSGA-II in order to address the problem of selecting Pareto solutions. The proposed algorithm can optimize multiple goals simultaneously and can effectively avoid additional iterations caused by changes in user preferences.

Using a bio-inspired intelligent model, Basu, et al. [28] discovered the optimal way to schedule IoT applications in cloud environments with heterogeneous multiprocessors. Evolutionary foraging traits and natural selection of genes have demonstrated that only the fittest species survive in nature. In this case, a fitness schedule is defined as one that complies with task order in a multiprocessor environment. Combining the genetic and ACO algorithms, only the most effective combinations of tasks are selected for each stage. The proposed scheduling algorithm is not preemptive and is based on the assumption that each task can be assigned to a single processor. It has been evaluated with different sizes of task graphs and various numbers of processors and has been demonstrated to be as effective as the traditional GA and ACO algorithms in a heterogeneous multiprocessor environment.

## III. PROPOSED METHOD

Cloud computing is a computing pattern to meet the computing and storing needs of the final users. The cloud-based data centers need to improve their performance constantly because of increasing service requests. Task scheduling is an essential part of cloud computing for optimizing resource utilization, reducing energy consumption, minimizing response times, and maximizing energy efficiency. The users send their requests to a manager. The manager receives the requests and transmits them to all the VMs. Hence, this force is used as a tool for information exchange. Gravity law has a critical role in

finding the most optimal path among the objects (VMs). We use GA's fitting function to select the best and most optimized VMs. Then, using GSA, a percentage of the population's chromosomes (some of VMs) are optimized and are known as the active children. In a repetition loop, some chromosomes are selected, and the GSA is called. We reduce the energy and cost for the active VMs.

#### A. Gravitational Search Algorithm

In Gravitational Search Algorithm (GSA), optimized finding using gravitational laws and moving in an artificial system is performed in discrete time. The system environment is the problem definition area. Hence, this power can be used as a tool for information exchange. The masses are determined using the objective function. The GSA is formed in two stages: a) proving a discrete-time artificial system in the problem environment, the objects' primary placement, providing the rules, and setting the parameters, b) time passing, objects' movement, and updating the parameters until the stop time [29].

The gravitational laws' role is critical to find the most efficient path among the objects. According to Newton's gravity laws, each object attracts other objects using gravitational power, and there is gravity between every two objects. The objects in the search area are defined by different features in the world, like accelerations (active or inactive), algebraic force, force vector, and distance between them. There are two laws that are regenerated in each object based on the power among the particles that perform based on acceleration.

- Newton's gravity law: each particle is attracted to another particle, and the gravitational interaction between two particles generates their mass and is proportional to the distance square between the particles inversely. The gravity force between two objects with masses of  $M_1$  and  $M_2$  and distance  $R$  is proportional to the multiplication of two objects' mass distance and inverse of the square of the distance between them. Newton obtained Eq. (1) for the gravitational force between two objects ( $F$ ) by calculating the  $G$  constant, named the gravity constant [30].

$$F = G \frac{M_1 M_2}{R^2} \quad (1)$$

- Newton's motion law: Force has a direct relationship to mass and internal acceleration. The next particle's velocity depends on the primary particle's velocity and the velocity change. A particle's acceleration (a) depends on the force and the mass of the particle [31].

The motion laws of Newton are the basic physics laws. Based on first Newton's law, each object maintains its stability or uniform movement on a direct line unless it is forced to change under one or some forces. Applying force to an object makes it accelerate based on its force and mass, according to the second Newton's law. More force leads to higher acceleration, and higher mass leads to less acceleration. Newton calculates the relation among acceleration, force, and mass using Eq. (2), where

acceleration, force, and mass are presented by  $a$ ,  $F$ , and  $M$ , respectively.

$$a = \frac{F}{M} \quad (2)$$

Acceleration is velocity changes in time unit, and velocity is passing a specified distance in a determined time duration. Therefore, particles that are heavier and closer to each other apply more gravitational force than lighter and farther particles. Another note is that in physics, there are three types of mass for an object. Active, passive, and inertia gravitational mass are equal for an object. Higher active gravitational mass for an object leads to higher gravitational force around it. The inactive gravitational mass shows the power of interaction in the gravitational field. Inertia mass is an object's resistance measure when changing its location and movement. Less Inertia, the mass of an object, makes more velocity changes. The amount of these three masses in physics is equal to each other.

#### B. Genetic Algorithm

Genetic Algorithm (GA) is a search technique in computer science to find the optimal solution. A solution for the considered problem is indicated using a list of parameters, namely chromosomes or genomes. The GAs uses the natural selection principle of Darwin to find the optimal formula for the patterns' prediction or comparison. In a nutshell, genetic analysis (GA) is a pattern-based programming approach that employs genetic evaluation to solve issues. The input is the issue, the solutions are programmed using the pattern, and the fitness function assesses each candidate solution that is essentially chosen randomly. The chromosomes are generally shown as a simple string of data, and other types of data structures also can be used. During each generation, each characteristic is evaluated, and the fitting value is measured using the fitting function. The stronger elements or the chromosomes with the fitting value near the optimal population have more chance to live during other periods and regeneration, and the weaker ones are destroyed. In other words, the algorithm saves the inputs near the optimal answer and ignores others. Then the algorithm enters a loop including four steps: selection, reproduction, mutation, and evaluation.

#### C. Hybrid Algorithm for Task Scheduling

A combination of GA and GSA is used in this section to solve the task scheduling problem in cloud computing. Both algorithms have advantages and disadvantages. For example, in GA, information about the selected person for hanging is destroyed, while GSA has a specific memory. In other words, in GA, the solutions are updated using the general operators, while GSA does not have such operators. In practical applications, the particles may lose variety during the algorithm execution because of parameter setting and executing the algorithm. Hence, they lose their ability to search in the search space. We conclude GSA works well in the primary stages of finding the solution. But it is trapped in the following stages. Thus, defining new operators for GSA is required to increase its efficiency in solving different non-linear criterion functions.

The new algorithm, GA-GSA, is proposed by combining the GA and GSA features. In this algorithm, GSA performance to find the optimal solution improves by adding genetic operators like selection, crossover, and mutation. First, the algorithm's solution is adjusted by the GSA. Then each solution is updated using genetic operators like selection, crossover, and mutation. The selection applies to find the best candidate based on the algorithm's fitting function. Then the solution is updated by applying the crossover and mutation. Elitism, a functional characteristic of GA, is a tool to select the best people for their children's reproduction and replacement. Exploration and exploitation abilities from the GSA algorithm improve by applying genetic operators. In this method, the advantages of GSA and GA by applying genetic operators to the GSA algorithm are embedded. First, the GSA algorithm is utilized to find the problem solution. Then the best solution is corrected during each period using the genetic operators for a balance between exploration and exploitation processes.

GSA and GA are two popular metaheuristic optimization techniques known for their successful application to a wide range of optimization problems. These algorithms are particularly suitable for addressing the cloud task scheduling problem due to the following reasons:

- Global optimization: Both GSA and GA are designed to search for global optima, enabling them to find optimal or near-optimal solutions for cloud task scheduling, which involves considering multiple tasks and resources.
- Population-based approach: GSA and GA work with a population of candidate solutions, allowing them to explore a diverse set of solutions simultaneously. This is beneficial for cloud task scheduling as it involves considering multiple scheduling possibilities and trade-offs.
- Non-deterministic search: GSA and GA employ a non-deterministic search strategy, making them flexible and suitable for the complex and dynamic nature of cloud task scheduling. They can handle uncertain arrival times and resource availability without relying on gradient information or assumptions about the problem's structure.
- Exploration and exploitation: GSA and GA strike a balance between exploration and exploitation, enabling them to explore different scheduling options while exploiting known good solutions. This balance is crucial for improving efficiency in cloud task scheduling.
- Scalability: GSA and GA can handle large-scale systems with numerous tasks and resources, which is essential for cloud task scheduling. They achieve scalability by parallelizing the evaluation and search processes, enabling efficient exploration and optimization in large-scale cloud environments.

- Adaptability: GSA and GA can be easily customized to incorporate problem-specific constraints and objectives. In cloud task scheduling, where various constraints such as task dependencies and resource availability exist, GSA and GA can adapt to handle these constraints and optimize specific objectives, making them flexible for different cloud environments.

1) *Gravitational search algorithm:* A particle force in the cloud is based on a gravitational constant, and  $G(t)$  is in a special time constant.  $G(t)$  specifies the particle potential and enhances the movement efficiency. The constant gravity help to exponentially increase the search space and efficiency improvement of the use of the resources. The gravitational constant  $G$  starts with a primary value and reduces over time.

2) *Calculating GA fitness function:* This method searches the problem space to find the best, not optimal answer. GA can be introduced as a general search method that imitates the natural biological evolution laws. This search usually uses to generate useful solutions for solving optimization problems. We use the GA concept to generate a difference among the Human Resources (HR) capabilities. HRs are important components of societies and organizations. Each organization's success depends on its HR. The organizations meet their goals using knowledge, experience, power, and human skills. Since HRs are distributed geographically, generating infrastructure is required to share knowledge, skills, and human experiences. In this method, each chromosome is considered a VM.

If  $S = \{VM1, VM2, \dots, VMn\}$  is the considered set of chromosomes, the chromosomes can be selected with the highest chance using the rank selection. In the rank-based selection plan, the chromosomes are saved in the population for the first time according to their fitting values based on Eq. (3), where  $p_i$  is the probability of selecting the  $i$ th chromosome,  $n$  is the population size,  $R(n)$  is the best chromosome, and  $R(1)$  is the worst chromosome in the population.

$$p_i = \frac{R(i)}{\sum_{i=1}^n R(i)} \quad i = 1, 2, \dots, n \quad (3)$$

3) *Calculating resources costs:* Assume  $R_j$  that is considered constant is the unit cost of the  $j$ th resource, and the max cost is the maximum cost of a user on the  $j$ th resource. Hence the cost of executing the  $i$ th task is estimated using Eq. (4). The max cost in this equation is the most expensive task. The total cost of a solution (chromosome) is calculated using Eq. (5), showing the cost of a chromosome in the population.

$$F_{cost}(I) = \frac{T(i, j) \times R_j}{Max\ cost^{1-a}} \quad (4)$$

$$F_{cost}(B) = \sum F_{cost}(j) \quad 1 \geq j \geq M \quad (5)$$

4) *Calculating energy consumption:* The energy model, including the system-level energy-saving techniques Dynamic Voltage Scale (DVS), acts based on a simple principle. It reduces the power supply voltage and the clock frequency of the CPU to reduce energy consumption. The energy model used in the Complementary Metal Oxide Semiconductor (CMOS) is used in this paper. The processor power is a dynamic estimate using Eq. 6, where A is the number of switches in each clock cycle,  $C_{ef}$  is the efficient load capacity, and V and f are the power supply voltage and the operational frequency, respectively. Based on the equation, the stored power supply voltage is a principal and important criterion. Hence, its reduction affects energy consumption.

$$P_{dynamic} = AC_{ef}V^2f \quad (6)$$

5) *Updating the masses based on the evaluation function:* The best position of the particles is returned to the tasks for scheduling. Then the tasks are assigned to the VMs based on their locations to execute on the data centers. Then, all the cloud GSA scheduling continues until all tasks on the VMs are executed to obtain the minimum time and cost of all the calculations. Best () saves the fitting value, which is the minimum value among the particles. Worst () saves the maximum fitting value among the particles in the search space. The new locations are considered the location of the new masses in the search space. The new masses' weights are normalized using the following equations. The best () and worst () values are calculated for the particles to minimize total cost and mass as follows.

$$m_i(t) = \frac{fit_j(t) - worst(t)}{best(t) - worst(t)} \quad (7)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^N m_j(t)} \quad (8)$$

In the above equations,  $fit_j$  shows the fitting of the  $i^{th}$  factor's mass at time t, worst () and best () show the amount of the merit of the worst and best factors of the population in time that is calculated using the following equations in the minimum finding problems.

$$best(t) = \frac{\min}{j \in (1, \dots, N)} fit_j(t) \quad (9)$$

$$worst(t) = \frac{\max}{j \in (1, \dots, N)} fit_j(t) \quad (10)$$

#### IV. EXPERIMENTS' RESULTS

CloudSim toolkit provides a convenient platform to model a virtualized cloud environment, which includes the components necessary to build virtual machines, brokers,

hosts, and data centers. It is a flexible and adaptable instrument suitable for facilitating the exploration, simulation, and seamless modeling of emerging cloud computing infrastructures. Consequently, we decided to use it as our experiments' simulation toolbox. A comparison of the proposed scheduling algorithm with state-of-the-art algorithms, such as the hybrid PSO-ACO, ACO, and improved PSO algorithms, has been made to evaluate its performance.

Table I provides the experimental parameters for our experiments. To assess these scheduling techniques, we ran our trials with 20, 300, and 500 jobs over 20 virtual computer resources. In these experiments, each CPU can handle 500, 1000, and 1500 MIPS. The task length ranges between 400 and 600 MI. Fig. 1 to 3 illustrate the experimental results. By varying the number of iterations, the capabilities of the four algorithms were evaluated. A comparison is made between the costs associated with different data sizes.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Number of tasks	100-500
Population size	100
Max iteration	200
Number of VMs	30
Memory size	512
MIPS	500-1500
Number of hosts	10

Fig. 1 presents a comparison of costs for four different algorithms with varying iterations. Among the metaheuristic algorithms, our algorithm demonstrates the lowest cost, followed by ACO, while IPSO yields the highest cost. Interestingly, the number of iterations does not significantly affect the performance of the PSO-based algorithm. In contrast, IPSO exhibits the highest costs, likely due to the presence of a jitter in the curve as the number of iterations increases. Conversely, both the ACO-PSO and our algorithm showcase smooth transitions between iterations, indicating their stability and efficiency.

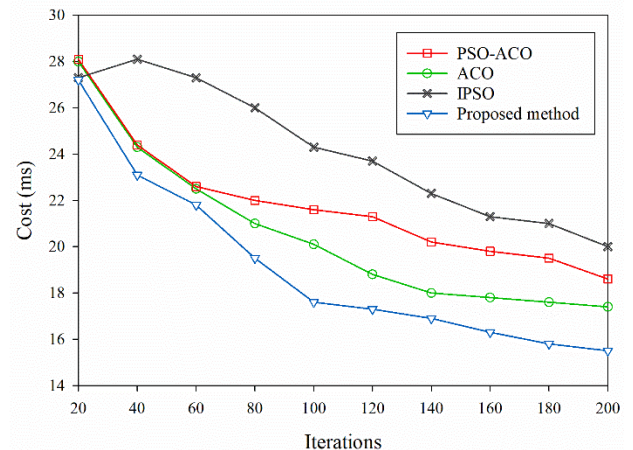


Fig. 1. Comparison for 100 tasks.



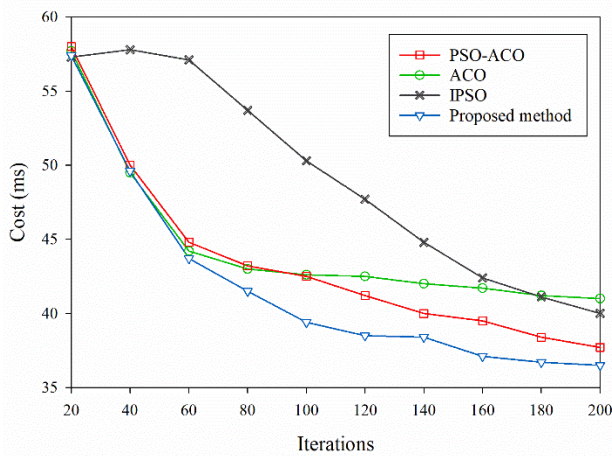


Fig. 2. Comparison for 300 tasks.

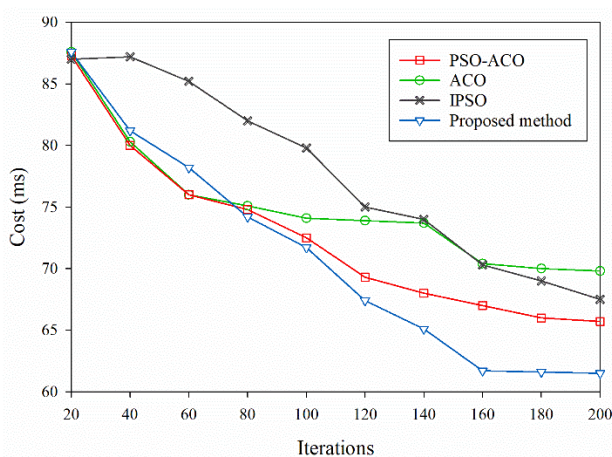


Fig. 3. Comparison for 500 tasks.

Moving on to Fig. 2, it illustrates the results obtained from different algorithms regarding total costs for a scenario involving 300 tasks. Our algorithm proves to be the most cost-effective, yielding the lowest amount of cost, while ACO represents the highest cost. It is worth mentioning that the PSO-ACO algorithm combines the local search and mutation procedures of both ACO and PSO simultaneously. In comparison to the other algorithms, our algorithm showcases a remarkable reduction in energy consumption. Specifically, it achieves a 6% reduction compared to IPSO, a 5% reduction compared to PSO-ACO, and an 8% reduction compared to ACO, all for a scenario involving 500 tasks and 200 iterations.

These findings demonstrate the superior energy efficiency of our algorithm. Furthermore, the observations from Fig. 3 reveal that as the task load increases, the optimization percentage of our algorithm improves significantly. This suggests that our algorithm adapts well to scenarios with higher task demands and exhibits a notable capability to optimize resource allocation efficiently. In summary, the comparisons and results presented highlight the strengths and advantages of our algorithm in terms of cost optimization, stability, energy consumption reduction, and adaptability to higher task loads.

## V. CONCLUSION

This research paper has made several theoretical contributions to cloud computing scheduling. Firstly, it introduced a novel hybrid algorithm that combines genetic and gravitational search algorithms to address the task scheduling challenge in cloud environments. This hybrid approach leverages the strengths of both algorithms, providing a more efficient and effective scheduling mechanism. By integrating genetic operators and gravitational search principles, our method offers improved optimization capabilities and better adaptability to dynamic workload patterns and resource availability. The key results of this research demonstrate that our hybrid algorithm surpasses previous approaches in terms of energy consumption. By achieving better optimization and adaptability, the proposed algorithm provides an advanced solution for cloud task scheduling. These findings have practical implications for cloud service providers and users, enabling more efficient resource utilization, improved energy efficiency, and enhanced quality of service. However, it is important to acknowledge the limitations of this study. The experimental evaluation was conducted on a specific set of benchmarks and scenarios, which may not fully capture the diversity and complexity of real-world cloud environments. Therefore, further validation and testing on a broader range of datasets and workloads would be valuable for comprehensively assessing the algorithm's performance. There are several hints for future research in this area. Firstly, investigating the scalability of the proposed hybrid algorithm to handle large-scale cloud environments would be worthwhile. Exploring the algorithm's performance under different QoS constraints and diverse task profiles could also lead to further improvements. Furthermore, considering the impact of task dependencies and dynamic resource allocation on scheduling effectiveness would contribute to a more comprehensive understanding of cloud task scheduling.

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# Shape Control of a Dual-Segment Soft Robot using Depth Vision

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**Abstract**—Pneumatic soft robots outperform rigid robots in complex environments due to the high flexibility of their redundant configurations, and their shape control is considered a prerequisite for applications in unstructured environments. In this paper, we propose a depth vision-based shape control method for a two-segment soft robot, which uses a binocular camera to achieve 3D shape control of the soft robot. A closed-loop control algorithm based on depth vision is designed for shape compensation when subject to its own non-linear responsiveness and coupling by solving for the shape feature parameters used to describe the robot and analytically modeling the motion of curved feature points. Experimental results show that the position and angle errors are less than 2 mm and 1° respectively, the curvature error is less than 0.0001mm-1, and the algorithm has convergence performance for L-type and S-type shape reference 3D shapes. This work provides a general method for being able to adjust the shape of a soft robot without on-board sensors.

**Keywords**—Pneumatic soft robot; shape control; depth vision; shape feature

## I. INTRODUCTION

In recent years, soft robots have attracted more and more attention due to their advantages in dexterous operation and safe interaction in complex unstructured environments, and have been widely used in exploration and rescue, medical surgery, seabed grasping and other fields [1]. The unique infinite degree of freedom soft mechanism gives the soft robot good environmental adaptability, but also brings challenges to the precise control of its overall shape [2], especially when it navigates in unstructured environments.

To fully utilize the flexibility of soft robots and apply them in restricted environments, such as complex trajectory tracking [3], it is necessary to simultaneously control their configurations to meet the desired complex shape requirements. Parameterized curve models have been widely used in soft robots, such as the PH curve [4] or spline curve [5]. In parameterized curves, Wiese et al. considered the third-order Hermite spline curve [6] for precise shape kinematics calculations of soft robots, while Gonthina et al. proposed a complex modeling method based on Euler parameterized curves [7], which has the advantages of high accuracy and computational efficiency but has not been used for control purposes. Existing methods calculate control points through curve arc length parameters [8] and optimize the positional errors numerically, but they are not suitable for solving feature

point mapping problems and involve complex numerical calculations.

Currently, model-based methods can achieve shape control but require 3D position and virtual joint parameters as feedback information [9]. In practical applications, due to the soft structure of soft robots, it is difficult to embed rigid sensors and high-cost limitations, making it sometimes impossible to directly measure 3D positions and shape parameters. In this case, vision-based shape control can provide a universal, economical, and feasible solution [10],[11],[12].

Vision-based feedback systems, due to their independence and small size, can provide visual information feedback for soft robots using cameras, and visual servo has been extensively studied [13],[14],[15]. Wang et al. [16] first achieved hand-eye visual servo control of cable-driven soft robots based on kinematic modeling, and Greer et al. [17] solved the visual servo problem of soft robots by estimating the Jacobian matrix from image feedback. Considering that the endpoint position of a soft robot can be detected and calculated using a visual method, a feasible shape can be determined in 3D space, and then a visual shape control method can be designed to track the desired reference shape [18]. Although parameterized curves have been proven to be feasible in 3D shape design tasks for continuum robots [19], it is still difficult to match the spatial position of currently measured feature points with the target position on the reference shape, making it difficult to control the feature points and therefore not suitable for designing the desired reference shape.

To address this issue, a constant-curvature-based three-dimensional shape feature design method is proposed. Curvature-based shape description methods have been widely used in modeling soft robots [20], and this paper uses a constant-curvature-based method to describe the three-dimensional shape of the robot. Then, the shape feature is determined using the solved curvature-based method to determine the desired three-dimensional shape curve. A visual shape control algorithm based on the constant-curvature feature is proposed. To perform simple and efficient visual shape control, markers are attached to the soft robot to capture its three-dimensional shape. Their spatial positions are then compared with the desired target positions to generate error feedback. Therefore, the feature matching problem is solved by constructing the shape feature. A visual control algorithm

based on inverse kinematics is designed to drive the soft robot to track the desired shape feature.

The main contributions of this paper are twofold. Firstly, in the case of reconstructing the three-dimensional coordinates of feature endpoints, the expected reference space shape feature is solved, and the shape curvature feature is introduced to solve the challenge of point feature correspondence, reconstructing the center curve of the soft robot. Second, using the solved shape feature, a three-dimensional visual shape algorithm is designed. In the remainder, the organization of this paper is as follows, Section II and Section III respectively explain the design of the soft robot's spatial shape feature and visual shape control algorithm, and Section IV performs experimental verification. The conclusion of this study is presented in Section V.

## II. SHAPE FEATURE DESIGN

The prototype soft body robot is shown in Fig. 1(a). The two-segment soft robot is made of silicone, both with a cross-sectional diameter of 30 mm and an overall length of 410 mm. The soft robot consists of two segments, each controlled individually by three air hoses, shown in Fig. 1(b). The robot can be made to perform specified movements by adjusting the air pressure variables, Overall view of the actuation system is shown in Fig. 1(c).

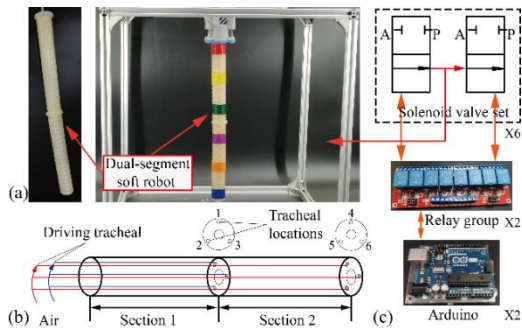


Fig. 1. Prototype of an air-driven soft-bodied robot. (a) Dual-segment soft robot. (b) Sketch of soft robot. (c) Overall view of the actuation system.

In practical applications of soft robots in unstructured environments, it may sometimes be impossible to obtain global pose and shape information for executing control tasks. In light of this, previous research has demonstrated the feasibility of vision systems in measuring pose and sensing shape, inspiring the development and application of effective visual control algorithms in such scenarios. To address the shape design and vision-based shape control problems of soft robots, a solution is proposed using a method based on constant curvature for shape feature design, which utilizes the given three-dimensional endpoint conditions that are capable of estimating the shape curve. Curvature has been widely used in academia to study the shape of soft continuum robots [21]. The objective of the curvature feature design task is to determine feasible reference shape features under the constraint of given endpoints. The method used is to establish a constant curvature motion model based on the given feature endpoints to solve the three-dimensional shape feature parameters of the curve and thus determine the shape curve of the soft robot.

Based on the geometric characteristics of soft robots, a series of continuous circular arcs are used to approximate smooth curves in this study. Therefore, the reference shape of the soft robot is considered to be approximated by a finite group of continuous constant curvature in free space [22],[23]. As shown in Fig. 2, the expression of the robot shape feature is written as the following function:

$$\begin{cases} K = [K_1, K_2, \dots, K_i, \dots, K_n] \\ L = [L_1, L_2, \dots, L_i, \dots, L_n] \\ \varphi = [\varphi_1, \varphi_2, \dots, \varphi_i, \dots, \varphi_n] \\ \theta = K \cdot L \end{cases} \quad (1)$$

where  $K$ ,  $L$ ,  $\varphi$  and  $\theta$  represent the vectors of curvature, arc length, deflection angle, and bending angle of the soft robot, respectively. The endpoint position can be represented using the chain rule of homogeneous transformation matrices, which has been extensively proven in the field of soft robotics [24]. Therefore, the curvature, arc length, bending angle, and deflection angle of each segment can be solved by using the endpoint position, and the function relationship between the endpoint coordinates and  $K$ ,  $\varphi$  and  $\theta$  can be directly obtained.

$$\begin{cases} x_e - x_s = \frac{1}{K} (1 - \cos \theta) \cdot \cos \varphi \\ y_e - y_s = \frac{1}{K} (1 - \cos \theta) \cdot \sin \varphi \\ z_e - z_s = \frac{1}{K} \cdot \sin \theta \end{cases} \quad (2)$$

where  $(x_e, y_e, z_e)$  and  $(x_s, y_s, z_s)$  denote the 3D spatial shape curve endpoints and start points.

This section therefore solves for the curvature features and generates a soft robot reference shape curve by giving constraints on the spatial endpoints.

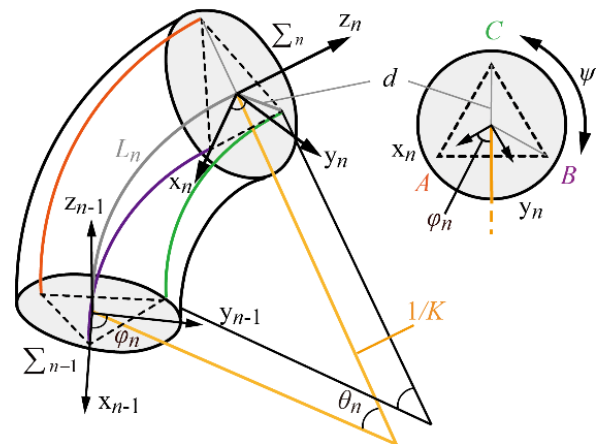


Fig. 2. Constant curvature geometry model.

## III. SHAPE CONTROL

This section discusses the design of a shape control algorithm based on deep vision, which can drive a soft robot to track the 3D reference shape solved in the first section. Typically, the main challenge faced by visual shape control

tasks is that point feature-based visual shape control algorithms are unable to address feature correspondence issues [25].

Shape control based on deep vision requires matching the currently measured shape parameters with the given expected shape parameters, which generates shape parameter errors. When considering the expected reference shape given in space and the nonlinear response characteristics of the soft robot itself [26], the relationship between shape features and robot motion becomes complex, making it difficult to establish feature correspondence between the reference point features and the detected three-dimensional points of the robot shape. This hinders the design of visual shape controllers. To address this problem, a visual shape control algorithm based on constant curvature is proposed, which uses curvature, endpoints, and inflection points as reference shape features, overcoming the obstacle of finding point feature correspondences.

### A. Shape Mapping Models

This section establishes a mapping model for shape features, laying the foundation for the design of visual shape control algorithms. A prototype of a two-segment soft robot driven by a six-pneumatic circuit is selected as the experimental platform. Three points are marked on the cross-section of each segment as features to adjust their motion in the spatial coordinate system. In the shape control scheme based on deep vision, the coordinates of these features should be compared with their expected reference coordinates to generate shape errors, which are then used to calculate the drive for closed-loop control. However, due to the difficulty in matching the reference position of the feature points with the currently measured position during the motion of the soft robot, visual shape control based on point features becomes challenging. This paper simplifies the solution of feature point correspondence by constructing shape curvature features. It is known that three feature points can uniquely determine the curvature, bending angle, and deflection angle of a circular arc, and these three feature points can be directly measured, as shown in Fig. 3, where and are the starting and ending points of the soft robot, respectively. Therefore, in general for the shape control task, we analyze the construction of the  $i^{\text{th}}$  shape feature.

Curvature, bending angle, and deflection angle are introduced as spatial curve shape features, while the inflection points and endpoints of the curve also determine the unique pose of the soft robot. Therefore, the expected reference shape feature parameters contain the reference curvature, bending angle, deflection angle, inflection point position, and endpoint position. These three-dimensional shape feature parameters can be solved based on the shape feature design task in the previous section. The reference spatial shape feature vector  $s_d$  is defined as follows:

$$\begin{cases} s_d = [f_d, p_d]^T \\ f_d = [f_{d,1}, \dots, f_{d,i}, \dots, f_{d,n}]^T \\ p_d = [p_{md,1}, \dots, p_{md,i}, \dots, p_{md,n-1}, \dots, p_s, p_e] \end{cases} \quad (3)$$

where  $f_d$  contains the combination of  $n$  curvatures, bending angles, and deflection angles calculated according to the constant curvature design algorithm, and  $p_d$  contains  $n-1$  inflection points  $p_{md}$  and two visual detection starting points  $p_s$  and ending points  $p_e$ . Therefore,  $2n+1$  features are used in the visual shape control task. The currently measured spatial shape feature vector is given by the following equation.

$$\begin{cases} s = [f, g]^T \\ f = [f_1, \dots, f_i, \dots, f_n]^T \\ p = [p_{m,1}, \dots, p_{m,i}, \dots, p_{m,n-1}, \dots, p_s, p_e] \end{cases} \quad (4)$$

The shape feature parameter error is defined as  $E = s_d - s$ , based on the given shape feature mapping, a visual-based three-dimensional shape control algorithm is developed, which uses the calibrated binocular camera to feedback the robot's 3D motion information, so that its actual shape finally converges to the reference shape. The schematic diagram of the control task is shown in Fig. 3, where represents the three marked points on the  $i^{\text{th}}$  segment, corresponds to the starting point, and corresponds to the ending point, used to construct the  $i^{\text{th}}$  segment's shape feature.

### B. Control Scheme

The control objective is to drive the soft robot to track the desired reference shape generated in the first part. This paper selects curvature, bend angle, deflection angle, inflection point, endpoint, and start point as the shape features to solve the correspondence problem between measured point features and their reference values. The number of selected shape features is  $m=2n+1$ , which drives the soft robot to converge to the desired shape. In the control task, the desired shape features are time-invariant.

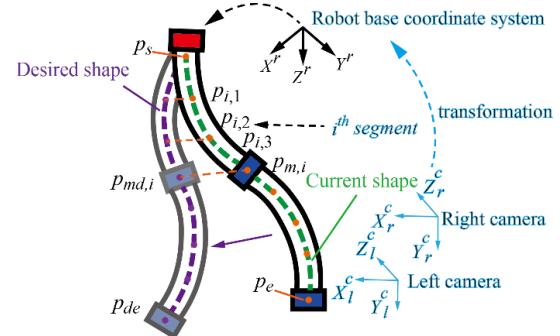


Fig. 3. Schematic diagram of a vision-based 3D shape control task.

Based on the method of describing soft robot shape features using constant curvature, a vision-based inverse kinematics shape control scheme has been developed as shown in Fig. 4. It should be noted that the endpoint of the soft robot is a key point used for shape control, and the measured endpoint position can be used for shape information feedback.  $s_n(K, \varphi, L)_n$  represents the current shape feature parameters,  $s_{dn}(K, \varphi, L)_{dn}$  represents the expected shape feature parameters, and  $A_{dn}$  represents the theoretical actuation output calculated by the controller based on the given expected shape parameter error  $(\Delta K, \Delta \varphi, \Delta L)$ .

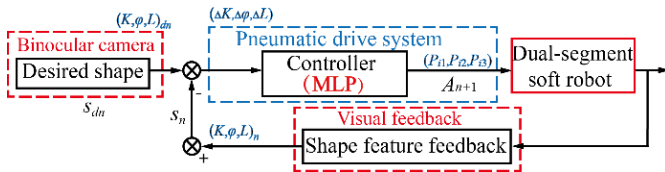


Fig. 4. Shape control scheme with feedback mechanism.

For soft robot, there is an unknown variable  $J$  which can be used to establish the mapping between shape parameters and actuation of soft robot

$$s_{dn} - s_n \approx J(A_{dn} - A_n) \quad (5)$$

Given the expected shape parameter  $s_{dn}$ , the corresponding expected induced pneumatic can be calculated as

$$A_{dn} \approx J^{-1}(s_{dn} - s_n) + A_n \quad (6)$$

where,  $J$  values of different shapes are different. After iteration,  $J$  is updated as  $J_n$ , which represents the unique value of iteration for the  $n^{th}$  time, thus, it can be obtained  $A_{dn}$

$$A_{dn} = J_n^{-1}(s_{dn} - s_n) + A_n \quad (7)$$

The challenge of this solution is how to accurately find  $J_n$  of different shapes. To solve this problem, a nonlinear mapping function is designed to make

$$A_{dn} = f_n(s_{dn}, s_n, A_n) \quad (8)$$

According to the known shape characteristic information, the method based on the inverse kinematics model and the empirical fitting formula is implemented to find the required actuating input, by updating the iterative feedback shape information to close to the desired shape

$$A_{dn} \leftarrow f_n(s_{dn}, s_n, A_n) \quad (9)$$

Under the non-extendable cavity hypothesis, as shown in Fig. 2, the relationship between a specific actuating length  $L_{n,i}$  and the segment shape parameter  $s_n(K, \varphi, L)_n$  can be defined geometrically

$$L_{n,i} = K_n L_n d \cos[\varphi_n + (i-1)\psi] \quad (10)$$

Where  $i \in \{1, 2, 3\}$  denotes the number of the chamber  $A, B, C$ ,  $\psi = \frac{2\pi}{3}$  denotes the trichotomy Angle of the circle, and the cross-section radius of the chamber is  $d$ . Let's rewrite the above equation

$$L_{n+1} - L_n = \underbrace{\begin{bmatrix} L_n dc_{\varphi_n} & -L_n K_n ds_{\varphi_n} & K_n dc_{\varphi_n} \\ L_n dc_{\varphi_n+\psi} & -L_n K_n ds_{\varphi_n+\psi} & K_n dc_{\varphi_n+\psi} \\ L_n dc_{\varphi_n+2\psi} & -L_n K_n ds_{\varphi_n+2\psi} & K_n dc_{\varphi_n+2\psi} \end{bmatrix}}_{J^{-1}} \underbrace{\begin{bmatrix} \Delta K_n \\ \Delta \varphi_n \\ \Delta L_n \end{bmatrix}}_{\Delta s_n} \quad (11)$$

According to the fitting of several experiments, it can be seen that the induced pressure has an approximate linear relationship with the chamber elongation, that is  $A_n \propto L_n$ , the  $f_n(\cdot)$  design is completed

$$A_{dn} = \alpha J_n^{-1}(s_{dn} - s_n) + A_n \quad (12)$$

Where  $\alpha = 0.2$  is the proportionality coefficient.

#### IV. CONTROL EXPERIMENTS

This section aims to verify the effectiveness of the proposed design of the soft robot shape features and the vision-based shape control algorithm. The experimental setup is shown in Fig. 6(a). A prototype of a two-segment soft robot driven by six pneumatic actuators is selected as the experimental platform for algorithm verification. Three different colored markers are labeled on each segment to construct the required shape features. A calibrated binocular camera is used to detect the motion and shape of the soft robot, and provide visual feedback to the controller by perceiving the spatial position of the marker feature points. The image processing framework process is shown in Fig 5, and the 3D reconstruction of the two-segment soft robot is based on the detected feature point positions. First, the RGB image of the soft robot is binarized, and the feature points are identified using color reduction and median filtering algorithms. The corresponding labels are assigned to the shape feature endpoints, and the shape reconstruction is completed by combining stereo depth information.

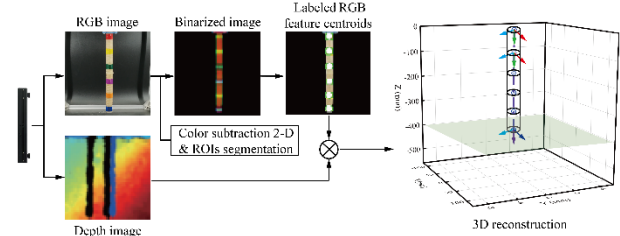


Fig. 5. Stereo vision tracking and 3D reconstruction of a soft robot.

The shape control objective is to drive the dual-segment soft robot to converge to a specified expected shape, using the known endpoint and inflection points as shape features and controlling the robot with the control algorithm. In the verification process, the soft robot base and binocular camera are fixed, ensuring that the starting point of the detected curve is consistent. Given the endpoint positions of the dual-segment soft robot in spatial coordinates, the feature curvature  $K$ , bending angle  $\theta$ , and deflection angle  $\varphi$  can be solved using Eq. (2), and the solved 3D shape features are used as the reference input for the shape controller, which can uniquely control the output robot reference shape. As shown in Fig. 6(b), L-shaped and S-shaped expected reference shapes can be tracked by detecting the three-dimensional positions of the feature endpoints through depth vision, allowing for the reconstruction of the soft robot's arbitrary omnidirectional motion configurations. Table I provides the calculated results of curvature  $K$ , bending angle  $\theta$ , and deflection angle  $\varphi$  for the L-type and S-type shape features. The proposed shape control



algorithm is then used to verify the performance of the soft robot tracking the L- type and S- type shapes.

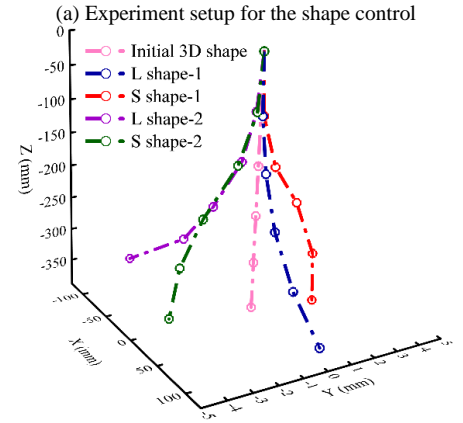
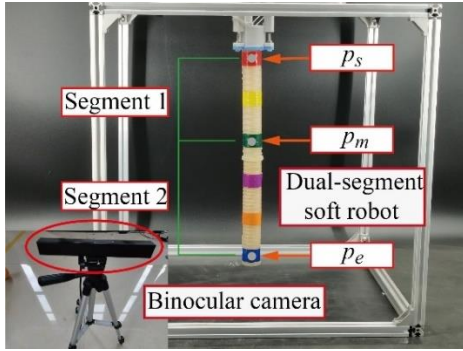


Fig. 6. Experiments on shape control of soft robots.

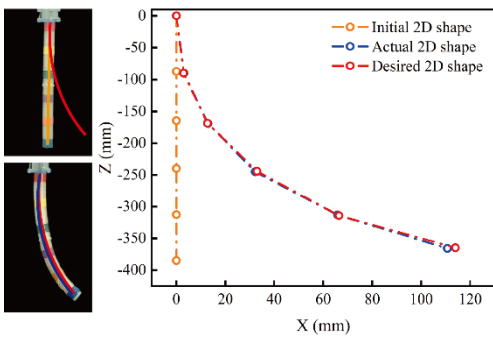
L-type shape control: As shown in Fig. 7, the performance of L-type shape control was verified. Fig. 7(a) shows the captured images during the L-type shape control task. In these images, the curve labeled with orange represents the initial

shape, the red curve represents the expected shape, and the blue curve represents the actual final shape, demonstrating the ability of the soft robot to achieve the expected 2D shape motion using the proposed control algorithm. To verify the accuracy and convergence ability of the proposed controller, the error curves of endpoint position, turning point position, bending angle, and curvature with respect to the iteration number are also displayed in Fig. 7(b) to (d). The error in shape feature parameters with respect to the expected shape is  $\Delta K_1=5.121e-5mm^{-1}$ ,  $\Delta\theta_1=0.12$ ,  $\Delta K_2=2.822e-5mm^{-1}$ , and  $\Delta\theta_2=0.64^\circ$ . The shape feature error of the soft robot converged after the second iteration of feedback using visual feedback of the shape feature information. It is noteworthy that the iteration number refers to the finite number of times used to achieve the expected shape using visual feedback of the shape feature information.

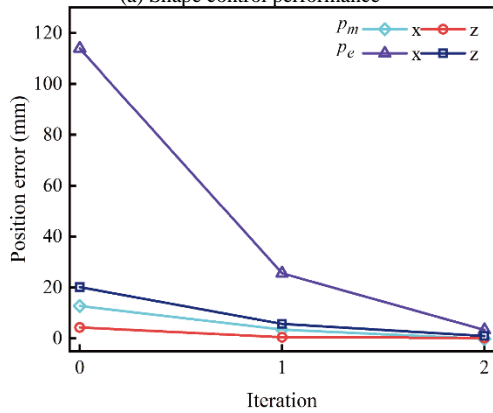
S-type shape control: The S-type shape means that the two segments deform in opposite directions. Fig. 8 shows the experimental results of the visual shape control performance of the S-type shape. Fig. 8(a) shows images captured from the camera and the captured three-dimensional shape curve during the control process. Compared to L-type shape control, the shape error is relatively significant, possibly due to the motion interference caused by the two segments with opposite deformations, where while the proximal part approaches the expected shape, the shape error of the distal part may increase. Fig. 8(b) to (e) show the errors of the endpoint positions, inflection point positions, bending angles, deflection angles, and curvatures of the two segments with iteration number. The final shape parameters of the soft robot also tend to be stable, with the errors of shape feature compared to the expected shape being  $\Delta K_1=0.0004mm^{-1}$ ,  $\Delta\varphi_1=0.69^\circ$ ,  $\Delta\theta_1=0.65^\circ$ , and  $\Delta K_2=0.0004mm^{-1}$ ,  $\Delta\varphi_2=0.996^\circ$ ,  $\Delta\theta_2=0.39^\circ$ . That is, the error of the soft robot shape curve also converges after the second iteration feedback.

TABLE I. SOLUTION RESULTS OF SHAPE CHARACTERISTIC PARAMETERS

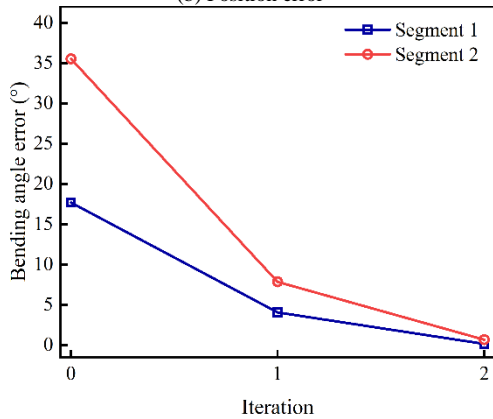
type	Given conditions			The first segment result			The second segment result		
	$p_s(mm)$	$p_m(mm)$	$p_e(mm)$	$K_1(mm^{-1})$	$\theta_1(^{\circ})$	$\varphi_1(^{\circ})$	$K_2(mm^{-1})$	$\theta_2(^{\circ})$	$\varphi_2(^{\circ})$
L	(0,0,0)	(12.7,0,-169.0)	(114.0,0,-364.9)	0.0016	17.68	0	0.0028	35.51	0
S	(0,0,0)	(6.4,0,0.6-166.9)	(12.7,2.7,-383.4)	0.0015	16.52	5.72	0.003	36.07	11.90



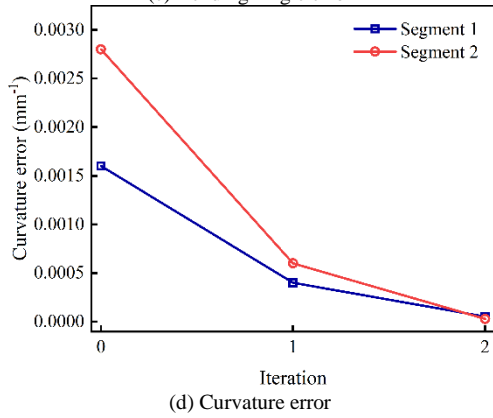
(a) Shape control performance



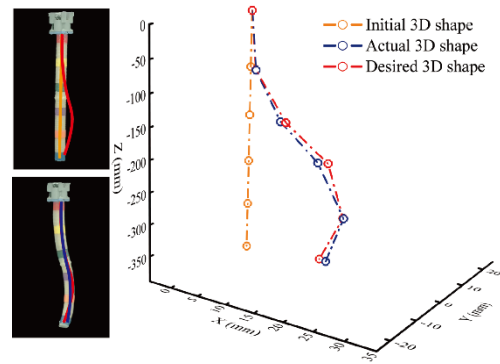
(b) Position error



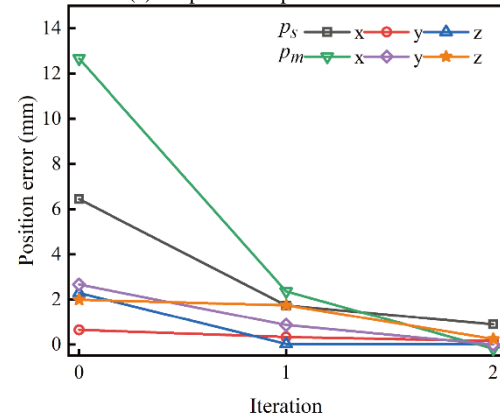
(c) Bending Angle error



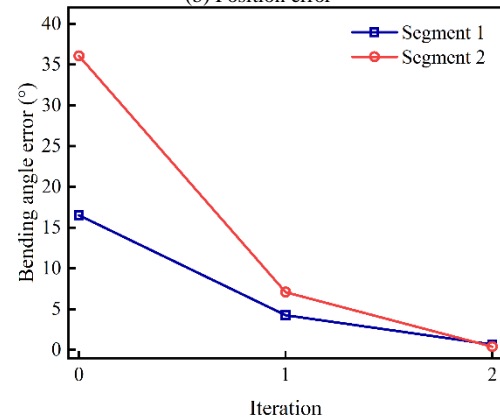
(d) Curvature error



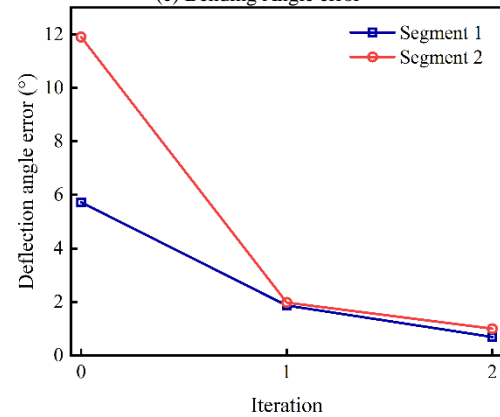
(a) Shape control performance



(b) Position error



(c) Bending Angle error



(d) Deflection Angle error

Fig. 7. L-type shape control results.



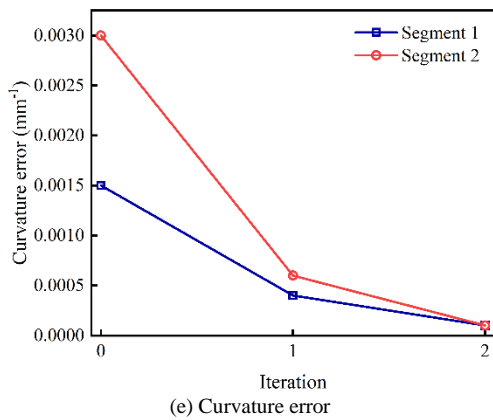


Fig. 8. S-type shape control results.

## V. CONCLUSION AND DISCUSSION

In this paper, a shape design algorithm and visual shape control scheme for a dual-segment soft robot in three-dimensional space were proposed. By using marker features, the problem of reference shape design and control was solved solely through visual feedback. In the shape tracking experiment, the spatial shape deviation of the dual-segment soft robot was obtained using depth vision, and the visual perception of the endpoint and inflection point was used as closed-loop feedback for shape compensation. With this method, the overall configuration of the robot was adjusted by controlling its shape features without adding any other onboard sensors. It has good effect in shape servo control of L-type and S-type shapes. The motion information of the robot is directly captured by visual sensing to generate the three-dimensional shape of the soft robot. In order to control the soft robot into the desired shape, the feedback and control of its shape feature parameters are transformed. The results showed that the position and angle errors of the shape feature were both less than 2mm and 1°, respectively, and the curvature error was less than 0.0001 mm<sup>-1</sup>. This method exhibited good precision tracking and convergence performance for the required L-type and S-type shapes. The problem of reference shape design and servo for continuously deformed soft robot with only visual feedback is solved. This work demonstrates that soft robots have unlimited applications in future explorations in rescue and minimally invasive surgery fields, enabling safer human-machine interactions. In the future work, especially for the shape dynamic control task of soft robots, an efficient 3D curve tracking method and a model for real-time calculation of shape feature parameters are needed to conduct dynamic response analysis of the shape control system, so as to propose a better shape control strategy to cope with the challenges brought by coupled motion. It will also further promote the research of accurate shape modeling and algorithm design, and the extension of dynamic control of soft robot shape will also be used in more complex interactive environments and fast response control tasks.

## ACKNOWLEDGMENT

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# Fast Pasture Classification Method using Ground-based Camera and the Modified Green Red Vegetation Index (MGRVI)

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**Abstract**—The assessment of aboveground biomass is important for achieving rational usage of pasture resources and for maximizing the quantity and quality of milk and meat production. This study presents a method for fast approximation of pastures' biomass. Unlike most similar studies, which rely on unmanned aerial vehicle and satellite obtained data, this study focuses on photos made by stationary or mobile ground-based visual spectrum camera. The developed methodology uses raster analysis, based on the MGRVI index, in order to classify the pasture into two categories: "grazed" and "ungrazed". Thereafter, the developed methodology accounts for the perspective in order to obtain the actual area of each class in square meters and in percent. The methodology was applied on an experimental pasture, located near the city of Troyan (Bulgaria). Two images were selected, with the first one representing a mostly ungrazed pasture and the second one – a mostly grazed one. Thereafter the images were analyzed using QGIS 3.0 as well as a specially developed software tool. An important advantage of the proposed methodology is that it does not require expensive equipment and technological knowledge, as it relies on commonly available tools, such as the camera of mobile phones.

**Keywords**—Pasture biomass; MGRVI; ground-based camera; classification

## I. INTRODUCTION

Extensive animal husbandry in mountainous areas is highly dependent on grass and its condition in meadows and pastures. The pastures are used during the summer for raising cattle gradually by parts, while the fodder is set aside to feed the animals in the winter. However, the production of grass is not unlimited and depends on various factors - topography, the impossibility of using mechanization to a large extent, the short vegetative cycle in high places (longer retention of snow, temperature differences and precipitation, drought). The intensive use of pastures and the incorrect management and selection of the appropriate capacity of the area in relation to the animals kept on it can cause degradation of the used pastures and lead to subsequent damage of them and to the environment. Therefore, the assessment of aboveground biomass is important in order to achieve the goal of rational use of pasture resources and to maximize the quantity and quality of milk and meat production.

Natural grass associations are not only accepted as a huge natural resource that enables environmentally friendly and low-cost rearing of ruminants, but they also have significant ecological functions: they protect the soil from water and wind erosion and groundwater from pollution [1-3], reduce the effect of greenhouse gasses, absorbing part of CO<sub>2</sub> in the process of photosynthesis, preserve biodiversity [4,5].

The meadows and pastures in Bulgaria occupy 27.8% of the usable area of the country, but a large number of them are not used in a systematic and regulated manner, as a result of which the grasslands degrade, and this also leads to a decrease in the productivity and quality of the obtained biomass [3]. Identifying and applying adequate measures requires a good knowledge of their condition [6,7]. This necessitates conducting research on the density of grass vegetation, evenness of grazing, participation of valuable cereal and legume species and the ratio between them, presence of shrubs, pests and pollution [8,9].

Grass communities are used by grazing and mowing (individually or in combination), which when carried out correctly limit the spread and development of shrubs and trees, suppress the dominance of rough and poisonous species, weeds and ruderals. Traditional grazing management factors are number, type and category of grazing animals, spatial and temporal distribution of forage demand, timing and length of grazing periods [10]. Overgrazing of grassland leads to the loss of valuable perennial species and subsequent soil erosion [11-14]. The lack of grazing also has a negative impact on the grassland, leading to the spread of weeds, overgrowth and the reduction of the grazing area [15].

Very often, the decrease in pasture productivity is also a result of the uneven distribution of grazing. According to [16], in arid and semi-arid regions, timely corrections of animal numbers and practices that are applied to alleviate unwanted selective grazing of animals improve grazing uniformity and are more effective in maintaining and improving pasture productivity than fencing and rotational grazing systems. Improving grazing uniformity can help both to increase productivity and to preserve biodiversity and habitats in grasslands [17]. By accurately determining the degree of grazing, it is possible to improve the management of the

pasture territory, to provide data for predictive and simulation models for its effective use [18].

Conventional methods for evaluating the indicators determining the extent and uniformity of grazing and the productivity of the rangeland area are subjective, time-consuming and only applicable to small-scale rangeland monitoring. These methods are particularly difficult in large, remote areas. Conventional methods involve laborious crawling over large areas, cutting and drying a large number of samples of a certain area (e.g., 0.25 m<sup>2</sup>), where the dried biomass values are recalculated to a larger area.

In order to maintain natural pastures in a state of high productivity, to increase the efficiency of their use, it is necessary to prospectively introduce innovative methods and technologies for remote and rapid analysis to estimate the density of the grass cover, the degree of grazing, the botanical composition, the productivity and quality of the vegetation from the point of view of precision agriculture and the intelligent management of natural grass associations.

Different automated approaches are used to assess the condition of pastures, in addition to the standard on-site sampling methods of the pasture itself. One of these approaches is to use sensors, to measure soil indicators and parameters, to send data about them to a software application and, based on the processing and analysis of this data, to make predictions about the state of the biomass on the surface [19-22]. It is obvious that this method is not particularly good and reliable. The information obtained through it about the condition of the plants on the surface is not direct, and on the basis of various indicators of the soil, attempts are made to make predictions about the plants.

Recently, the methods using various sensors and cameras on board unmanned aerial vehicles (UAV) are relevant and intensively developed. Their development provides new alternatives for collecting data from meadows, as they are much more mobile and offer different possibilities than those of agricultural machinery and agricultural aviation, and even satellite images. There is already quite a bit of research into the applicability of such technologies [23,24] and definitely this approach gives promising results in biomass estimation compared to manual field measurements. Key advantages of such approach include access to hard-to-reach areas, slow flight speed and, respectively, the possibility of good quality photography, development of technologies in this area and cameras allow detailed images; there is no risk for the people who use the technique or for the pilots for example. The disadvantages of this approach are that this type of equipment is still relatively expensive, and working with it is also not so simple and requires certain knowledge and experience, which is why not every farmer will decide on such a step to purchase such devices.

The use of cameras with multispectral sensors allows to compile/determine vegetation indices, based on RGB and infrared images and use these indices to estimate grassland surface biomass [25,26]. Remote sensing is an effective tool to address the challenges of grassland vegetation sampling to establish land cover characteristics and accurately account for grassland biomass given its high spatio-temporal variability

and large spatial scales [27-29]. Understanding this variability and how it differs regionally can help improve rangeland management by informing how to adjust stocking levels in atypical years and avoid overgrazing or insufficient forage availability in drought years [30].

According to [31], the monitoring of the condition of the grass cover of pastures is of crucial importance for their good management, as the combination of data from conventional field surveys with remote sensing (with a moderate resolution) will help to increase the accuracy of the quantitative assessment of trends in the changes of grass cover and productivity of the pasture area. And digital image analysis (aerial photographic analyses) can be a fast and precise technique for estimating the proportion of different plant groups in the grassland [32,33].

Different studies have investigated the application of remote sensing for assessment of pastures' biomass. For example, in [34] the authors compared two grazing practices for evaluation of the vegetation characteristics of a pasture: high-resolution satellite and UAV imagery. Different vegetation indices were used, such as NDVI, EVI2, LAI, WDRVI, etc., all of which require the use of near-infrared spectrum. The results showed that both approaches provide a useful tool for the farmers to optimize the management of the pasture. Similarly, in [35] UAV obtained RGB and multispectral imaging was used for assessing the pasture biomass using NDVI, NDRE, GNDVI and GRVI vegetation indices. To the best of our knowledge, no previous studies have suggested the application of ground-based cameras for assessment of the pasture condition.

All these methods for biomass estimation have their advantages and several common drawbacks - it is not easy for a farmer or even a herdsman to make this estimate himself. Furthermore, most of them rely on vegetation indices that need the infrared spectrum, which adds a significant limitation and increases the price of the sensor. This research is aimed at developing a methodology based on image processing that allows easy assessment of the condition of pastures using ordinary photographic images (even from a phone). If the images taken by livestock keepers are properly stored (for example, image databases are organized [36]), they can subsequently be used for more in-depth analysis and matching to trace how the grazing process has progressed [37]. Based on the analysis of the images, along with historical data on temperature, humidity and soil condition, it is also possible to predict what the pasture's condition may be expected to be for some period of time in the future.

The goal of this study is to develop a model which allows fast assessment of the biomass condition of pastures and meadows, which is based on a ground-based visual spectrum camera. The method should be applicable with a wide range of devices, including mobile phones, and allow easy approximation of the grazed areas.

## II. MATERIALS AND METHODS

As already stated, this study aims to develop a methodology that allows assessing the grazed area of pastures, which can be divided into three steps, as shown in Fig. 1.

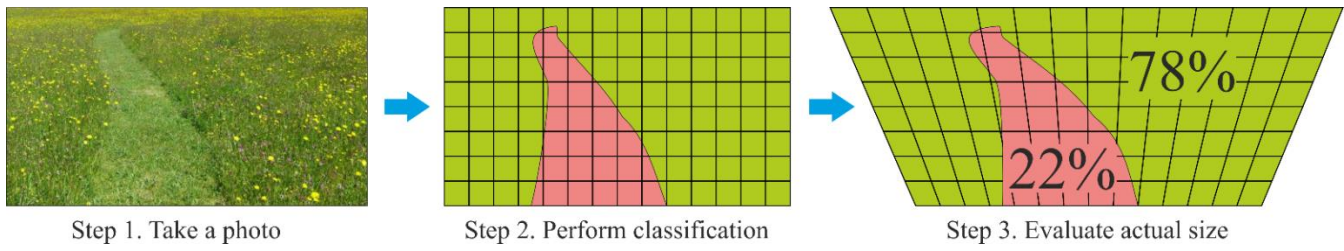


Fig. 1. Summary of the proposed model.

### Step 1. Take a photo

For the first step any visual spectrum (RGB) camera can be used, which is either ground-based or UAV-based. However, it is important to know the dimensions in meters of the observed quadrilateral. In the current study it is assumed that the quadrilateral is an isosceles trapezoid, i.e., the camera is horizontally leveled with the ground.

### Step 2. Perform classification

Several RGB indices are explored in [38]. All of them are affected by the illumination quality of the images being used and care should be taken when using it to process images where there are areas affected by shadowing. Therefore, in our study we use a relatively flat pasture with a sufficiently large area and without trees shading it.

In this step a classification is performed in order to distinguish the grazed and ungrazed parts of the pasture. It is based on the MGRVI, proposed in [39]. It is considered to give the best results when separating vegetation from soil and is defined as follows:

$$MGRVI = \frac{G^2 - R^2}{G^2 + R^2} \quad (1)$$

where  $R$  and  $G$  are the red and green components, respectively, of a RGB colored pixel. MGRVI takes values from -1 (when  $R = 255$  and  $G = 0$ ) to +1 (when  $R = 0$  and  $G = 255$ ).

Next, all pixels of the image are classified in one of the two categories:

- 1) If  $MGRVI \leq 0$  then it is assumed to represent a grazed area;
- 2) If  $MGRVI > 0$  then it is assumed to represent an ungrazed area.

### Step 3. Evaluate the actual size of the grazed and ungrazed areas

In order to implement this step, the following approximations are made:

- 1) It is assumed that the pasture is perfectly flat and the camera is horizontally leveled;
- 2) It is assumed that all pixels on the same row represent the same width and height of the pasture.

It is known that under the above conditions the rectangular image, captured by the camera, corresponds to an isosceles

trapezoidal ground surface (Fig. 2). Let its two bases be  $m$  (the short one, which is near the camera) and  $n$  (the long one, which is away from the camera), its two legs are with equal size  $d$ , and all of them are measured in meters. If the image is represented with  $x$  horizontal and  $y$  vertical pixels, it is necessary to obtain the corresponding ground surface to each pixel.

If the image has  $y$  vertical pixels (from 1 to  $y$ ), then there are  $y+1$  horizontal lines (from 0 to  $y$ ) separating them (Fig. 2). Considering the shortest line (Line  $y$ ) has length  $m$  and the longest one (Line 0) has length  $n$ , then the length of the  $k^{\text{th}}$  line  $x_{l(k)}$  can be obtained with:

$$x_{l(k)} = \frac{n-m}{2} \left(1 - \frac{2k}{y}\right) + \frac{n+m}{2} \quad (2)$$

where  $k$  takes values from 0 to  $y$ .

If the image has  $x$  pixels (from 1 to  $x$ ), then the width of all pixels on the  $k^{\text{th}}$  row can be approximated as an average of their two bases (Fig. 3):

$$x_{px(k)} = \frac{x_{l(k-1)} + x_{l(k)}}{2x} \quad (3)$$

where  $k$  takes values from 1 to  $x$ .

Next, in order to approximate the corresponding height of each row of pixels, the height  $h$  of the trapezoid should be obtained:

$$h = \sqrt{d^2 - \left(\frac{n-m}{2}\right)^2} \quad (4)$$

In order to account for the influence of the perspective on the pixel height, a coefficient is defined for each pixel row, which is obtained according to:

$$p(k) = \frac{x_{l(k-1)} + x_{l(k)}}{2} \quad (5)$$

Then the corresponding pixel height of the  $k^{\text{th}}$  row can be approximated with:

$$y_{px(k)} = h \cdot \frac{p(k)}{\sum_{z=1}^y p(z)} \quad (6)$$

Finally, the corresponding area of each pixel on the  $k^{\text{th}}$  row can be obtained with:

$$A_{(k)} = x_{px(k)} \cdot y_{px(k)} = \frac{x_{l(k-1)} + x_{l(k)}}{x} \cdot h \cdot \frac{p(k)}{\sum_{k=1}^y p(k)}, m \quad (7)$$



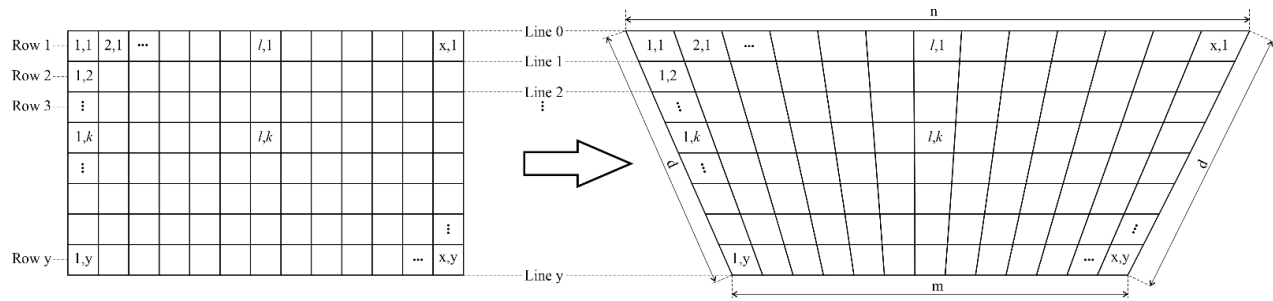


Fig. 2. Correspondence between the pixels and the observed pasture area.

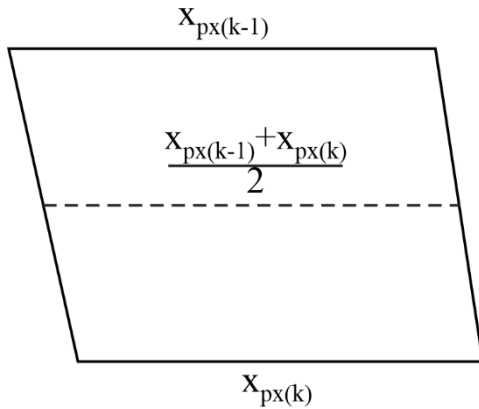


Fig. 3. Obtaining the pixel width as an average of its bases.

Using the above equations the cumulative area of each class can be obtained from Step 2 of the proposed methodology.

### III. RESULTS AND DISCUSSION

In order to test the developed methodology, an experimental study was performed on the 23<sup>rd</sup> of November 2022. The investigated pasture is located on the territory of the Research Institute of Mountain Stockbreeding and Agriculture Troyan (coords: 42.91135333102527, 24.703057318209225), as shown in Fig. 4.



Fig. 4. Location of the experimental pasture on the territory of the Research Institute of Mountain Stock-breeding and Agriculture, Troyan, Bulgaria

The analysis of the pasture at the moment of the experimental investigation showed that cereal and leguminous grasses predominate it. Furthermore, parts of the pasture are grazed and others are ungrazed. Closeup image samples from the pasture are presented in Fig. 5.



Fig. 5. Examples presenting the condition of the pasture: (a) An ungrazed part of the pasture with cereal and leguminous grasses; (b) A partly grazed part of the pasture with cereal grasses.

A number of photos of the pasture were made, using a Mobotix Mx-M16TB-R079 camera. It includes an optical sensor with resolution 3072x2048 px and an infrared sensor with resolution 336x252 px, though in this study only the visual spectrum data has been used. Two photos were selected for additional analysis, which are presented in Fig. 6:

- Image 1 (left) contains a part of the pasture, where the condition is mostly ungrazed. It can also be seen that there is an area in the upper part of the image, which represents an artificial object;
- Image 2 (right) contains a part of the pasture, which is mostly grazed. Furthermore, it contains a person standing on the field, which allows investigating the influence of artificial objects on the developed methodology.





Fig. 6. The selected RGB images that are being analyzed: (a) A mostly ungrazed area of the pasture; b) A mostly grazed area of the pasture with an artificial object (a person) on it.

The QGIS 3.0 software has been used to implement the image analysis and classification part of the methodology. Initially the MGRVI vegetation index is used to create raster contours for each input image, as shown in Fig. 7. From it can be unambiguously confirmed that the contours are dividing the grazed from the ungrazed areas of the pasture very precisely. This confirms that the chosen vegetation index is appropriate for the situation.



Fig. 7. Close-up of the created raster contours from a pasture image.

Next, according to the developed methodology, the pixels of the images are classified into grazed and ungrazed. This is

implemented by converting the contours to polygons and classifying them in two classes based on their fid property. The results from the classification for the two testing images are presented in Fig. 8.

Next, the developed methodology for analysis of the classified images has been implemented in a specialized software tool, using the Microsoft Visual Studio 2019 environment. It has been used to evaluate the grazed and ungrazed areas of the pasture, the results from which are summarized in Table I. According to the performed analysis, Image 1 represents a pasture, where 21% (57 m<sup>2</sup>) of the area is either grazed or represents artificial objects, and 79% (218 m<sup>2</sup>) of the area is ungrazed. These results indicate that this part of the pasture is in good condition and the animals could still be kept there.

Image 2 represents part of a pasture, where 71% (194 m<sup>2</sup>) of the area is grazed (or artificial), and 29% (81 m<sup>2</sup>) is ungrazed, i.e., the farmer should consider moving the animals to another part of the pasture.

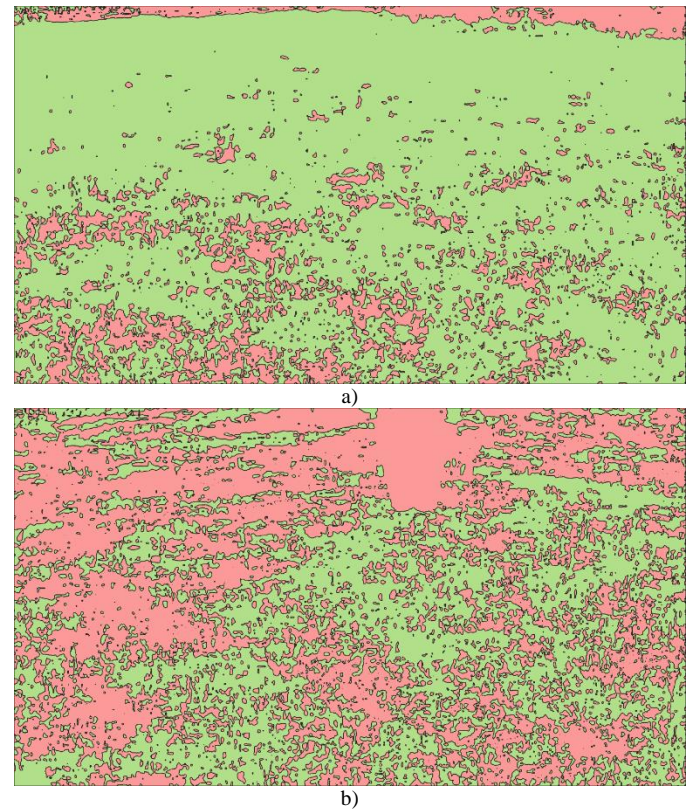


Fig. 8. Classification results from the analysis of: (a) Image 1; (b) Image 2.

TABLE I. RESULTS FROM THE CLASSIFICATION OF THE TWO PASTURE IMAGES

Image	Grazed area		Ungrazed area	
	m <sup>2</sup>	%	m <sup>2</sup>	%
Image 1	57	21	218	79
Image 2	194	71	81	29

The analysis of the obtained results allows us to make several observations. The performed classification using the MGRVI index allows correct identification of grazed and ungrazed areas of the pasture under the current conditions of

the investigated pasture. Nevertheless, it should be noted that the study was done in a period without significant rainfall and with lower temperatures. Therefore, it could be speculated that the MGRVI index might be inappropriate in periods of intense growth, such as mid spring to early summer, when there is no significant color difference between grazed and ungrazed areas. This shows that more studies might be required if a complete solution is to be created.

As was already mentioned Image 2 partly contains the contours of a human being, which means that the actual condition of the pasture behind him is unknown. And even though in this study this area was classified as grazed, this should not be considered as a rule. The analysis was performed only with data from the visual spectrum, and therefore the results of the classification depend entirely on the color of the clothes the person is dressed in. Similar conclusion can be made for Image 1, where the top pixel lines represent an artificial object. It was also classified as a grazed area because of the color of the object, yet in the general case the classification could be different.

Considering the aforementioned, the general recommendation that could be made when taking such photos is to try not to include any artificial objects within the photographed area. Another option might be to add an additional spectrum (such as infrared), which allows easy identification of some artificial objects. For example, living creatures would naturally return higher temperature than the surroundings. Similar results are expected from artificial objects, which were exposed to continuous solar radiation. Naturally, the inclusion of additional spectrum would require the modification of the vegetation index used.

The proposed method has several limitations, which should be considered when using it. It provides an assessment of the state of the pasture by showing its total and actual productivity, yet it cannot assess and give an idea of the suitability for consumption grass within the pasture, because the animals have their preferences and do not graze all types of grass. According to the accepted approximations, the pasture should be flat, if accurate classification of it should be conducted, which is another limitation of the proposed model. If the observed area is not ideally flat, this will create some errors in the calculations. The impact of the aforementioned limitation might be reduced if the evaluation of the area is performed using a UAV, yet this would require the farmer to make a relatively significant investment for acquiring the appropriate tools. Furthermore, the ability to pilot a UAV requires a certain qualification, which most of the farmers do not have.

That is the reason the proposed method was not intended to provide highly accurate results, but to perform fast and easy approximation of the grazed area, which is an important factor for the rotation of animals on pastures. An important advantage of this study is that it does not require the use of expensive equipment and specific technologies, because it relies on commonly available tools, such as the cameras of mobile phones. This way the developed model could be used by pretty much all farmers if appropriate tools are provided, and the only requirement towards the users is to have general knowledge on working with mobile devices.

#### IV. CONCLUSIONS

This study presents the development of a method for fast assessment of the grazed pasture areas with the use of ground-based cameras. The classification is based on the MGRVI index, which is known to allow easy differentiation between areas with grazed and ungrazed vegetation. The created classification map is then resized in order to account for the effect of the perspective, which allows fast and relatively accurate assessment of the actual grazed and potentially ungrazed areas in m<sup>2</sup> and in percentages.

The main advantage of the proposed model is that it does not require expensive equipment, such as UAVs, but rather relies on commonly available technologies such as the cameras of mobile phones. This way if an appropriate tool, which implements the proposed methodology is developed, it could offer decision-making support for all farmers in the process of rotating their animals on pastures, without any specific technological or knowledge requirements. The development of such user-friendly mobile application is an important follow-up task, which would allow applying the developed methodology in practice.

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# Instructional Digital Model to Promote Virtual Teaching and Learning for Autism Care Centres

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**Abstract**—The COVID-19 pandemic has led to temporary school closures affecting over 90% of students worldwide. This has exacerbated educational inequality, particularly for students with learning disabilities such as autism spectrum disorder (ASD), whose routines, services, and support they rely on have been disrupted. To address this issue, it is important to investigate virtual teaching and learning (VTL) strategies that can provide a more effective learning experience for these unique learners. The main objectives of this research are twofold: to investigate the challenges faced by teachers and students with ASD in Malaysia when adapting to online education, and to explore how the learning process occurs during the pandemic. Additionally, the study aimed to identify suitable VTL technology for autism care centres. Four autism care centres were visited for on-site observation activities, and interviews were conducted with the care centre principals. Two sets of online questionnaires were distributed to 10 autism care centres, where 6 principals and 16 teachers provided feedback. The data collected through on-site observations, interviews, and online questionnaires, were then analysed to construct an instructional digital model (IDM) for VTL. The model is very significant as a guide for the development of VTL platform for autism care centres. Finally, a VTL platform development framework was created, which provides a structure for system developers to conduct further research on the development of VTL platform based on the IDM. The framework aims to facilitate the successful implementation of the VTL.

**Keywords**—Instructional digital model; virtual teaching and learning; autism; online learning; pandemic

## I. INTRODUCTION

In response to the COVID-19 pandemic, the government of Malaysia implemented the Movement Control Order (MCO) which resulted in the closure of all kindergartens, public and private schools, including day schools and full boarding schools [1]. This disruption in the traditional classroom setting meant that many students, including those with special needs, were unable to continue their studies [2]. In response, online learning was implemented at home, but this has caused concern about the quality and inclusiveness of education, and the risk of many students being left behind has increased. In this new environment, schools, teachers, students, and parents have had to adapt to a new norm and method of teaching and learning [3].

Due to the pandemic, students with learning disabilities have faced significant challenges as their communication with

teachers has been hindered, and their access to educational resources has been restricted [4]. Among them, students with autism spectrum disorder (ASD) require specialised support to ensure that they can learn the same material as their peers in a manner that suits their skills and abilities [5]. Thus, a novel education approach is necessary to address the distinct requirements of these students in this new situation.

The lack of educators specialised in teaching students with special needs, particularly those with autism, presents significant difficulties in providing effective education [6]. However, there is now a glimmer of hope for enhancing teaching and learning methods for students with ASD through the progress of digital technology. Assistive and instructional technology allows students on the autism spectrum to participate more fully in their education, whether it is in their home, school, or community, thereby providing equal opportunities for students with special needs and those without [7].

To support virtual teaching and learning (VTL) for students with ASD, a special platform should be considered to allow these students to gain the same knowledge as other students, and thus reduce the learning gap between them. The challenges of teaching and learning involving students with ASD should be studied to determine the Information and Communication Technology (ICT) needs for teachers at care centres. An instructional digital model (IDM) needs to be established to guide the development and effective implementation of VTL.

Thus, this study aimed to answer the following research questions:

- 1) What are the challenges encountered by teachers and students with ASD when adopting online education, and how does the learning process unfold during the pandemic?
- 2) What type of ICT environment is required to facilitate the inclusion of students with ASD in virtual learning, particularly during a pandemic?
- 3) How can an IDM for VTL be developed for students with ASD based on the gathered information on their needs and limitations?

In order to answer the research questions, on-site visits were made to four selected autism care centres to obtain visual insight and understand what types of ICT equipment and tools are available and utilized at those centres. During these visits,

in addition to observing the premises, principals were also interviewed. Online questionnaires were created and distributed to the teachers and principals. The questionnaire aimed to obtain information about the ICT facilities available at the centres, as well as to gather feedback from teachers and principals on their profiles, perceived ICT skills, experiences, problems and challenges during pandemic, and their opinions on the potential integration of VTL. The study data were analysed and used to construct an IDM specifically for autism care centres.

This research paper aims to investigate the challenges and potential benefits of utilizing VTL for autism care centres. The following sections begin with a review of related works in the field. The methodology section describes the approach taken to conduct the research, including data collection and analysis methods. The analysis and discussion section presents the findings and examines their implications. Based on the results, recommendations are provided for the construction and implementation of the proposed IDM for autism care centres. The paper concludes with a summary of the findings, future directions for research, and the potential impact of IDM on the field of virtual teaching and learning for students with autism.

## II. RELATED WORKS

### A. Efforts by International Organisations

The United Nations (UN) recognises that digital technologies can be a powerful tool for individuals with ASD to access educational and vocational opportunities. Digital learning technologies have been recognised as a cost-effective way of providing specialised training and support for individuals with ASD, and they can also help to create a more inclusive society by reducing barriers to learning and employment. In 2020, the UN launched a global initiative called the "Roadmap for Digital Cooperation," which aims to ensure that everyone has access to the benefits of digital technology, including individuals with disabilities such as autism. The roadmap highlights the importance of promoting digital literacy and skills, as well as the need for accessible and inclusive digital technologies [8]. Another significant initiative is the UN's Sustainable Development Goals (SDGs), which aim to achieve universal access to quality education, including for individuals with disabilities, by 2030. SDG 4.5 specifically calls for the elimination of gender disparities in education and the promotion of inclusive and equitable education for all, including individuals with disabilities such as autism [9]. In addition to these overarching initiatives, the UN has also developed specific programs and resources to support digital learning for individuals with ASD. For example, the UNICEF Office of Research-Innocenti, in partnership with the World Autism Organisation and the International Society for Autism Research, developed a toolkit in 2020 to support the implementation of digital technologies for children with ASD. The toolkit provides guidance on how to adapt existing digital learning resources to meet the needs of children with ASD, and it includes case studies and best practices from around the world [10].

The World Health Organisation (WHO) has been actively promoting digital health through its Global Observatory for eHealth (GOe) initiative. The WHO has also published several

reports and guidelines on digital health for children with disabilities, including autism. The report highlights the importance of using digital technologies to promote health equity of children with disabilities and provides recommendations for governments and education providers [11].

The World Autism Organisation (WAO) is a non-profit organisation that focuses on improving the quality of life for individuals with ASD worldwide. WAO has launched the Autism Connection, an online community for individuals with ASD and their families. The platform provides a safe and supportive space for individuals with ASD to connect with others and share their experiences. The platform also offers resources and information on autism, including virtual events and webinars. Additionally, WAO has launched a campaign to raise awareness of the importance of virtual learning and the need to ensure that individuals with ASD have access to quality education, regardless of their location or circumstances. Through these efforts, WAO is supporting the education and development of individuals with ASD and their families, as well as the wider community [12].

### B. Online Education for Individuals with ASD in Malaysia

According to the World Health Organisation (WHO), approximately 1% of children worldwide have autism [13]. In Malaysia, research indicates that the prevalence of autism has increased, with an estimated ratio of 1 in 68 individuals without autism, and around 9,000 children are born with autism each year. The Ministry of Health (MOH) reports that the number of diagnoses for autism spectrum disorder has steadily risen over the last decade, with 589 children aged 18 and under diagnosed with ASD in 2021, a 5% increase from the previous year [14].

According to the Education Act 1996, students under the responsibility of the Ministry of Education (MOE) who have special needs are those with visual, hearing, and learning impairments. Learning disabilities refer to cognitive issues that are considered treatable and allow students to receive formal education. The Malaysian Education Development Plan (MEDP) 2013-2025 has outlined clear objectives to be met over a 13-year period concerning quality, equity, access to education, as well as educational management efficiency and effectiveness. Eleven strategic shifts have been formulated to transform the education system, with the first shift being to provide equal access to internationally recognised quality education. Students with special needs, such as those with autism, are included in this objective [15]. The Shared Prosperity Vision 2030 (SPV 2030) highlights people with special needs as a target group. The overarching principle of the new national policy is to promote the development of all communities in Malaysia [16].

Several organisations and bodies in Malaysia are responsible for providing support and assistance to individuals with ASD. One such organisation is the National Autism Society of Malaysia (NASOM), which aims to provide services and support to individuals with ASD and their families [17].

In recent years, the Malaysian government has made efforts to provide online education for individuals with ASD. One

such initiative is the MOE TV Pendidikan program, which provides online classes for students with special needs, including those with autism. The program includes subjects such as mathematics, science, and language, and is available for primary and secondary school students [18][19].

Another government initiative is the MyAutism Portal, which is an online platform that provides resources and information on autism for parents, caregivers, and educators. The portal includes various modules, such as early intervention, communication, and social skills. Additionally, the Malaysian Communications and Multimedia Commission (MCMC) has launched the JomBelajar@Home program, which provides online education for students with disabilities, including autism [20][21]. The program includes a range of subjects, including academic and vocational skills, and is accessible to students with disabilities nationwide. With the current COVID-19 pandemic situation, online education has become increasingly important for individuals with ASD who require special education.

### C. Other Related Studies

The COVID-19 pandemic has presented numerous challenges for children with ASD and their families. It has increased the burden on caregivers of children with ASD, who may not have access to the necessary resources to manage their child's condition. This highlights the need for more resources and support for caregivers, who play a critical role in the care of children with ASD [22].

A study conducted by [23] surveyed parents of children with ASD in the United States and found that they faced several challenges related to the provision of education and support for their children. These challenges included lack of resources and difficulties in maintaining routines. To address these challenges, Stenhoff et al. [24] provided guidance for educators and caregivers on how to support children with ASD during the pandemic. They stressed the importance of maintaining routines and structure, providing clear communication, and using visual supports to help children understand and cope with the changes brought about by the pandemic. The researchers explored the challenges faced by parents of children with ASD in Taiwan during the pandemic and the strategies they used to overcome them. They found that parents faced difficulties in adapting to online learning and employed a variety of strategies to overcome these challenges.

Several studies have investigated the impact of the COVID-19 pandemic on the support and therapy available for children with ASD. Johnsson et al. [25] conducted a study in India and found that teletherapy could be an effective solution for children with ASD who may not have access to traditional therapies due to the pandemic. This highlights the potential of teletherapy to overcome the lack of access to traditional therapies and provide remote access to therapy. Similarly, Furar et al. [26] investigated the impact of the pandemic on social support for families of children with ASD in Greece and found that the lack of social support has significantly affected these families, who already have limited access to experts and resources. This emphasises the need for more support for families of children with ASD, particularly during times of crisis. Furthermore, Syriopoulou-Delli et al. [27] reviewed

technology-assisted services for individuals with ASD and found that while such services have the potential to provide additional resources and support, there is a need for more resources and expertise to ensure their effectiveness and accessibility.

## III. METHODOLOGY

### A. Overview

Research plays a vital role in gathering information and data to support the development of evidence-based practices. In the context of autism care centres, research is crucial for understanding the needs of children with ASD and developing effective care strategies. Hyett et al. [28] emphasized the importance of employing various research methods in autism care centres to gain a better understanding of the needs of children with ASD and to develop effective care strategies.

The purpose of this research was to investigate the challenges encountered by teachers and students with ASD when transitioning to VTL during the COVID-19 pandemic, and to explore how the learning process unfolds in this new context. Additionally, the use of ICT in the practices and services of several autism care centres in Malaysia was also part of the study. To achieve the research goals, several activities were undertaken, including literature review, on-site observations, interviews with principals, and an online questionnaire for both teachers and principals of the autism care centres. The literature review provided a theoretical framework for the study, while on-site observations allowed for a deeper understanding of the challenges faced by teachers and students with ASD during the pandemic. Interviews with principals provided insights into the strategies used by the centres to support VTL, and the online questionnaire helped gather information from the participating teachers about their experiences and challenges regarding VTL for students with ASD.

In summary, the research emphasises the significance of using diverse research techniques to comprehend the VTL requirements of children with ASD and to produce effective care and teaching strategies in the form of digital content. The outcomes of the study are expected to facilitate the construction of an Instructional Digital Model that can support the creation of a VTL platform specifically designed for autism care centres.

### B. On-site Observation

Observation is a commonly used research method that involves direct observation and recording of behaviours and activities in a specific setting. In an autism care centre, observation can be used to study the interactions between teachers and students with ASD, the physical environment, and the effectiveness of different care strategies [29].

To conduct on-site observation in autism care centres, the researchers visited four different autism care centres from different organizations to prevent any bias. A guideline in the form of an on-site observation form was used to observe ICT facilities available at the centres. The form consisted of five sections that were specific to particular aspects of the facilities, including ICT infrastructure, security, storage, teaching and



learning, and administration. Each section required direct observation to record comments and judgments on the ICT aspects [30].

To ensure that no aspect was left unobserved, the researchers checked all required aspects on the form before concluding the observation. Through on-site observation, the researchers gained insight into the operations of the autism care centres and identified potential areas for improvement. Notes were taken, and practices or services that involved ICT were recorded.

### C. Interviews

Interviews are widely used in research to explore a range of topics related to autism, including telehealth services [31], social communication challenges [32], and classroom-based interventions [33]. Interviews are a valuable research method for exploring the experiences and perspectives of those involved in autism care, as they provide detailed and nuanced insights into the topic [34].

In this study, interviews were conducted with the principals or managers of the four autism care centres during on-site observation activities. Informed consent was obtained from each participant prior to the interview, which was based on semi-structured questions covering various aspects of the premise facilities, teachers' profiles, skills, experiences, ICT tools used in teaching, and challenges faced during the pandemic. The semi-structured questions were designed to elicit detailed information from the participants about their experiences with ICT tools in teaching and their challenges during the pandemic. The interviews were conducted in person and lasted between 30 to 60 minutes, and the audio recordings were transcribed and analysed to identify themes and patterns in the data.

In conclusion, interviews are a valuable research method for exploring the experiences and perspectives of those involved in autism care. In this study, interviews with the principals or managers of the autism care centres provided valuable insights into the use of ICT tools in teaching and the challenges faced during the pandemic. The data collected from the interviews were used to support the findings of the research and to develop recommendations for improving the use of VTL in autism care centres.

### D. Online Questionnaire

Online questionnaire is a research method that involves administering a set of questions to individuals through an online platform [35]. In an autism care centre, this method can be used to gather information from a large sample of individuals who related with students ASD, such as families, and caretakers. For instance, researchers can administer surveys to caretakers and families to understand their experiences with the care provided in the centre.

Similarly, surveys can be administered to staff members to gather information on their training needs, challenges, and suggestions for improving care. Through online surveys, researchers can collect data from a wide range of participants, providing a more comprehensive understanding of the needs of individuals with ASD [36].

This study utilized an online questionnaire as a data collection method due to time constraints and the pandemic situation that limited in-person meetings. The study used a convenience sampling technique to disseminate the questionnaire to potential respondents. The selection of autism care centres was based on their accessibility and proximity to the researcher, rather than a probability-based sampling method. The data collection platform used was Google Form, and link of questionnaire was distributed via email and the WhatsApp application to several autism care centres in Malaysia. Respondents could complete the online questionnaire on their laptop, desktop, tablet, or mobile phone, and it took approximately five minutes to finish.

The study developed two sets of online questionnaires: one for principals and another for teachers or caretakers of students with ASD who received care at the participating centres. The questionnaires were based on structured questions that covered various aspects of the participants' profiles, ICT skills, ICT experiences, ICT tools used in teaching, and challenges they faced during the pandemic [37]. The questionnaires were designed to be user-friendly and easily accessible through online platforms. The teachers and principals were provided with a link to the respective questionnaire through email and were given clear instructions on how to complete the questionnaire. The responses from the questionnaires were collected and analysed to identify themes and patterns in the data.

## IV. ANALYSIS AND DISCUSSION

### A. Overview of Research Findings

The flow of the research process to investigate the impact of the COVID-19 pandemic on teaching and learning in the selected autism care centres in Malaysia consists of several stages. A summary of the research findings based on the research process is as illustrated in Fig. 1.

The initial stage in the research process flow is data collection, whereby the investigators employed three primary methods, namely on-site observations, interviews, and online questionnaires, to collect information. The second stage is data analysis and findings, where the researchers utilised NVIVO, a qualitative data analysis software, to organise and structure the data obtained. The information collected through on-site observations, interviews, and online questionnaires underwent analysis, and the outcomes were integrated to identify recurrent themes and patterns. During this phase, three themes emerged: 1) Challenges encountered during the pandemic; 2) ICT requirements; and 3) Instructional model.

The third stage comprises interpreting the data analysis results to gain a more profound comprehension of the difficulties, technology prerequisites, and instructional approaches employed by autism care centres during the pandemic. The interpretation process involves scrutinizing the data and recommendations based on the findings within the context of existing literature and theories associated with the influence of challenges on education and the utilization of technology to promote VTL. The outcome of this phase is the identification of VTL platform elements, recommended technologies, and digital platform features.

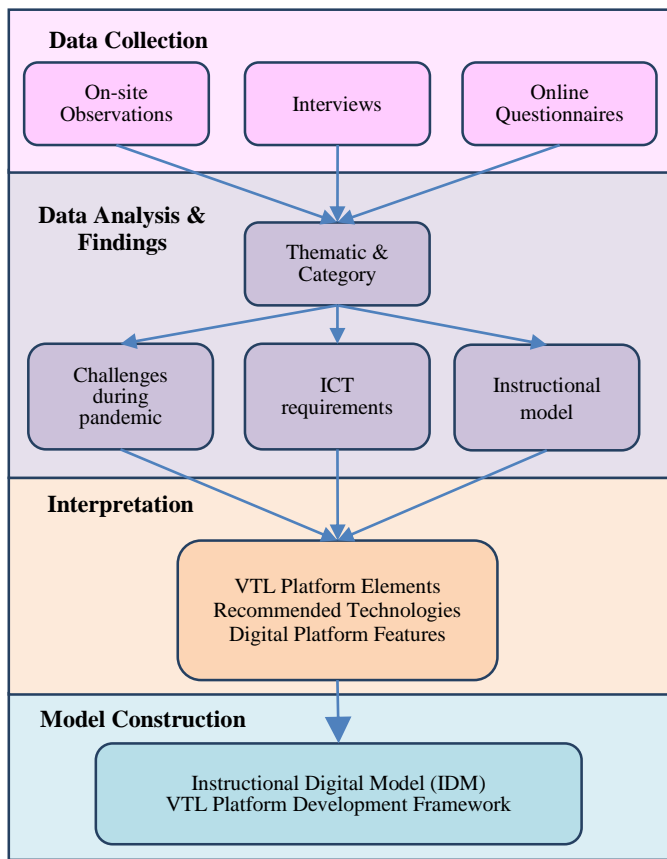


Fig. 1. Research process flow and findings.

In the research process, the ultimate step involves constructing a model where the researchers utilised the findings from earlier stages to create an IDM for VTL in autism care centres. The objective of the IDM is to tackle the issues caused by the COVID-19 pandemic and enhance the educational experience for children with ASD in the virtual environment. The core of IDM consists of strategies, methods, and skills tailored to meet the specific requirements of students with ASD in the VTL context. At this stage, the researchers also formulated the proposed framework for the VTL development.

**B. Preliminary Analysis**

Based on the online questionnaire that received responses from 16 teachers, the result revealed that 87.5% of the responding teachers were female, and 76% were under 36 years of age. Most of them had between 1-5 years of experience in teaching-learning related to autism, and only 31.3% had ever attended a course or had a special education certificate.

In terms of ICT skills, the result found that 62.5% of the responding teachers did not have any certification in ICT skills, and 93.8% had knowledge in Microsoft Office. WhatsApp was the most commonly used social media for communication with parents or guardians. The study revealed that there is a relatively large gap between teachers' knowledge and virtual learning skills, with the majority of the respondents having moderate or very little knowledge about VTL. Videos from YouTube were the most often software used for teaching,

followed by downloaded apps from the internet, Ms PowerPoint, and others.

**C. Data Analysis**

Table I shows the categories of information collected and structured using NVIVO application. The first source, on-site observations, captured information on ICT infrastructure, including internet and WiFi availability, ICT security measures such as CCTV cameras and door access, and ICT tools for teaching and learning such as PCs, laptops, tablets, LCD TVs, digital boards, projectors, social media, educational software, and related websites. The observations also covered ICT tools for administration, including MS Office, email, and accounting systems, as well as ICT storage tools such as file explorer, USB pen, and external HD.

The second source, interview transcriptions, captured information on the premise facilities, including classrooms, kitchens, and offices, as well as the students' demographic, staff resources, teaching content and modules, financial resources, and management and administration. The interviews also captured information on the problems and challenges encountered during the pandemic.

The third source, online questionnaires, captured information on the profiles of the teachers and caregivers, their skills and experiences, ICT tools used for teaching, problems and challenges encountered during the pandemic, and their views on VTL for students with ASD.

TABLE I. DATA SOURCES AND NODES

Sources	Nodes
On-site Observation	ICT Infrastructure (Internet, WiFi)
	ICT Security (CCTV Camera, Door Access)
	ICT for Teaching Learning (PC, Laptop, Handphone, Tablet, LCD TV, Digital board, Projector, Social media, Edu software, related websites)
	ICT for Administration (Ms Office, Email, Accounting System)
	ICT Storage (File Explorer, USB Pen, External HD)
Interview Transcription (principals)	Premise facilities (classroom, kitchen, office, etc)
	Students/children demographic
	Staff resources
	Teaching content and modules
	Financial resources
	Management and administration
Online Questionnaire (teachers, principals)	Problems and challenges during pandemic
	Profiles
	Skills
	Experiences
	ICT tools used for teaching
	Views

Overall, the table shows that the study collected a wide range of information related to the impact of the pandemic on teaching and learning in autism care centres. The information is structured in a way that enables easy comparison and analysis, making it easier to draw conclusions and make recommendations based on the findings.

Three themes emerged from the data analysis were: teachers' challenges during the pandemic, ICT requirements for online teaching and learning, and an instructional model for students with ASD. The following sections provide analysis of each theme and its implications for teaching and learning in the context of the pandemic.

*D. Theme 1: Challenges during the Pandemic*

The first theme that emerged from the data analysis was the challenges that teachers faced during the pandemic. This theme is directly related to the first research question as stated in the initial section. Useful information acquired through interview sessions with participants, observations and online questionnaire were taken into account as evidence and inputs for data analysis.

Table II shows the challenges faced by teachers of the care centres in teaching children with ASD during the pandemic. As the pandemic has affected many aspects of daily life, it has also brought challenges to teaching and learning for children with ASD.

TABLE II. CHALLENGES IN TEACHING CHILDREN WITH ASD (TEACHERS' FEEDBACK)

Challenges	Description of findings
Cooperation from parents	Parents play a critical role in supporting their children's education, especially during the pandemic when much of the learning takes place at home. Ensuring cooperation from parents is important to maintain the continuity of education.
Funds for activities	Activities outside the classroom are essential for children with ASD, and the pandemic has limited the opportunities for these activities. Funding can be a challenge for carrying out these activities in a safe and effective manner.
Communication and behavioural problems	Children with ASD often struggle with communication and behaviour, and these challenges have been amplified during the pandemic due to the disruption of routines and increased stress levels.
Managing emotions and behaviours	Children with ASD may have difficulty managing their emotions and behaviours, and this can be exacerbated by the pandemic.
Repetition of teaching methods	Children with ASD often require repetition of teaching methods to achieve satisfactory learning outcomes, and this can be a challenge for educators during the pandemic when resources may be limited.
Cultivating discipline	Daily routines are essential for children with ASD, and cultivating discipline in performing these routines can be challenging during the pandemic when routines may be disrupted.
Children tantrums	Children with ASD may have tantrums, and these can be exacerbated by the pandemic due to increased stress levels.
Sexual development of autistic adolescents	Adolescents with ASD may have difficulty understanding sexual development and behaviours, and this can be a challenge for educators during the pandemic when access to resources may be limited.
Self-management and use of toilet	Children with ASD may require support in self-management and using the toilet, and this can be a challenge for educators during the pandemic when resources may be limited.

The teachers feedback provided a range of problems, including the lack of adequate training on online teaching, limited access to ICT infrastructure and resources, and difficulties in maintaining student engagement and motivation.

Table III outlines the significant difficulties and obstacles encountered by autism care centres amid the pandemic, as identified through a comprehensive analysis and feedback from principals.

TABLE III. CHALLENGES OF AUTISM CARE CENTRES DURING THE PANDEMIC (OVERALL ANALYSIS)

Challenges	Description of findings
Limited access to therapy and services	Many autism care centres had to temporarily close or reduce their services due to the pandemic. This has resulted in limited access to therapy and services for individuals with ASD, which can have a significant impact on their progress and development.
Staffing shortages	Some autism care centres have experienced staffing shortages due to illness, quarantine, or personal reasons. This has made it challenging to provide education, adequate care and support for individuals with ASD.
Financial difficulties	The pandemic has resulted in financial difficulties for the autism care centres, as they have had to incur additional expenses related to Personal Protective Equipment (PPE), cleaning, and sanitisation. This has led to reduced services and increased financial burden on the centres.
Changes in routine	Individuals with ASD thrive on routine and predictability. However, the pandemic has disrupted routines and introduced uncertainty, which can cause distress and anxiety for individuals with ASD.
Social isolation	Individuals with ASD may already struggle with social skills and communication, and the pandemic has made social isolation more prevalent. This can lead to increased feelings of loneliness, anxiety, and depression.
Technology challenges	All autism care centres have to adapt to virtual care and therapy, which can be challenging for individuals with ASD who may struggle with technology or have difficulty engaging in virtual sessions.

In conclusion, autism care centres in Malaysia have faced significant challenges during the COVID-19 pandemic. These challenges have affected the delivery of care and support as well as teaching and learning for individuals with ASD, resulting in increased stress and difficulties for both individuals with ASD and their caregivers.

*E. Theme 2: ICT requirements for online teaching and learning*

The second theme that emerged from the data analysis was the ICT requirements for online teaching and learning. The results of this data analysis have helped a lot to answer the second research question and shed light on the specific ICT needs in the context of autism care.

To gather comprehensive information regarding the ICT facilities available in autism care centers, an online questionnaire was administered due to the limitations posed by conducting on-site observations. This questionnaire was thoughtfully designed to elicit feedback on the utilization of

ICT tools and the overall capabilities of the care centers in integrating technology into their educational practices. The questionnaire received responses from 16 participants, including teachers and principals, representing six different autism care centers.

The gathered feedback, as described in Table IV, provided significant insights into the current state of ICT implementation within the participating autism care centers.

TABLE IV. ICT FACILITIES IN AUTISM CARE CENTRES

Type of Information	Description of findings
Age of autism care centre	Four centres had been operating for less than five years, one for less than ten years, and one for more than ten years.
Number of teachers	Most centres had more than five teachers. Four centres had between 10 and 20 children, while the other two had between 30 to 50. None of the centres could accommodate more than fifty children.
ICT skills	All centres had at least two teachers with ICT skills or who had attended ICT courses.
ICT infrastructure	All centres had Internet, Wi-Fi, PCs, and laptops. They also had their own websites, but most lacked multimedia and teaching-learning applications.
Software systems	None of the centres had specific software systems for administration, teachers, and learning schedules.
Network community	Three centres had a network community, while the other three did not.
Virtual teaching	Five centres frequently conducted virtual teaching-learning during the pandemic, while one did it rarely.
Communication media	WhatsApp was the most common communication medium between administrators of care centres and parents. Facebook and telephone were also frequently used.
Information communicated to parents	Invitations were the most common form of information communicated to parents, followed by news and notifications.
ICT needs	PCs and laptops were the ICT needs that all care centres stated they most wanted to help the teaching/learning process. Most centres also needed teaching-learning software, digital screen boards, and multimedia tools.
ICT knowledge and skills	Two centres stated they needed skills in using software that can help management. Two centres stated they did not need any ICT skills. The other two centres each stated they needed basic ICT technology skills and skills in using software that can aid teaching.
Digital storage	All centres used File Explorer, USB Pen Drives, Google Drive, Facebook, and YouTube for digital storage.

The teachers responded that they required a range of digital tools and resources to support online teaching, including learning management systems, video conferencing platforms, and digital content. They also responded to the need for reliable internet connectivity, devices such as laptops or tablets, and appropriate software.

The findings suggest that the autism care centres need to invest in the necessary ICT infrastructure and resources to support online teaching and learning. This includes providing teachers and students with the necessary hardware and

software and ensuring that they have reliable access to the internet. The autism care centres should also invest in developing or adopting learning management systems and video conferencing platforms that are user-friendly and accessible.

#### F. Theme 3: Instructional Model

The third theme that emerged from the data analysis was the instructional model being practiced by the autism care centres during the pandemic. Based on compilation of data collection through the on-site observation, interviews, and online questionnaires, not many autism care centres have transitioned to VTL to continue providing educational and therapeutic services to children with autism. Based on the findings, the weaknesses of VTL practice in those autism care centres are described in Table V.

TABLE V. FINDINGS OF INSTRUCTIONAL PRACTICE IN THE AUTISM CARE CENTRES

Findings	Description of findings
Lack of access to necessary digital tools	The feedback obtained from teachers indicated a need for a range of digital tools and resources to support online teaching, including learning management systems, video conferencing platforms, and digital content. Some autism care centres have no necessary funds or infrastructure to provide these tools to their teachers and students.
Poor internet connectivity	Reliable internet connectivity is essential for online teaching and learning, but some autism care centres may be located in areas with poor internet infrastructure, making it difficult for teachers and students to access online resources and participate in virtual classes.
Limited availability of devices	Teachers and students require laptops or tablets to access digital resources and participate in virtual classes, but not all autism care centres have enough devices to meet the needs of all their students.
Lack of training	Some teachers may not have the necessary skills and training to effectively deliver online instruction and may require additional training and support to adapt to the new virtual teaching environment.
Difficulty in engaging students	Some students with ASD may struggle with the lack of face-to-face interaction and find it challenging to engage with online instruction, which could hinder their learning progress. Teachers may need to adapt their teaching strategies to keep students engaged and motivated.

The findings suggest that the autism care centres should explore virtual platforms as a viable alternative to traditional classroom-based learning. This includes developing and implementing strategies that promote student engagement and motivation, such as gamification and collaborative learning activities. The autism care centres should also ensure that students have the necessary skills and resources to support online learning, such as digital literacy skills and access to appropriate ICT resources.

### V. RESULTS AND RECOMMENDATION

#### A. Proposed VTL Platform Elements

The proposed elements of a VTL platform for children with ASD should be meticulously designed to address the

distinctive needs of these learners, as illustrated in Fig. 2. By integrating these elements into a VTL platform, it is envisaged that children with ASD will benefit from a customized and effective learning experience tailored to their specific requirements.

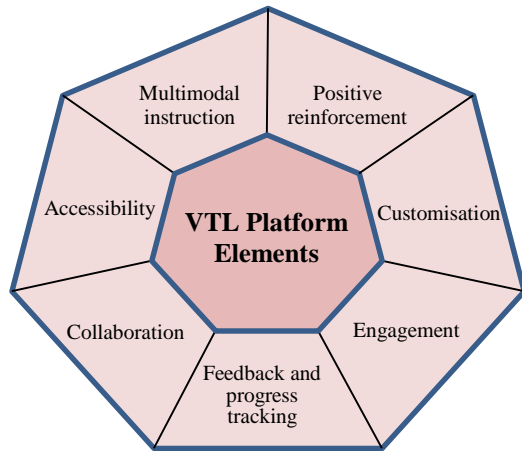


Fig. 2. VTL Platform elements for Autism Care Centres

Table VI describes the proposed elements of a VTL platform for autism care centres.

Overall, the design and implementation of a comprehensive VTL platform specifically tailored for children with ASD have the potential to revolutionize their learning experience, ensuring that they receive the individualized support and resources they need to thrive academically and socially.

TABLE VI. PROPOSED ELEMENTS OF A VTL PLATFORM FOR AUTISM CARE CENTRES

Elements	Description
Accessibility	VTL platform and tools should be accessible to children with different abilities and disabilities. Accessibility features such as text-to-speech, closed captioning, and audio descriptions should be available.
Customisation	VTL platform should allow for customisation based on the individual needs of each child with ASD. This may include adapting the pace and difficulty of instruction, providing visual aids, and accommodating sensory preferences.
Multimodal instruction	VTL platform should provide instruction using multiple modes, such as visual, auditory, and kinesthetic, to meet the diverse learning needs of children with ASD.
Engagement	VTL platform should be designed to actively engage children with ASD in the learning process. Interactive and multimedia materials such as videos, games, and simulations can be used to enhance engagement and maintain attention.
Collaboration	VTL platform should provide opportunities for collaboration and communication between teachers, parents, and children with ASD. Online forums, chat rooms, and video conferencing can be used to facilitate collaboration and social interaction.
Feedback and progress tracking	VTL platform should include features that allow for feedback and progress tracking. Teachers and parents should be able to monitor the child's progress and provide feedback to support learning and development.
Positive reinforcement	VTL platform should include positive reinforcement strategies to motivate and encourage children with ASD. This may include rewards and praise for completing tasks and achieving goals.

### B. Proposed Technology and Digital Platform Features

During the COVID-19 pandemic, there are several technologies that can be used in various ways to support individuals with ASD. Immersive learning has been identified as a promising approach to address the learning challenges faced by students with ASD [38]. Immersive learning utilises virtual and augmented reality (VR and AR) technologies to create engaging and interactive learning environments that can be customised to meet the individual needs of students with ASD [39].

The immersive learning environment can be customised to meet the unique sensory processing needs of students with ASD, which provides a comfortable and engaging learning experience. Moreover, immersive learning environments can improve communication and social skills by allowing students to interact with virtual characters and environments [38]. Immersive learning has also been shown to be an effective tool for teaching a range of skills, including academic content, vocational skills, and life skills [40][41][42]. This versatility makes immersive learning a valuable tool for educators who work with students with ASD. Studies have shown that immersive learning can be effective in improving the social, communication, and vocational skills of students with ASD [43]. Therefore, immersive learning should be considered an important tool for educators who are working with students with ASD.

In summary, there are several technologies that can be used in various ways to support individuals with ASD. Some suggestions are described in Table VII.

TABLE VII. RECOMMENDED TECHNOLOGIES FOR AUTISM CARE CENTRES

Components	Description
Teletherapy	Many therapists and educators have turned to teletherapy, which uses videoconferencing technology to provide therapy and instruction remotely. This allows individuals with ASD to continue receiving therapy and support during the pandemic, even if they are unable to leave their homes or attend in-person appointments.
Virtual classrooms	Virtual classrooms have been used to provide instruction and support for individuals with ASD during the pandemic, allowing them to continue their education and social interaction from home.
Social media and communication apps	Social media and communication apps have been used to provide social interaction for individuals with ASD, who may have difficulty with face-to-face interactions.
Augmented Reality and Virtual Reality	These technologies have been used to provide immersive, interactive experiences for individuals with ASD, which can be especially beneficial for those who have difficulty with traditional learning methods.
Assistive technology	Assistive technology, such as speech-to-text and text-to-speech software, can be used to support individuals with ASD in their communication and learning.
Mobile apps	There are mobile apps designed for individuals with ASD which provide educational and behavioural support, as well as for communication and social skills development.
Adaptive devices	Adaptive devices, such as switches and joysticks, have been used to provide access to technology for individuals with ASD who may have difficulty using standard input devices.



Overall, technology plays an important role in supporting individuals with ASD during the COVID-19 pandemic, by providing flexible, customised learning opportunities, and social interaction, as well as providing access to therapeutic and educational resources.

As for the features of digital platform, they are listed and described in Table VIII.

TABLE VIII. FEATURES OF DIGITAL PLATFORM

Features	Description
Flexibility	Digital platform allows individuals with ASD to learn at their own pace and on their own schedule, which can be especially beneficial for those who have difficulty with traditional classroom settings.
Customisation	Digital platform can be customised to meet the specific needs of individuals with ASD, such as providing visual aids, audio support, and other accommodations.
Social interaction	Digital platform can provide opportunities for social interaction for individuals with ASD, who may have difficulty with face-to-face interactions. Virtual classrooms, social media and other online platforms can provide a safe and comfortable environment for socialisation.
Access to resources	Digital platform can provide access to a wide range of resources and materials that can be used to support the learning of individuals with ASD, such as videos, interactive activities, and simulations.
Remote learning	Digital platform can be done remotely, which can be beneficial for individuals with ASD who may have difficulty traveling to a physical location, or who may benefit from the reduced social interaction that remote learning provides.
Access to specialised teachers	Digital platform can provide access to specialised teachers, such as those trained in autism education, who can provide individualised instruction and support.
Access to global resources	With digital platform, individuals with ASD can access resources and educational materials from around the world, which can be beneficial for those who live in areas with limited resources.

In summary, the use of digital platforms can offer a multitude of benefits for individuals with ASD. It can provide a flexible and customizable learning experience that can be tailored to the specific needs and preferences of the learner, a safe and comfortable learning environment, social skills development, and access to a wider range of learning opportunities. This is particularly important for individuals with ASD, who may have different learning styles and sensory preferences. As such, digital platforms should be considered as an important tool for educators and caregivers who are working with individuals with ASD.

### C. Proposed Instructional Digital Model

Students with ASD have been notably impacted by the COVID-19 pandemic, which has caused considerable disruptions to traditional classroom-based learning. To address this challenge and promote VTL in autism care centres, an IDM has been proposed based on the challenges and needs, which are part of findings of this research study. The IDM for VTL aims to enhance the learning experience for children with ASD, making it more effective and engaging.

As depicted in Fig. 3, the proposed IDM for VTL comprises of three core components: VTL Strategies, VTL Methods, and VTL Skills.

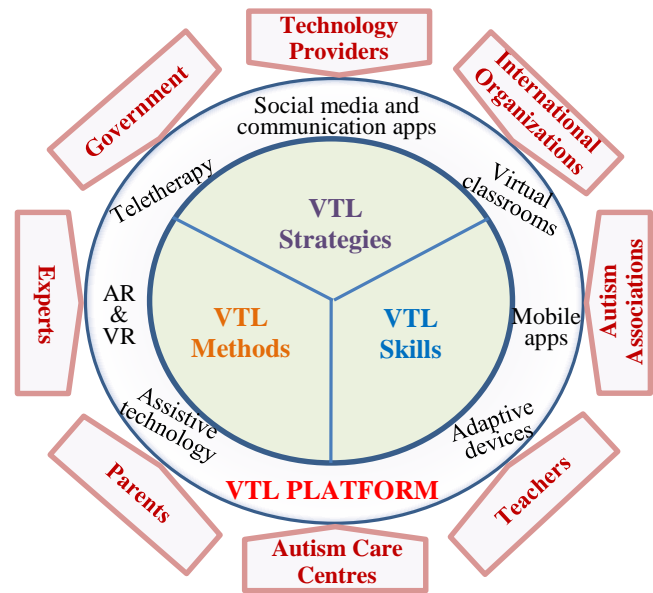


Fig. 3. Instructional Digital Model (IDM) for VTL

**VTL Strategies:** The first component of the IDM is VTL Strategies. These strategies refer to the various ways in which teaching is organised and delivered to students with ASD. They involve a range of approaches designed to enhance learning, such as the use of visual aids, repetition, and positive reinforcement. VTL Strategies also include ways to address specific needs of students with ASD, such as social skills training, sensory integration, and behaviour management.

**VTL Methods:** The second component of the IDM is VTL Methods. This component refers to the specific techniques and tools used to deliver instruction in a virtual learning environment. VTL Methods include the use of multimedia, interactive tools, and virtual reality. They also include adaptations of traditional teaching methods to suit the online environment, such as the use of digital whiteboards, chat rooms, and video conferencing.

**VTL Skills:** The third component of the IDM is VTL Skills. These refer to the specific abilities that teachers and students with ASD need to acquire to be successful in a VTL environment. VTL Skills may include the ability to navigate digital platforms, use of assistive technologies, and self-regulation techniques. Additionally, students with ASD may need support in developing social skills and self-advocacy skills to interact with their teachers and peers in the online classroom.

In summary, the IDM for VTL proposes to enhance the learning experience for teachers and children with ASD by incorporating strategies, methods, and skills designed to meet the specific needs of this population. By leveraging the strengths of technology, the IDM aims to create a more effective and engaging learning experience for students with ASD, even in the face of disruptions caused by the COVID-19 pandemic.



D. Proposed VTL Platform Development Framework

Developing and implementing a VTL platform for autism care centres requires a framework to ensure its effectiveness and success. The framework provides a structured approach to developing and implementing the VTL, ensuring that all aspects of the learning experience are accounted for and that they align with the specific needs of students with ASD.

The framework for developing the VTL platform for autism care centres is depicted in Fig. 4.

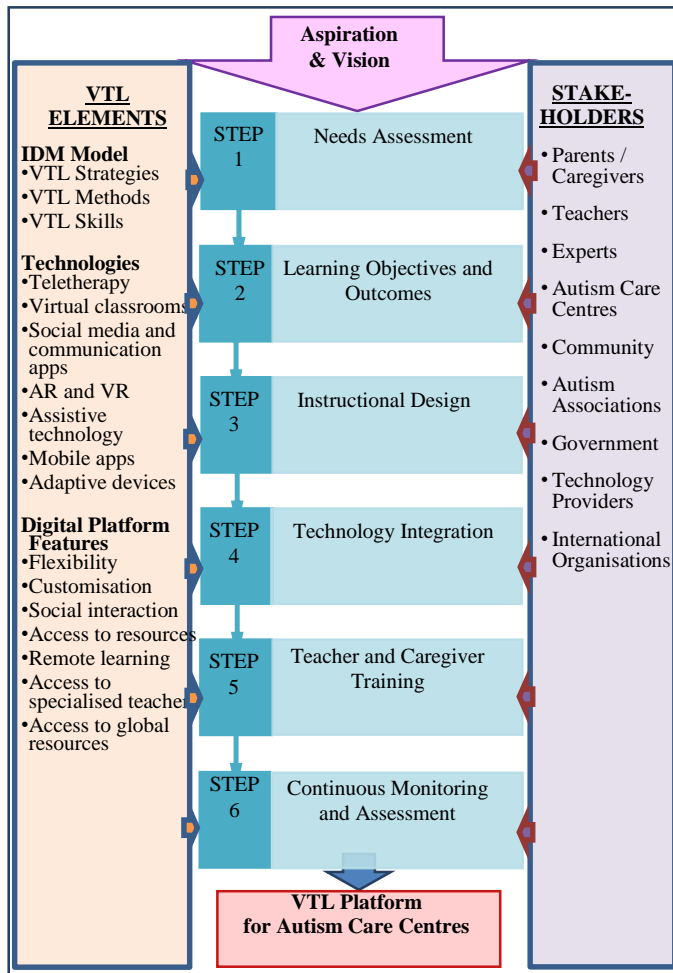


Fig. 4. VTL Platform Development Framework for Autism Care Centre

The framework also enables a standardised approach to be adopted, ensuring that the VTL is consistent across different care centres and teaching environments. Additionally, it provides a mechanism for evaluating the effectiveness of the VTL, identifying areas for improvement and ensuring that the IDM continues to evolve to meet the changing needs of students with ASD.

Details of the VTL platform development framework are described in Table IX.

In summary, the VTL platform for autism care centres is anticipated to provide a more effective and engaging learning experience for children with ASD in autism care centres in Malaysia. By following the steps outlined in this proposal,

autism care centres can develop a customised VTL platform that addresses the specific learning needs and challenges of children with ASD, while integrating appropriate technology tools and methods for VTL. The framework also includes training and ongoing support for teachers and caregivers, as well as a process for continuous monitoring and assessment of the effectiveness of VTL. Overall, the framework is essential for the successful development and implementation of the VTL platform for autism care centres, providing a roadmap for its creation and ensuring that it is effective and responsive to the needs of students with ASD.

TABLE IX. PROPOSED VTL PLATFORM DEVELOPMENT FRAMEWORK FOR PROMOTING VTL

Activity	Description
Step 1: Needs assessment	The first step in developing a VTL platform is to conduct a needs assessment to identify the specific learning needs and challenges of children with ASD in the centre. The needs assessment should also take into account the resources and technology available at the centre. This information can be collected through surveys, interviews, and observation.
Step 2: Learning objectives and outcomes	Based on the needs assessment, clear learning objectives and outcomes should be developed to guide the development of instructional materials and strategies. These learning objectives should be specific, measurable, achievable, relevant, and time-bound (SMART).
Step 3: Instructional design	The next step in developing a VTL platform is to design the instructional materials and strategies that will be used for VTL. The instructional design should be tailored to the specific learning needs of children with ASD and take into account their learning preferences, strengths, and challenges. Instructional materials and strategies should be engaging, interactive, and relevant to the learning objectives and outcomes.
Step 4: Technology integration	The development should include the integration of appropriate technology tools and platforms for VTL. This may include platforms such as Zoom, Google Classroom, or Microsoft Teams, as well as assistive technology tools such as text-to-speech or speech-to-text software. The technology integration should be aligned with the instructional design and the specific learning needs of children with ASD.
Step 5: Teacher and caregiver training	To ensure the successful implementation of VTL, it is important to provide training to teachers and caregivers on how to use the instructional materials, strategies, and technology tools effectively. This training should include best practices for VTL for children with ASD, as well as strategies for addressing technical issues and providing ongoing support to children and their families.
Step 6: Continuous monitoring and assessment	The operation of VTL should include a process for continuous monitoring and assessment of the effectiveness of VTL. This may include regular check-ins with children and their families, as well as ongoing assessment of learning outcomes and progress towards the learning objectives. This information should be used to adjust the instructional materials, strategies, and technology tools as needed to ensure the best possible learning experience for children with ASD.

### E. Comparison of IDM and other similar platforms

To assess the potential performance of the platform based on the proposed IDM, two popular platforms that provide learning needs for students with ASD were selected, and a comparison was made using the IDM criteria as described in Table X.

This comparison table provides an overview of the different features offered by the proposed IDM, Autism Speaks Learn@Home, and Therapy Tribe, helping to identify their strengths and weaknesses in relation to VTL platform elements, VTL platform technology, and digital platform features.

Under the category of VTL Platform Elements, the table compares the accessibility, customisation, multimodal instruction, engagement, collaboration, feedback and progress tracking, and positive reinforcement. The proposed IDM scores high in accessibility, customisation, engagement, collaboration, and offers positive reinforcement. Autism Speaks Learn@Home and Therapy Tribe also have high accessibility but score lower in customisation and collaboration.

TABLE X. COMPARISON OF IDM AND OTHER PLATFORMS

Feature	ProposedIDM	Autism Speaks Learn@Home	Therapy Tribe
<b>VTL Platform Elements</b>			
Accessibility	High	High	High
Customisation	High	Moderate	Moderate
Multimodal Instruction	Yes	Yes	Yes
Engagement	High	High	High
Collaboration	High	Low	High
Feedback and Progress Tracking	Yes	Yes	Yes
Positive Reinforcement	Yes	Yes	Yes
<b>VTL Platform Technology</b>			
Teletherapy	Yes	No	Yes
Virtual Classrooms	Yes	Yes	Yes
Social Media and Communication Apps	Yes	No	No
Augmented Reality and Virtual Reality	High	None	Low
Assistive Technology	Yes	No	Yes
Mobile Apps	Yes	Yes	Yes
Adaptive Devices	Yes	No	Yes
<b>Digital Platform Features</b>			
Flexibility	High	Low	Low
Customisation	Yes	No	No
Social Interaction	Yes	No	Yes
Access to Resources	High	High	High
Remote Learning	High	Low	Moderate
Access to Specialized Teachers	Yes	No	Yes
Access to Global Resources	Yes	No	No

Moving on to VTL Platform Technology, the table compares teletherapy, virtual classrooms, social media and communication apps, augmented reality and virtual reality, assistive technology, mobile apps, and adaptive devices. The proposed IDM supports teletherapy, virtual classrooms, social media and communication apps, and has a high presence of augmented reality and virtual reality. Autism Speaks Learn@Home lacks teletherapy and social media apps, while Therapy Tribe lacks virtual classrooms and has a low presence of augmented reality and virtual reality.

In terms of Digital Platform Features, the table compares flexibility, customisation, social interaction, access to resources, remote learning, access to specialized teachers, and access to global resources. IDM excels in flexibility, customisation, social interaction, access to resources, remote learning, and access to specialized teachers. Autism Speaks Learn@Home has lower flexibility and lacks customisation, while Therapy Tribe also lacks customisation and access to global resources.

In summary, it can be concluded that the proposed IDM offers a comprehensive virtual learning platform for autistic students. In comparison, Autism Speaks Learn@Home and Therapy Tribe exhibit strengths in certain areas but may have limitations in terms of customisation, collaboration, and access to specific technologies. While all three platforms aim to support autistic students in their virtual learning journey, the proposed IDM distinguishes itself with its inclusive features and advanced technologies designed to address the specific needs of autistic learners.

## VI. CONCLUSION AND FUTURE WORKS

### A. Conclusion

This report has presented the findings of a case study on the impact of the COVID-19 pandemic on teaching and learning of autism care centres in Malaysia. The research methods used in this study provided valuable insights into the practices and services of several autism care centres. On-site observation, interviews, and online questionnaire were all effective methods for gathering data. The findings of the study identified three main themes, including teachers' challenges during the pandemic, ICT requirements for online teaching and learning, and instructional model.

The findings suggest that autism care centres need to invest in training teachers on online teaching and the use of ICT resources provide the necessary ICT infrastructure and resources to support online teaching and learning, and explore digital models as a viable alternative to traditional classroom-based learning. These findings have important implications for teaching and learning in the context of the pandemic and beyond.

A special fund for autism care centres needs to be proposed and established to upgrade their ICT facilities, especially in digital content development. Regarding future research, further studies on innovative tools using advanced technology such as virtual reality (VR) and augmented reality (AR) have to be carried out to include them as part of the VTL platform. More interviews and detailed discussions with the autism experts and technologists on new methods of digital teaching and learning

for autism need to be conducted to generate comprehensive ICT requirements for the development of VTL platform.

In conclusion, the IDM proposed for promoting VTL in autism care centres in Malaysia provides a promising solution for addressing the unique learning needs of children with ASD. By following the steps outlined in the proposed framework, autism care centres can develop a customised VTL platform that addresses the specific learning needs and challenges of children with ASD, while integrating appropriate technology tools and methods for VTL. The VTL platform can provide a more effective and engaging learning experience for children with ASD and may improve their social, communication, and vocational skills. With the VTL platform's potential benefits, it could be considered an essential tool for educators who are working with children with ASD in autism care centres in Malaysia.

### B. Future Works

To ensure the effective implementation of the VTL platform in autism care centres, several key steps can be taken as potential suggestions for future works. These steps involve conducting a pilot study with a small sample of students with ASD, their teachers, and caregivers to evaluate the usability, acceptability, and efficacy of the VTL based on the proposed IDM. If successful, the VTL could be expanded to other locations, including different countries, to observe its performance in diverse cultural and linguistic contexts.

Additionally, incorporating emerging technologies such as artificial intelligence into the IDM can enhance the learning experience for students with ASD. Long-term outcomes of the VTL should also be assessed, including academic and social achievements, to determine its effectiveness over an extended period. Collaboration with stakeholders such as policymakers, education leaders, and technology providers can ensure the sustainability and widespread adoption of the VTL, while also integrating new technologies into the platform.

Furthermore, developing training programs for teachers and caregivers is crucial to equip them with the necessary skills to implement the VTL effectively and address any challenges that may arise. Evaluating the cost-effectiveness of the VTL platform and incorporating teachers and parents' feedback throughout the development process are important aspects to consider for the ongoing improvement and relevance of the VTL in meeting the needs of students with ASD.

In summary, future research of IDM to promote VTL for autism care centres holds significant promise for further advancements and improvements. By providing a comprehensive and individualized learning experience, IDM has the potential to enhance academic achievements, social skills development, and overall well-being for autistic students. The use of advanced technologies like AI and AR/VR, combined with the customization features of IDM, can create engaging and inclusive learning environments. Moreover, IDM's collaborative and interactive features foster peer interactions, socialization, and the development of essential life skills. Ultimately, IDM has the potential to revolutionize the field of VTL for autism by offering an effective and accessible platform for tailored instruction, promoting inclusive

education, and empowering autistic students to reach their full potential.

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# Investigating OpenAI's ChatGPT Potentials in Generating Chatbot's Dialogue for English as a Foreign Language Learning

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**Abstract**—Lack of opportunities is a significant hurdle for English as a Foreign Language (EFL) for students during their learning journey. Previous studies have explored the use of chatbots as learning partners to address this issue. However, the success of chatbot implementation depends on the quality of the reference dialogue content, yet research focusing on this subject is still limited. Typically, human experts are involved in creating suitable dialogue materials for students to ensure the quality of such content. Research attempting to utilize artificial intelligence (AI) technologies for generating dialogue practice materials is relatively limited, given the constraints of existing AI systems that may produce incoherent output. This research investigates the potential of leveraging OpenAI's ChatGPT, an AI system known for producing coherent output, to generate reference dialogues for an EFL chatbot system. The study aims to assess the effectiveness of ChatGPT in generating high-quality dialogue materials suitable for EFL students. By employing multiple readability metrics, we analyze the suitability of ChatGPT-generated dialogue materials and determine the target audience that can benefit the most. Our findings indicate that ChatGPT's dialogues are well-suited for students at the Common European Framework of Reference for Languages (CEFR) level A2 (elementary level). These dialogues are easily comprehensible, enabling students at this level to grasp most of the vocabulary used. Furthermore, a substantial portion of the dialogues intended for CEFR B1 (intermediate level) provides ample stimulation for learning new words. The integration of AI-powered chatbots in EFL education shows promise in overcoming limitations and providing valuable learning resources to students.

**Keywords**—ChatGPT; chatbots as learning partners; EFL chatbot system; dialogue creation

## I. INTRODUCTION

English has become the most widely spoken language globally, with approximately 1.5 billion people speaking it as a first, second, or foreign language [1]. As a result, English proficiency is increasingly becoming essential for success in various fields such as academics, business, and international relations. Undoubtedly, English language learning can significantly benefit foreign language students. From an academic standpoint, English is essential in various fields, including science, technology, engineering, and mathematics, where English is the primary language of instruction and research. Moreover, by mastering English, students can increase their chances of success in their later global careers, as it is commonly used in international business.

Despite the benefits, learning a new language can be challenging, and for foreign language students, learning English can be particularly difficult due to several factors [2]–[4]. One significant challenge foreign language students face in learning English is the lack of opportunity to practice speaking the language [4]–[7]. Many previous studies have shown that speaking a language is essential for effective communication and language acquisition [2], [8], [9]. Thus, the lack of speaking practice can lead to a significant barrier in language acquisition, as speaking is essential to build fluency and confidence in using the language. When left alone, this situation can lead to demotivation and further decrease opportunities to practice.

To deal with this situation, using chatbots in language learning has gained increasing research attention in recent years [10]–[15]. Several studies have found that chatbots can be an effective tool for helping EFL students learn the language. One of the main benefits of practicing with a chatbot is that students can gain conversation experience in a safe, low-pressure environment [11]. Furthermore, through the recent advancement of speech recognition and synthetic speech technologies, chatbots can be implemented to simulate real-life conversations [10], [15]. Other than that, a previous study also showed that students often feel less judged when they receive feedback or corrections from the chatbot [10], [11]. Furthermore, chatbots can enable students to practice anywhere and at any time outside the classroom, thus increasing their language exposure [10], [11], [15], [16]. Such flexibility can help them to overcome the challenge of limited opportunities to practice, particularly for students who may not have access to native speakers.

A successful chatbot system for language learning *typically* involves several key components, including a speech recognition (SR) module, audio content, and reference dialogue content. In previous studies, we have covered subjects related to a speech recognition module and audio content for a chatbot system for helping EFL students to learn English [10], [11]. One study evaluated the use of Vosk, an internet-free speech recognition module, and found that limiting the vocabularies recognized by the SR module during runtime improved the system's ability to recognize student speech input, resulting in a more pleasant learning experience [11]. In another study, WaveNet, a deep learning-based speech synthesizer, was evaluated for generating audio content in an EFL chatbot system [10]. While students could distinguish that the content produced by WaveNet sounded less natural

than actual human speech, they produced fewer errors when transcribing the WaveNet-generated audio, indicating that it was easier to understand.

While numerous previous studies have extensively explored speech recognition and technology for developing audio content, the chatbot's dialogue content is often still sourced from existing materials produced by humans. With the advancements in artificial intelligence and deep learning technology, it is now possible for machines to generate readable and contextually appropriate content. Using machine-generated content could reduce reliance on human-produced content in the development process, thus reducing the cost and time needed significantly. Therefore, this research aims to evaluate the potential of using artificial intelligence (AI)-generated content for reference dialogue in an EFL chatbot system.

The evaluation of the potential of machine-generated content for an EFL chatbot system will focus on a chatbot implementation by OpenAI, ChatGPT [19]. ChatGPT is a novel chatbot implementation with impressive abilities to return coherent and contextually appropriate responses based on user requests. By leveraging the vast amounts of text data, ChatGPT can generate text in various styles and tones, making it a promising option for generating content suitable for numerous purposes [19]. For EFL content generation, OpenAI has excellent potential to generate English content that could be useful for EFL students.

Therefore, this study aims to evaluate the appropriateness of ChatGPT-produced materials for dialogue practice in language learning. As ChatGPT is a relatively new technology that hasn't been extensively explored in this context, investigating its capabilities becomes necessary. We will utilize ChatGPT to produce a series of dialogue practice materials and employ multiple readability metrics to thoroughly analyze their suitability. By gaining insights into the characteristics of ChatGPT-generated dialogue, we can identify the most appropriate audience to maximize learning benefits. Determining the target audience that can derive the most from these materials will allow us to optimize their use and enhance the effectiveness of language learning experiences.

## II. LITERATURE REVIEW

### A. Voice-enabled Chatbot for EFL Learning

There are two types of chatbots: text-based and voice-enabled chatbots classified based on their modality. Voice-enabled chatbots have been proposed as a helpful tool for learning and practicing a second language (L2) speaking skills. A study in [12] discovered that L2 learners appreciated the chatbot's capacity to expose them to various conversational expressions and vocabulary and enable repetitive practice. On top of that, L2 learners prefer chatbots over human partners due to their fear of making mistakes and appearing incompetent during interactions with human partners [13].

A recent study by Han [14] showed how Alexa, a general voice-enabled chatbot, could help students by engaging them in conversations to practice their speaking skills. The

experimentation indicated that chatbot-assisted learning improved students' pronunciation and language fluency. Moreover, post-questionnaire responses showed that the integration of such chatbot positively impacted students' interest in learning and enhanced their motivation to learn. Similarly, using readily-available chatbots such as Google Assistants [15], [16], and Alexa [17], [18] also led to positive improvements in students' language proficiency. Researchers noted that students felt less embarrassed and anxious when practicing with a chatbot [15], [16]. Furthermore, chatbots promote self-directed foreign language learning outside school settings where native speakers are hard to find [17], [18].

Although general chatbots may seem appealing, several studies have suggested that such system adaptation may be less effective for L2 learners as it may not cater to their specific needs [21], [22]. Therefore, several criteria should be considered when designing a chatbot for language learning, such as language learning potential, learners' suitability, and authenticity [21]. The language learning potential criterion can be further broken down into components like interactional modification and task focus. Secondly, the learners' suitability criterion should consider various factors, such as language proficiency, age, learning style, and individual characteristics. Lastly, the authenticity criterion indicates that the materials presented within the chatbot should imitate real-life tasks that learners are likely to encounter.

A previous study [21] that implemented a task-oriented chatbot for helping students in their learning journey yielded promising results. The chatbot could maintain lengthy English conversations and engage in L2 problem-solving tasks with participants. Researchers noted that this type of speaking experience is hard to provide in regular EFL classes due to class size and time constraints within the curriculum. Similarly, an evaluation of a specifically designed EFL chatbot in [23] demonstrated the significant potential of its adaptation. The study found that the chatbot matched students' learning styles and enabled them to learn ubiquitously, thus making them enjoy their learning experience. Regardless, the study's pre-test and post-test settings revealed no significant improvement in students' Oral Proficiency Interview – Computer (OPIc) scores after the system adoption. The mixed findings in chatbot research indicate a need for further investigation.

### B. Readability Metrics for English Materials

Readability metrics are tools used to measure how easily readers can understand a written text. They are commonly used to evaluate the appropriateness of text materials by determining the complexity of the language used within the presenting material based on specific criteria. Flesch Reading Ease [24], Dale-Chall [25], and McAlpine EFLAW [26] are several commonly used readability metrics for English text materials. These metrics consider factors such as syllable counts, mini words counts, or a dictionary of difficult words to calculate a score that reflects the text's difficulty level.

Previous studies showed that these metrics could help assess the appropriateness of text materials for EFL learning [27], [28]. By utilizing these readability metrics, we can evaluate the language complexity of the chatbot's responses



and ensure they are appropriate for the target audience. For instance, if the chatbot generates too complex responses for low-level EFL learners, it may stunt their ability to comprehend and learn using the material. However, high-level EFL learners may find the material less challenging and unstimulating if the responses are simple enough. By assessing the readability of chatbot-generated material, researchers and developers can ensure that the language complexity is appropriate for the targeted EFL learner group, thus enhancing the learning experience.

For example, a study in [28] showed how Flesch-Kincaid readability metrics could be used to analyze the difficulty level of English textbooks for Chilean EFL high school students. The study illustrated how readability metrics could be used to recommend adjustments to English teaching materials according to students' level of comprehension. Another study by Gao et al. in [27] also showed the potentiality of several readability metrics as features to predict chatbots' popularity. The study found that very popular and unpopular chatbots have significant readability scores, thus indicating that readability metrics can be a valuable indicator to reflect users' interest in chatbot adoption.

This research will use three different readability metrics to assess the appropriateness of chatbot-generated material for EFL learning. This combination was chosen because each metric employs a different strategy to calculate the readability score. For instance, Flesch Reading Ease considers the syllable count when calculating the material's readability. Differently, Dale-Chall utilizes difficult words not commonly used in everyday language for calculating the difficulty. On the other hand, McAlpine EFLAW computes the readability score by using mini-words in a given text

1) *Flesch reading ease*: is a tool used to assess the readability of a given text in English. It works based on a formula proposed by Rudolf Flesch in [24]. The Flesch Reading Ease score is between 0 and 100, indicating how easy or difficult it is to understand a text. A higher score indicates that the text is easier to read, while a lower score indicates that the text is more challenging to read. The definition of the Flesch Reading Ease score is given in Formula 1,

$$206.835 - 1.015 \times \left(\frac{W}{S}\right) - 84.6 \times \left(\frac{s}{W}\right) \quad (1)$$

where  $s$ ,  $W$ , and  $S$  represent the number of syllables, words, and sentences in the given text, respectively. Then, the interpretation of the score is shown in Table I.

2) *Dale-Chall readability formula*: this is another readability formula first developed by Edgar Dale and Jeanne Chall in the 1940s adjusted further in 1995 [25]. The formula calculates a text's readability by considering its number of difficult words. The formula defines a difficult word as any word that is not in a list of common words familiar to most fourth-grade students. The formula generates a score that ranges from 0 to 10. A score of 0 indicates that the text is effortless to read, while a score of 10 indicates that the text is

challenging to read. The formula for calculating the raw score of the Dale-Chall readability score is given by Formula 2.

TABLE I. FLESCH READING EASE SCORE INTERPRETATION

Score	US School Level	Description
90.00-100.00	5 <sup>th</sup> grade	Very easy to read. Easily understood by average 11 years old students.
80.00-90.00	6 <sup>th</sup> grade	Easy to read. Conversational English for consumers.
70.00-80.00	7 <sup>th</sup> grade	Fairly easy to read.
60.00-70.00	8 <sup>th</sup> and 9 <sup>th</sup> grade	Plain English. Easily understood by 13 to 15 years old students.
50.00-60.00	10 <sup>th</sup> – 12 <sup>th</sup> grade	Fairly difficult to read.
30.00-50.00	College	Difficult to read.
10.00-30.00	College Graduate	Very difficult to read. Best understood by university graduates
0.00-10.00	Professional	Extremely difficult to read. Best understood by university graduates.

$$0.1579 \times \left(\frac{DW}{W} \times 100\right) - 0.0496 \times \left(\frac{W}{S}\right) \quad (2)$$

where  $W$ ,  $DW$ , and  $S$  represent the number of words, difficult words in the given text, respectively. The interpretation of the Dale-Chall readability score is given in Table II.

TABLE II. DALE-CHALL SCORE INTERPRETATION

Score (x)	Description
$x < 5.0$	Easily understood by an average 4 <sup>th</sup> grade student or lower.
$5.0 \leq x < 6.0$	Easily understood by an average 5 <sup>th</sup> or 6 <sup>th</sup> grade student.
$6.0 \leq x < 7.0$	Easily understood by an average 7 <sup>th</sup> or 8 <sup>th</sup> grade student.
$7.0 \leq x < 8.0$	Easily understood by an average 9 <sup>th</sup> or 10 <sup>th</sup> grade student.
$8.0 \leq x < 9.0$	Easily understood by an average 11 <sup>th</sup> or 12 <sup>th</sup> grade student.
$9.0 \leq x$	Easily understood by an average college student

The Dale-Chall readability formula was revised in 1995 to improve its accuracy and reliability. The revision included a new list of 3,000 familiar words compiled based on surveys of fourth-grade students. This new list replaced 769 words on the previous one, which had become outdated over time [25]. This research will use the new version of the Dale-Chall readability formula.

3) *McAlpine EFLAW readability formula*: is specifically developed to measure the readability of English language materials for non-native speakers of English. It regards mini words as a linguistic feature that can make English texts difficult for non-native speakers to read. Mini words are common words of one, two, or three letters. In the previous study [25], the researcher argued that a cluster of mini words in wordy cliches, colloquial expressions, and phrasal verbs confuse international readers. The McAlpine EFLAW readability score calculation is given by Formula 3.

$$EFLAW \text{ Score} = \frac{W+M}{S} \quad (3)$$

where W, M, and S represent the number of words, mini-words, and sentences in the given text. The interpretation from the McAlpine EFLAW score can be seen in Table III.

TABLE III. MCALPINE EFLAW SCORE INTERPRETATION

Score (x)	Description
$x \leq 20.49$	very easy to understand
$20.49 < x \leq 25.49$	quite easy to understand
$25.49 < x \leq 29.49$	a little difficult
$29.49 < x$	very confusing

### C. Generative Pre-training Transformers, InstructGPT, and ChatGPT

Generative Pre-trained Transformers (GPT) have emerged as a significant advancement in natural language processing (NLP) and have gained immense popularity in recent years [30], [35]. GPT, developed by OpenAI, is a deep learning model based on the Transformer architecture. It is designed to generate coherent and contextually relevant text given a prompt. The model employs a self-attention mechanism, allowing it to capture dependencies between words efficiently [30]. GPT achieved state-of-the-art performance on a wide range of language tasks due to its ability to learn from large amounts of text data. The original GPT model was trained on a dataset containing 40GB of text data from the internet [30]. As of today, OpenAI's ChatGPT is based on the GPT-3.5 model. While there is no publicly available information about the exact amount of data used for training GPT-3.5 specifically, it is worth noting that GPT-3, on which GPT-3.5 is built, was trained on a substantial corpus of text data. GPT-3's training dataset comprised approximately 570GB of text sourced from various types of content, including books, websites, and articles [31]. This extensive and diverse dataset facilitated GPT-3's ability to grasp language patterns and acquire a broad understanding of knowledge and context.

Like any other transformers-based large language model (LLM), GPT training divides into pre-training and fine-tuning stages [31]. A language model is trained on a large corpus of publicly available text data during pre-training. The model learns to predict the next word in a sentence, acquiring a broad understanding of grammar, context, and world knowledge. After pre-training, the model is fine-tuned on specific downstream tasks using supervised learning. The fine-tuning process involves training the model on a narrower dataset with labeled examples. This step allows the model to specialize in a specific task such as language translation, sentiment analysis, or question answering. There is no publicly detailed information available about how ChatGPT was trained. However, the documentation of ChatGPT mentioned that it was using a pre-trained by using a larger LLM than GPT-3 on a more significant amount of data. Then, the model was fine-tuned further to generate detailed responses based on given instructions or demonstrations (InstructGPT), using Reinforcement Learning from Human Feedback (RLHF) [32], [33].

RLHF is a technique used to improve the performance of language models through iterative fine-tuning using human-generated feedback [33]. RLHF involves collecting comparison data where different model responses are ranked

by quality. These rankings are used to create a reward model, which guides the model's training using reinforcement learning algorithms such as Proximal Policy Optimization (PPO) [34]. RLHF has been used to refine GPT models, enhancing their output quality and reducing biases—the series of human-in-the-loop iterations allowing the model to generate more coherent responses.

## III. RESEARCH METHODOLOGY

### A. Tools and Materials

As previously mentioned, this research evaluated the appropriateness of artificial intelligence (AI)-generated dialogue for EFL students using several readability criteria. The generated dialogues are intended as reference dialogue in the mobile application to help students practice their speaking skills. Students can choose a topic using the app and practice their English skills, as shown in Fig. 1.

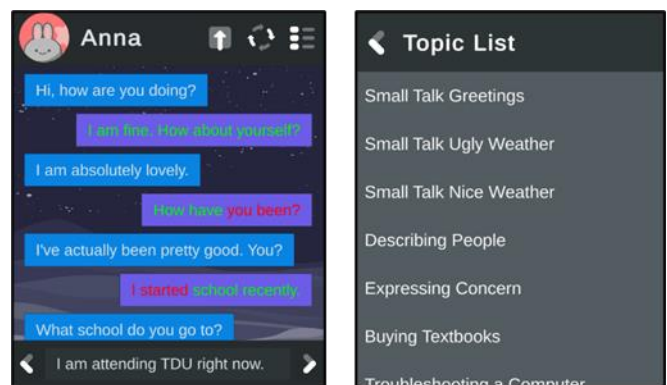


Fig. 1. Voice-enabled chatbot mobile application.

The app provided a range of topics that students could use to practice their listening, reading, and speaking simultaneously. After selecting a topic, the app will load the reference dialogue on the selected topic. The app will always start the conversation using TTS technology by converting the first line into the reference dialogue. Then, to reply to the conversation, the student can choose one of three text options in the reference dialogue. Based on their choice, the app will engage them in a read-a-loud activity and evaluate their pronunciation using SR technology. By comparing the student's text choice and the SR transcription result, the app will re-render some text parts in red if they are not present in the transcription; otherwise, they will be in green. The conversation between a student and the bot will continue if there is still a line of dialogue in the reference dialogue. Fig. 2 depicts the interaction between the student and the app.

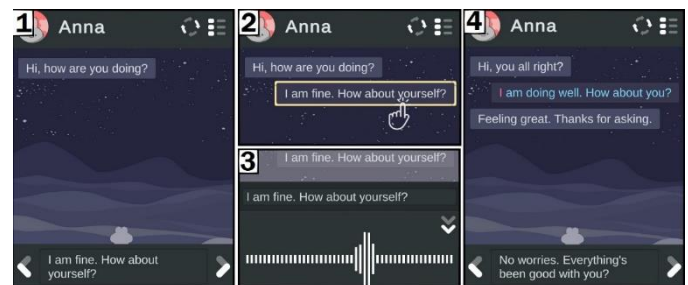


Fig. 2. Students' interactions with the application.

A successful learning outcome in a dialogue practice can only be achieved when students are willing to keep practicing the dialogue repeatedly. Students can learn more about what they are trying to understand with each repetition. Moreover, when stimuli are learned by repetition, they are remembered better and retained for a longer time. Dialogue variability is an essential factor affecting students' motivation to keep practicing. If the reference dialogues need to be more varied, students may feel bored having to practice using them repeatedly. The dialogue's difficulty level is another crucial factor affecting the learning process's success. Dialogues that are too difficult will undoubtedly lower the confidence level of the students and decrease their motivation to learn. Teachers generally spend much time and effort creating teaching materials that fulfill those two criteria.

Therefore, this research evaluates the possibility of using AI-generated materials as a reference dialogue within the app. The reference dialogues were generated by using OpenAI's ChatGPT. The dialogues were produced by inputting the following prompt to the bot: "Please help me to make a dialogue to help EFL students to practice their English. The dialogue is between A and B. A is an undergraduate student at ABC University. B is an exchange student from Italy. The topic is {{topic name}}", where {{topic name}} was selected from Table IV.

TABLE IV. LIST OF TOPICS GENERATED BY CHATGPT

Topic (1 <sup>st</sup> – 5 <sup>th</sup> )	Topic (6 <sup>th</sup> – 10 <sup>th</sup> )	Topic (11 <sup>th</sup> – 15 <sup>th</sup> )
Greet new exchange student	Fermented foods	Learn programming
Lunch Invitation	Sumo wrestling	Summer's vacation
Play arcade on weekends	Coin Laundry	Traveling to Kyoto
Foods and hobbies	Favorite snacks	Buying new clothes
Learn to use chopsticks	Sightseeing in Tokyo	Last week in Tokyo

In the prompt above, the lines "The dialogue is between A and B. A is an undergraduate student at Tokyo Denki University. B is an exchange student from Italy" are intended to give context to the AI so it could create a livelier dialogue related to students. Furthermore, a series of topics in Table IV means to test whether the ChatGPT can produce various topics for students to practice. On top of that, we asked ChatGPT to give two or three alternative lines of dialogue for each line in the produced dialogue. Later, in the experimentation, using a single dialogue from ChatGPT, 30 unique combinations will be generated. Therefore, 450 unique sample combinations of dialogues will be analyzed.

### B. Metrics and Measurements

Based on each ChatGPT-generated dialogue, an analysis process was first carried out using three readability metrics: Flesch Reading Ease, McAlpine EFLAW, and Dale-Chall readability metrics. The Flesch Reading Ease metric is intended to measure the difficulty level of a dialogue by considering the ratio of polysyllables in all words in the dialogue. The more polysyllables there are, the more complex the dialogue is assumed to be according to this metric. On the other hand, the McAlpine EFLAW metric is used to consider mini-words in dialogue. The more mini-words used, the metric assumes more complex it is. Lastly, the Dale-Chall metric

considers a list of difficult words compiled from previous studies.

The usage of these three metrics aims to cover the flaws of each metric with the other two metrics. Since the Flesch Reading Ease metric only considers the number of polysyllables in its calculation process, sentences with multiple mini-words will be considered easy to understand. Therefore, the McAlpine EFLAW readability score calculation process is carried out to complement the weakness of the metric. Then, the Dale-Chall metric is also used to determine the difficulty level of the text based on words that have few polysyllables but are challenging to understand, such as "abide," "deem," and "quail".

Based on the scores generated by each metric, a process of interpreting the difficulty level of the dialogue is carried out. The interpretation will be made by first visualizing the distribution of the difficulty level of the generated dialogue. From the visualization results, an analysis is carried out to determine the complexity of the ChatGPT-generated dialogues.

## IV. RESULTS

Based on 450 dialogue samples that aim to simulate conversations between the bot and the students in the application, the Flesch Reading Ease score for each sample was first calculated. Then, through the resulting scores, a visualization was carried out to show the scores' central tendency and distribution from all samples. Fig. 3 shows the distribution of scores from all samples.

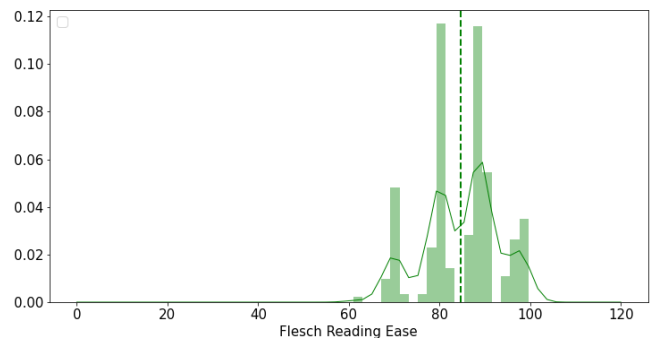


Fig. 3. Flesch reading ease scores' distribution from all samples.

Fig. 3 shows that the sample dialogues have a score distribution ranging from 60 to 100, with most samples having scores in the range of 80-90. Hence, it can be concluded that most of the simulated dialogues are easily comprehensible to sixth-grade elementary school students. Additionally, since there is a small yet significant portion of samples with scores between 60 and 80, they can also serve as sufficient stimuli for junior high school students. However, the generated materials may not be suitable for senior high school students or students in higher education, as they could easily comprehend such materials, thus not providing an appropriate level of challenge for their learning. This interpretation can be further extended for EFL students by referring to the previous study [29]. Since most samples have scores between 80 and 90, students with a Common European Framework of Reference for Languages (CEFR) level of A2 (elementary level) will benefit the most

when using the materials. While the materials could still be suitable for students with CEFR levels A1 (beginner) and B1 (intermediate), students with levels B2 (upper intermediate) to C2 (advanced) may find the materials less challenging and too simple.

Next, the Dale-Chall readability scores were calculated for all sample dialogues. Fig. 4 illustrates the distribution of the resulting scores across all samples.

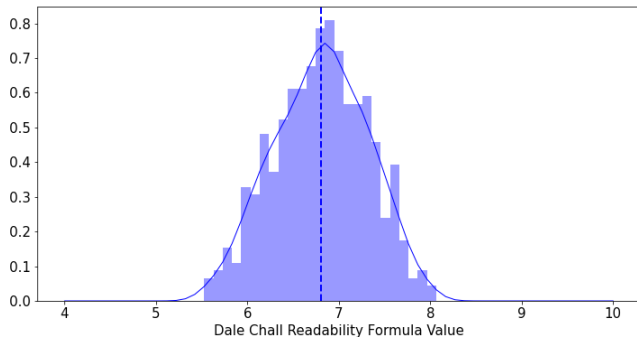


Fig. 4. Dale-Chall readability formula values' distribution for entire samples.

Similarly to the previous interpretation, based on the distribution of resulting scores shown in Fig. 4, it can be argued that the generated materials are most suitable for sixth-grade elementary school students or students in the early years of junior high school (CEFR A2 and B1). Moreover, the absence of samples with Dale-Chall scores above 8.0 confirms that the generated materials are unsuitable for students with CEFR levels B2 to C2. Finally, the McAlpine EFLAW score was calculated for each simulated conversation. The visualization of the score distribution can be observed in Fig. 5. Referring to the resulting scores in Fig. 5, as none of them have a score below 20, it can be interpreted that the resulting materials do not extensively utilize mini-words that could confuse EFL students when consuming them.

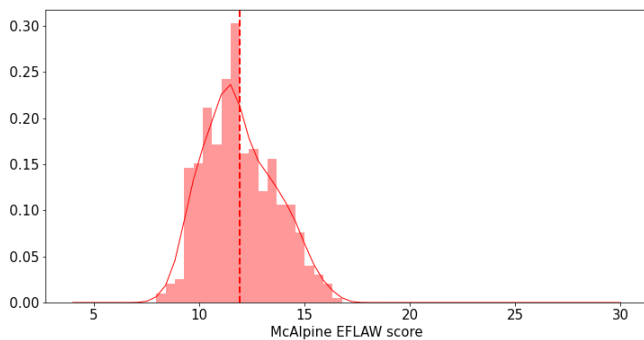


Fig. 5. McAlpine EFLAW scores' distribution for all samples.

## V. DISCUSSIONS

Based on the experimentation results, several conclusions can be drawn regarding the suitability of ChatGPT-generated materials as EFL chatbot reference dialogues. Firstly, the minimal McAlpine EFLAW score observed in all simulated conversations suggests that the dialogues generated by ChatGPT do not contain excessive use of mini-words. This indicates that wordy clichés, colloquial expressions, and

phrasal verbs, which could potentially confuse international readers, were avoided in the resulting dialogue [19]. The consistently low McAlpine EFLAW scores across all simulated dialogues indicate that EFL students can easily comprehend and understand the content. These findings provide confidence in the appropriateness of ChatGPT-generated materials as reference dialogues for EFL chatbot systems.

Additionally, the resulting Flesch Ease Reading scores indicate that most ChatGPT-generated materials are most suitable for students with CEFR levels A2 [20]. By referring further to the definition of CEFR level A2, the generated materials will be most appropriate to be used by students who exhibit the following characteristics.

- **Vocabulary:** Understand most everyday words and phrases related to personal information and basic needs; and many words and phrases related to hobbies, travel, and work.
- **Grammar:** Understand simple grammatical structures (e.g., present and past tenses) and basic question forms.
- **Reading:** Able to read short and simple texts, such as simple stories, with the help of a dictionary.
- **Writing:** Write basic sentences and short texts about personal experiences or daily routines.
- **Listening:** Understand simple and direct information in everyday conversations or short speeches on familiar topics.
- **Speaking:** Engage in basic conversations, and ask and answer questions about personal details, preferences, requests, or suggestions.

This interpretation was further supported by the resulting Dale-Chall scores obtained from the simulated dialogues. Although the Dale-Chall score calculation considers different criteria than the Flesch Reading Ease formula, a similar interpretation was reached.

## VI. CONCLUSION

In this research, we investigate the potential of ChatGPT to generate reference dialogues to help EFL students improve their English proficiency. The reference dialogues might be helpful for an EFL chatbot in mobile applications considering more limited computing resources available on mobile devices. The underlying justification stems from the fact that simulating a deterministic conversation flow involves significantly fewer computational resources than running a complex Question and Answer Generation model. However, as users may feel bored practicing using the same lines of dialogue repeatedly, each line might need alternative replies to make the conversation more varied. Therefore, based on a dialogue generated by ChatGPT, alternative replies are created by asking the model to rephrase each line within the dialogue.

Moreover, we conducted an analysis using multiple readability metrics to determine the optimal target audience for the ChatGPT-generated materials. Only a few mini-words in the generated materials suggest they are free from wordy



clichés, colloquial expressions, and phrasal verbs that could confuse EFL students. Furthermore, the resulting Flesch Ease Reading scores further affirm that the produced dialogues are most suitable for supporting students with CEFR A2. Likewise, the resulting Dale-Chall scores also support the same conclusion. The produced dialogues are well-suited for students with CEFR A2 proficiency, as they can comprehend most of the words used. Furthermore, a substantial portion of the dialogues intended for CEFR B1 can provide the CEFR A2 students with great stimulus to learn new words.

## VII. FUTURE WORK

In future work, it would be valuable to investigate the potential of ChatGPT in generating reference dialogues for different target audiences, particularly those with CEFR B2 proficiency or above. This would involve exploring the adaptability of ChatGPT's dialogue generation capabilities to cater to the specific language needs and complexities of higher-level English learners. By expanding the scope of the study to include higher proficiency levels, we can assess the effectiveness of ChatGPT-generated materials in supporting the language learning journey of a wider range of EFL students.

Additionally, it would be beneficial to explore and experiment with different prompting techniques to further enhance the variety and quality of the dialogue generated by ChatGPT. By utilizing innovative techniques, such as direct task specification, task demonstration or mimetic proxy, we can potentially influence the generated dialogues to align more closely with the desired characteristics and objectives for different target audiences.

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# ConvNeXt-based Mango Leaf Disease Detection: Differentiating Pathogens and Pests for Improved Accuracy

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**Abstract**—Mango farming is a key economic activity in several locations across the world. Mango trees are prone to various diseases caused by viruses and pests, which can substantially impair crops and have an effect on farmers' revenue. To stop the spread of these illnesses and to lessen the crop damage they cause, early diagnosis of these diseases is essential. Growing interest has been shown in employing deep learning models to create automated disease detection systems for crops because of recent developments in machine learning. This research article includes a study on the application of ConvNeXt models for the diagnosis of pathogen and pest caused illnesses in mango plants. The study intends to investigate the variety in how these illnesses emerge on mango leaves and assess the efficiency of ConvNeXt models in identifying and categorizing them. Images of healthy mango leaves as well as the leaves with a variety of illnesses brought on by pathogens and pests are included in the dataset used in the study. In the study, deep learning models were applied to classify mango pests and pathogens. The models achieved high accuracy on both datasets, with better performance on the pathogen dataset. Larger models consistently outperformed smaller ones, indicating their ability to learn complex features. The ConvNeXtXLarge model showed the highest accuracy: 98.79% for mango pests, 100% for mango pathogens, and 99.17% for the combined dataset. This work holds significance for mango disease detection, aiding in efficient management and potential economic benefits for farmers. However, the models' performance can be influenced by dataset quality, preprocessing techniques, and hyperparameter selection.

**Keywords**—Mango disease; pest; pathogens; machine learning; deep learning; convnext models

## I. INTRODUCTION

Mangoes, scientifically known as *Mangifera indica* L. (Family: Anacardiaceae), are tropical and subtropical fruits that are native to Indo-Burma. India boasts the largest variety of mangoes, with more than a thousand identified types [1]. India is a major mango-producing nation.

With 2.5 million hectares producing 18.0 million tonnes of mangoes per year, India takes the top spot and produces almost 50% of the world's mangoes. A significant barrier to mango cultivars producing their maximum production potential is insect infestations. Mangoes are reported to be infested by 400 distinct kinds of insect pests worldwide [2]. The pest complex and the structures of the pest community have undergone substantial change because of commercial mango agriculture, which is defined by the area expansion, altered cropping

patterns, varietal replacements and increasing chemical interventions. Moreover, climate change has unintentionally encouraged invading species or caused the creation of new pests. Formerly regarded as a minor or secondary pests, thrips, mealybugs, mites, leaf webbers, scales, stem borer, etc., have recently developed into a major concern. Mangoes are reported to be infested by 400 distinct kinds of insect pests worldwide [3].

The fruit mango is full of nutrients and has a distinct flavour, aroma and taste. With flavonoids like beta-carotene, alpha-carotene and beta-cryptoxanthin, it is a fantastic source of vitamin A. According to research findings, eating natural fruits that are high in carotenes can help prevent lung and mouth cancer. Mango fruit also contains a wealth of vitamins, minerals, fibre, prebiotic dietary substances and antioxidant components, all of which are good for human health. Consuming mango fruit guards against colon, breast leukaemia and prostate cancer, according to the recent studies [4].

One of the earliest illnesses associated with mango was powdery mildew, which is extensively present around the globe. One of the most dangerous diseases in the world is mango malformation sickness. The export market, which demands great fruit quality, is particularly concerned about mango bacterial canker, also known as bacterial black spot. Stem-end rot and mango dieback are two of the most significant diseases influencing mango yield and post-harvest losses internationally [5]. Mango wilt is a harmful disease that destroys plants.

Mango crops are commonly affected by various pests, including white scale and red wax scale, which consume the mango's leaves and fruit, causing damage and reduced quality. Other common pests include the mango leaf beetle, which can cause defoliation and the mango seed weevil, which infests the mango fruit and causes premature fruit drops [6]. Fruit flies, mealybugs, felt scales, long tailed mealybugs, shoot borers and stone weevils are also commonly found in mango crops and can cause various types of damage to the leaves and fruit. Mango shoot caterpillars, gall midges and stone bugs are also known to infest mango crops and cause stunted growth, reduced yield and fruit drop [7].

Image processing may identify plant diseases. The fruit, leaves and stems are frequently affected by disease signs. The ability to automatically detect plant disease from raw photos using Artificial Intelligence.

An efficient image-learning system for isolating plant diseases is the deep learning approach that uses neural networks. While neural networks learn how to obtain attributes to train, it can automatically extract properties from photos [8]. These methods rely on Deep Learning (DL) and conventional Machine Learning (ML) techniques.

Having a solid dataset to work with is essential for effective machine learning. The models are built or trained using the hidden patterns that these algorithms extract from the dataset and future occurrences are predicted using these learned patterns [9]. As a result, there is a strong relationship between a machine learning system's performance and the dataset's quality. Size, intra-class integrity, interclass dissimilarity and label quality, such as noise in the labels, are a few factors that may determine a dataset's quality [10].

## II. LITERATURE SURVEY

Shripad Veling et al. [11] utilized the MATLAB function "Imadjust" to enhance contrast in photographs of diseased mangoes. The improved contrast aided in the extraction of essential characteristics such as Energy, Correlation, Entropy, Cluster prominence, Homogeneity, Cluster shadow, Variance, and Dissimilarity. Their system achieved an accuracy of 90% with 92 tested samples, employing Support Vector Machines (SVM) as a classifier. The segmentation process took three seconds, while classification only required 0.1 seconds.

Faye, D et al. [12] evaluated the effectiveness of DL algorithms for predicting mango illnesses, highlighting shortcomings in their solutions. The identified issues included problems with leaf segmentation, a lack of real-time diagnosis, and insufficient training data. These challenges are crucial for researchers working on automatic detection of mango illnesses.

In their work, Kusriani et al. [13] augmented the pre-trained VGG-16 deep learning model with a fully connected network consisting of two additional layers. They took into account practical operational challenges faced by Indonesian farmers in gathering and analyzing visual data. By incorporating contrast and affine transforms, the supplemented data process achieved an overall accuracy of 76%. However, when classification was performed without augmentation on a combination of all three datasets, the accuracy dropped to 67%.

Md. Rasel Mia et al. [14] collected a training dataset comprising various photos of mango leaves with different illnesses. They developed a machine learning method using an SVM classifier that could automatically recognize symptoms of mango leaf diseases by uploading and matching fresh photos with the learned data. Their approach achieved an average detection and classification score of 80% for four different illness types.

The approach proposed by Ritika et al. [15], which utilizes a python-based webpage, offers considerable benefits to farmers in terms of pest control and pesticide application. Although SVM had low accuracy of approximately 43%, investigating the RGB values improved the results. By implementing XGBoost and CatBoost, a higher accuracy was achieved compared to SVM. Furthermore, their custom-built CNN system provided a respectable accuracy of 72.05%.

Sarder Iftekhar Ahmed et al. [16] obtained photographs from four mango orchards in Bangladesh, resulting in a collection of 4000 images representing seven illnesses found on approximately 1800 different leaves. To minimize sample bias, diverse locales in Bangladesh were selected. The images were meticulously labeled by human specialists, noise was removed, and the images were scaled to standard forms for machine learning analysis.

Arun Malik et al. [17] employed the transfer learning models VGG-16 and MobileNet for mango classification. They combined these models using the stacking ensemble learning approach to create a hybrid model. The authors constructed a dataset of 329 sunflower images obtained from Google Images, which were divided into five categories. The proposed hybrid model was compared to several contemporary deep learning models based on accuracy using the same dataset.

Inchara R et al. [18] have two objectives: first, to review the latest advancements in mango fruit evaluation prior to market delivery, and second, to explore untapped areas in post-harvest mango fruit handling. Their technology simplifies illness identification by automating the process and alerting users to any afflicted ailments. Aspects such as color, size, and shape influence the grade of the fruits and the satisfaction of the buyers.

Soleha Kousar et al. [19] present a unique technique that combines the Kuwahara filter for edge enhancement with histogram equalization to enhance image clarity and contrast. The Local Binary Pattern (LBP) feature extraction approach is used to recover significant features, enabling training of the Multi-layer Convolutionary Neural Network (MCNN) classifier. This method achieves an impressive 99% accuracy.

A standard, open-access collection of 4000 images of mango leaves with around 1800 distinct leaves is created by Sarder Iftekhar Ahmed et al., [20]. A categorical cross-entropy is used as the loss function in the CNN and ResNet50 models to handle the multi-class classification issue. The squared hinge loss is used in the CNN-SVM model.









## III. METHODOLOGY

### A. Dataset Description

1) *Mango pathogen dataset*: This dataset consists of 4000 JPEG images of mango leaves with a resolution of 240x320 pixels. Around 1800 images are unique, while the rest were generated by zooming and rotating the original images. The dataset includes a category for healthy leaves and seven categories of mango leaf diseases, including Anthracnose, Bacterial Canker, Cutting Weevil, Die Back, Gall Midge, Powdery Mildew, and Sooty Mould [21]. Every one of the eight categories has 500 photos, ensuring a fairly even distribution of examples. Using machine learning and computer vision techniques, this dataset may be used to distinguish between healthy and sick leaves (two-class prediction) and to detect various illnesses (multi-class prediction). Researchers and practitioners can use this dataset for crop disease detection and diagnosis, as well as for the development and evaluation of machine learning models for

automated identification and classification of mango diseases. Details of the classes of Mango Pathogen dataset is shown in Table I.

TABLE I. MANGO PATHOGEN DATASET DETAILS

<i>Mango Pathogen Dataset</i>		
Class Name	Image Details	
Anthracnose	500	
Bacterial Canker	500	
Cutting Weevil	500	
Die Back	500	
Gall Midge	500	
Healthy	500	
Powdery Mildew	500	
Sooty Mould	500	

2) *Mango pest dataset*: This dataset focuses on detecting pests that harm mango farming, which have a large economic impact on the country. It features photographs taken in mango farms where 15 types of pests, which result in structural and aesthetic defects in mango leaves, are present. The dataset comprises of 510 unique photos, encompassing the 15 pest categories plus the original mango leaf look, creating 16 classes [22]. The dataset was enhanced to increase its size and replicate the extensive data collecting method used by farmers. A total of 62,047 picture samples from the data augmentation procedure were employed to train the network. Annotations for both the original and enhanced picture samples are included in the dataset, which was divided into training, validation and testing sets. Using variable quantities

of pictures for training, validation and testing. Pictures in JPEG format are provided in every version of the dataset. Details of Mango Pest Dataset are shown in Table II.

TABLE II. MANGO PEST DATASET DETAILS

<i>Mango Pest Dataset</i>		
Class Name	Image Details	
Apoderus_javanicus	100	
Aulacaspis_tubercularis	100	
Ceroplastes_rubens	100	
Cisaberoptus_kenyae	100	
Dappula_tertia	100	
Dialeuropora_decempuncta	100	
Erosomyia_sp	100	
Icerya_seychellarum	100	
Ischnaspis_longirostris	100	
Mictis_longicornis	100	
Neomelicharia_sparsa	100	
Normal	100	
Orthaga_euadrsalis	100	
Procontarinia_matteiana	100	
Procontarinia_rubus	100	
Valanga_nigricornis	100	

TABLE III. CONVNEXT MODELS' ARCHITECTURAL DETAILS

Model	Number of Layers	Number of Parameters	Architecture	Batch normalization	Dropout	Top-1 Accuracy	Top-5 Accuracy
ConvNeXtTiny	23	8.6 million	2 layers with 64 channels and 3x3 filters	Yes	Yes	66.90%	88.80%
ConvNeXtSmall	29	17.1 million	4 layers with 128 channels and 3x3 filters	Yes	Yes	73.90%	93.30%
ConvNeXtBase	56	44.2 million	8 layers with 256 channels and 3x3 filters	Yes	Yes	77.50%	94.80%
ConvNeXtLarge	98	136.1 million	16 layers with 512 channels and 3x3 filters	Yes	Yes	79.30%	95.60%
ConvNeXtXLarge	164	366.4 million	32 layers with 1024 channels and 3x3 filters	Yes	Yes	80.20%	95.90%

TABLE IV. CONVNEXT MODELS' EVALUATION DETAILS

Model	Computational Complexity	FLOPs	Activation Function	Regularization	Residual connections	Image augmentation	Transfer learning	Fine-tuning
ConvNeXtTiny	1.46 GMac	0.37B	ReLU	L2 regularization	No	Yes	Yes	Yes
ConvNeXtSmall	3.07 GMac	0.77B	ReLU	L2 regularization	No	Yes	Yes	Yes
ConvNeXtBase	14.34 GMac	3.59B	ReLU	L2 regularization	Yes	Yes	Yes	Yes
ConvNeXtLarge	41.34 GMac	10.34B	ReLU	L2 regularization	Yes	Yes	Yes	Yes
ConvNeXtXLarge	150.27 GMac	37.57B	Swish	DropBlock	Yes	Yes	Yes	Yes

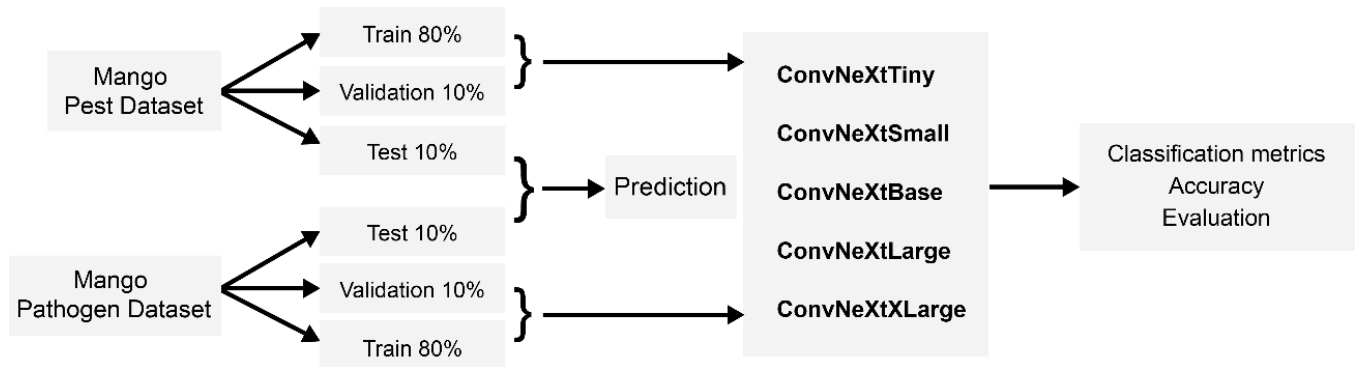


Fig. 1. Proposed methodology.

### B. Procedure Used

The training process for a Transfer Learning model used for the mango leaf disease dataset involves feeding the model with labelled images and adjusting the weights to minimize the loss function. The accuracy of the model is evaluated using a separate set of labelled images during the testing process, while the validation process fine-tunes the model to prevent overfitting by testing it on a set of labelled images not used in training. A diagram illustrating the procedure is shown in the Fig. 1. The study involved two datasets, namely the pathogen and pest dataset of mango leaves. ConvNeXt models were trained separately for both datasets and also combined and trained.

### C. Transfer Learning Models Used ConvNeXt Models

ConvNeXt was developed as an extension of the transformer architecture, which was originally designed for natural language processing tasks [23]. The transformer architecture consists of a series of encoder and decoder layers, which learn to encode and decode sequential data.

ConvNeXt extends the transformer architecture to image recognition tasks by incorporating convolutional layers into the encoder and decoder layers. This allows ConvNeXt to learn spatially localized features of an image, while also leveraging the attention mechanism of the transformer.

In contrast to traditional convolutional neural networks, which typically comprise of a series of convolutional layers followed by fully connected layers, ConvNeXt uses a parallel convolutional structure that allows for increased model capacity and improved performance on image recognition tasks [24].

In Table III and Table IV parameters [25] used are

1) *Number of Layers*: The number of layers refers to the depth of a neural network, where each layer performs a set of computations on the input data before passing it to the next layer.

2) *Number of Parameters*: The number of parameters refers to the total number of learnable parameters in a neural network, which includes weights and biases.

3) *Architecture*: The architecture refers to the design and organization of a neural network, including the number of layers, the size of each layer and the connections between them.

4) *Batch normalization*: Batch normalization is a technique used to normalize the input data to each layer of a neural network, improving the overall stability and convergence of the model.

5) *Dropout*: Dropout is a regularization technique used to prevent overfitting in neural networks by randomly dropping out some of the neurons during training.

6) *Top-1 Accuracy*: Top-1 accuracy is a metric used to evaluate the performance of a neural network on a classification task, measuring the percentage of predictions that match the correct label.

7) *Top-5 Accuracy*: Top-5 accuracy is similar to top-1 accuracy, but measures the percentage of predictions that include the correct label within the top 5 predictions.

8) *Computational Complexity*: Computational complexity refers to the amount of time and resources required to perform computations in a neural network.

9) *FLOPs*: FLOPs (FLoating-point Operations Per second) is a measure of the number of floating-point arithmetic operations a neural network can perform per second[26].

10) *Activation Function*: The activation function is a mathematical function used to introduce non-linearity into the output of a neural network layer [27].

11) *Regularization*: Regularization refers to techniques used to prevent overfitting in neural networks, such as dropout and weight decay [28].

12) *Residual connections*: Residual connections are connections between layers that bypass intermediate layers,

allowing the input to flow directly to the output and improving the flow of gradients during training [29].

13) *Image augmentation*: Image augmentation is a technique used to increase the amount of training data by randomly transforming images, such as rotating, scaling or flipping.

ConvNeXts have several advantages over traditional transformers for image recognition tasks [30]. They are

1) *Spatial information*: Transformers were originally designed for sequence tasks such as natural language processing where spatial information is not as important as the order of the tokens. However, for image recognition tasks, the spatial information of the pixels is crucial. ConvNeXts include convolutional layers that can capture spatial information, enabling the model to learn local features in the image.

2) *Parameter efficiency*: Transformers have a high number of parameters due to the large attention matrices, which can limit their scalability. ConvNeXts use a parallel convolutional structure which allows for increased model capacity without a large increase in parameters, making them more efficient in terms of memory and computation.

3) *Robustness to object scale*: ConvNeXts are better able to handle object scales than transformers. In transformer-based models, the receptive field of the model is fixed and cannot change. In contrast, ConvNeXts use convolutional layers which have a varying receptive field size, enabling them to capture features at different scales.

4) *Improved accuracy*: ConvNeXts have achieved state-of-the-art performance on several benchmark image recognition datasets, including ImageNet and CIFAR-10. They have shown improved accuracy compared to traditional convolutional neural networks and transformer-based models.

Overall, the incorporation of convolutional layers in ConvNeXts provides a more efficient and effective approach to leveraging the power of transformers for image recognition tasks [31].

TABLE V. MANGO PEST DATASET IMPLEMENTATION RESULTS FOR CONVNEXT MODELS

Mango Pest Dataset			
Model	Training Accuracy	Validation Accuracy	Testing Accuracy
ConvNeXtTiny	100 %	100 %	90.90 %
ConvNeXtSmall	100 %	100 %	92.65 %
ConvNeXtBase	100 %	100 %	96.00 %
ConvNeXtLarge	100 %	100 %	97.75 %
ConvNeXtXLarge	100 %	100 %	98.78 %

Model	Testing Accuracy
ConvNeXtXLarge	98.78%
ConvNeXtLarge	97.75%
ConvNeXtBase	96.00%
ConvNeXtSmall	92.65%
ConvNeXtTiny	90.90%

TABLE VI. MANGO PATHOGEN DATASET IMPLEMENTATION RESULTS FOR CONVNEXT MODELS

Mango Pathogen Dataset			
Model	Training Accuracy	Validation Accuracy	Testing Accuracy
ConvNeXtTiny	100 %	99.88 %	99.75 %
ConvNeXtSmall	100 %	99.875 %	99.5 %
ConvNeXtBase	100 %	100 %	99.375 %
ConvNeXtLarge	100 %	99.875 %	99.875 %
ConvNeXtXLarge	100 %	100 %	100 %

TABLE VII. COMBINATION OF BOTH MANGO PEST AND MANGO PATHOGEN DATASET IMPLEMENTATION RESULTS FOR CONVNEXT MODELS

Combination of Both Mango Pest and Mango Pathogen Dataset			
Model	Training Accuracy	Validation Accuracy	Testing Accuracy
ConvNeXtTiny	100 %	97.237%	97.23%
ConvNeXtSmall	99.53%	97.237 %	96.97 %
ConvNeXtBase	99.60 %	98.816 %	98.02 %
ConvNeXtLarge	100 %	98.947 %	98.01%
ConvNeXtXLarge	100 %	100 %	99.16%

#### IV. IMPLEMENTATION RESULT

The Table V provides the training accuracy, validation accuracy and testing accuracy for five different models (ConvNeXtTiny, ConvNeXtSmall, ConvNeXtBase, ConvNeXtLarge and ConvNeXtXLarge) trained on a Mango Pest Dataset.

The accuracy of the model over the training set throughout the training process is referred to as training accuracy. The accuracy of the model on a different validation set is referred to as validation accuracy, and this accuracy is used to assess the performance of the model during training and adjust its hyperparameters. The accuracy of the model under test is its performance on a brand-new test set that it has never seen or used before.

All five models had 100% accuracy on the training set, demonstrating that they had flawless memorization of the training data. Achieving 100% training accuracy, however, is not necessarily a desirable thing because it may signify overfitting, in which the model matches the training data too well and may not generalise well to new data.

The validation accuracies of the models vary, with the larger models generally achieving higher accuracy than the

smaller ones. However, the difference in validation accuracy between the models is relatively small, which suggests that the models are not overfitting to the training data.

Overall, the ConvNeXtXLarge model achieved the highest testing accuracy of 98.786747%, indicating that it is the best performing model on this Mango Pest Dataset.

The Table VI provides the training accuracy, validation accuracy, and testing accuracy for five different models (ConvNeXtTiny, ConvNeXtSmall, ConvNeXtBase, ConvNeXtLarge, and ConvNeXtXLarge) trained on a Mango Pathogen dataset.

The testing accuracies of the models are high, with all five models achieving above 99% accuracy. The ConvNeXtXLarge model achieved the highest testing accuracy of 100%, showing that it is the best performing model on this Mango Pathogen dataset. However, the difference in testing accuracy between the models is relatively small, which suggests that they are all performing well on this task. Overall, the results suggest that all five models are effective at identifying pathogenic infections in mangoes, with larger models performing slightly better than smaller ones.



Comparing the Table III and Table IV, it is seen that the performance of the ConvNeXt models on the Mango Pathogen dataset is better than on the Mango Pest dataset. All models achieved 100% training accuracy on both datasets, indicating that they could fit the training data perfectly. However, the testing accuracy of the models on the Mango Pathogen dataset is higher than on the Mango Pest dataset, suggesting that the models are better able to generalize to unseen data in the pathogen classification task.

The architecture of the ConvNeXt models may have contributed to their performance on these datasets. In both tables, the models have increasing accuracy as the model size increases, with the largest model, ConvNeXtXLarge, achieving the highest accuracy on both datasets. This suggests that increasing the model size and complexity can improve the model's ability to learn and classify patterns in the data.

The ConvNeXt models combine convolution layer, pooling layers, & fully linked layers in terms of their technical features. These models use the concept of grouped convolutions to capture both local and global dependencies in an image. The key idea behind ConvNeXt models is to create a network architecture that balances computational efficiency and modeling capacity. By using grouped convolutions, the number of parameters and computations required in each convolutional layer is reduced compared to fully connected convolutions. This enables deeper models with a large receptive field without significantly increasing the computational cost. The number of filters, the size of the filters, the number of groups, as well as the number of layers are some of the hyperparameters for the models. The algorithms' performance on the datasets may have also been influenced by the selection of hyperparameters. The selection of these hyperparameters can significantly affect the performance of ConvNeXt models based on different datasets.

In Table V to VI, the implementation results of ConvNeXT models for mango pest and mango pathogen datasets are

presented separately. In contrast, Table VII shows the implementation results of ConvNeXT models for a combination of both mango pest and mango pathogen datasets.

The results of Table V shows that all models performed well on the mango pest dataset, with the ConvNeXtXLarge model achieving the highest testing accuracy of 98.79%. The results of Table VI demonstrate that all models also performed well on the mango pathogen dataset, with the ConvNeXtXLarge model achieving perfect testing accuracy of 100%.

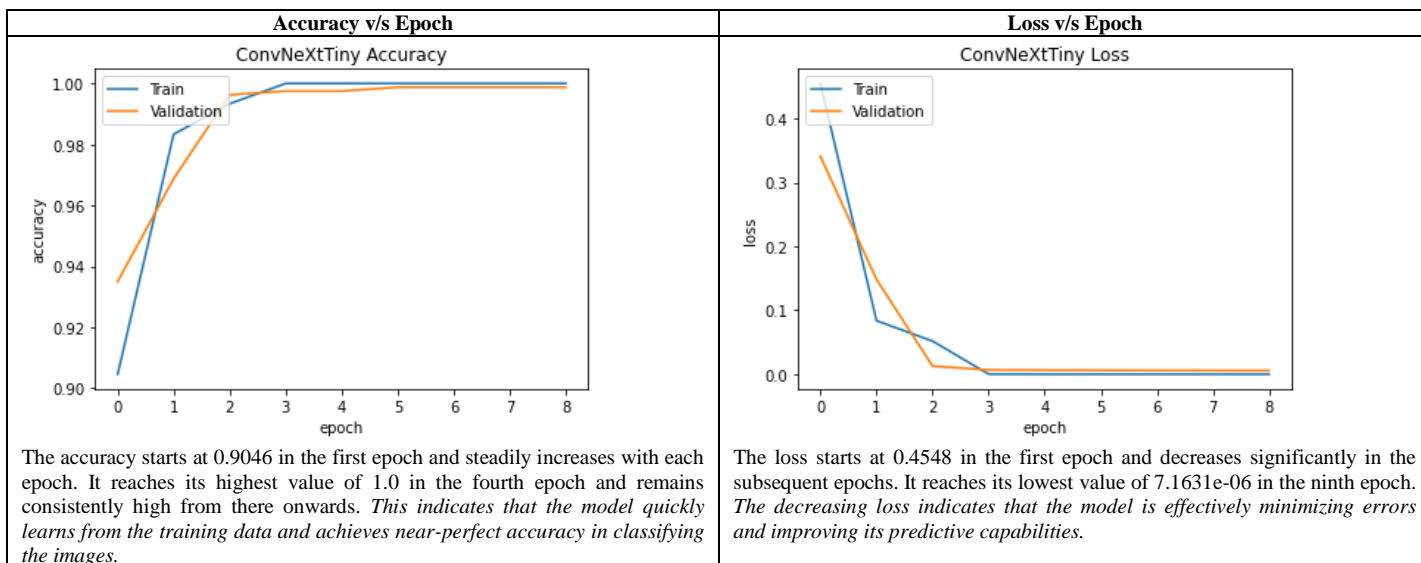
In Table VII, which shows the results for a combination of both mango pest and mango pathogen datasets, the testing accuracy of all models decreased compared to their performance in Table V and VI. This decrease in accuracy is likely due to the increased complexity of the combined dataset. However, the ConvNeXtXLarge model still achieved the highest testing accuracy of 99.17%, indicating its effectiveness in handling the combined dataset.

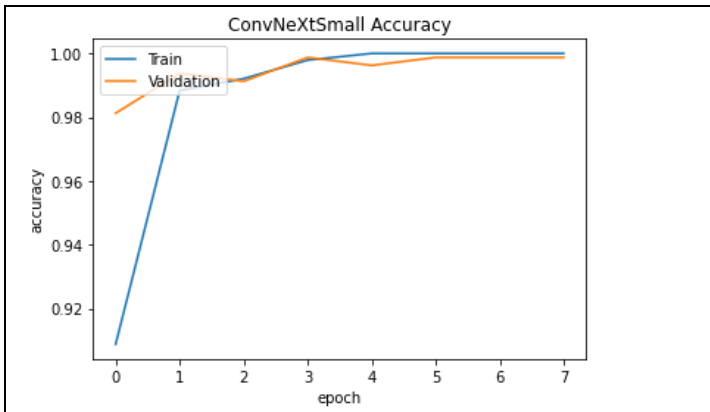
Overall, the results of Table VII suggests that using a combination of both mango pest and mango pathogen datasets can provide more comprehensive information about the health of mango leaves. While the accuracy of the models decreased slightly when using the combined dataset, the ConvNeXT models were still effective in detecting both pests and pathogens on mango leaves.

Table VIII shows Accuracy V/s Epoch and Loss V/s Epoch Graph for various ConvNeXt Models.

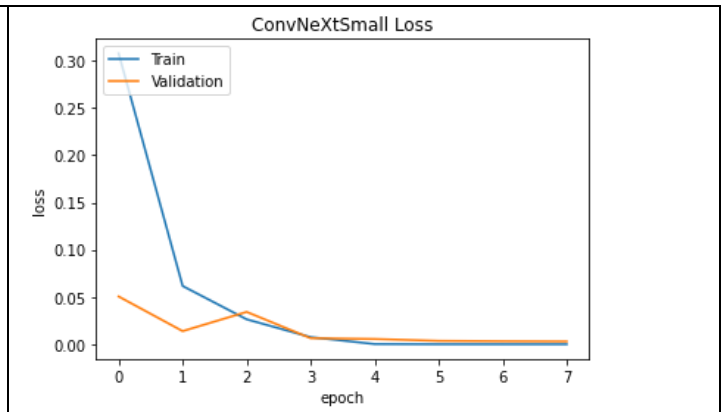
The effectiveness of the ConvNeXtTiny model upon the Mango Pathogen dataset is as shown in the confusion matrix in Fig. 2. The columns of the confusion matrix represent the anticipated labels, while the rows represent the genuine labels. Each cell of the matrix represents the count of cases where the predicted class (column) aligns with the actual class (row).

TABLE VIII. ACCURACY V/S EPOCH AND LOSS V/S EPOCH GRAPH FOR VARIOUS CONVNEXT MODELS

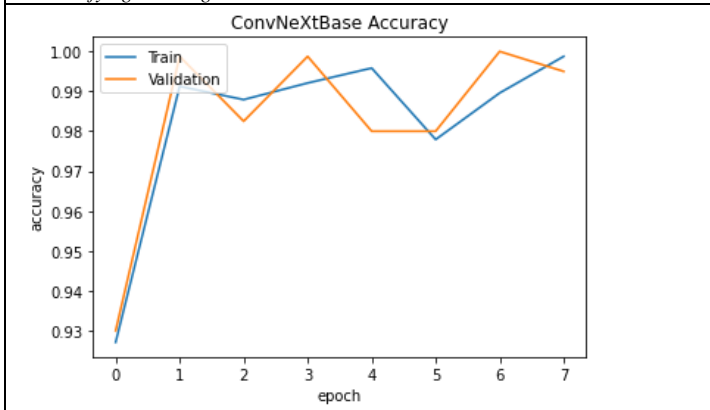




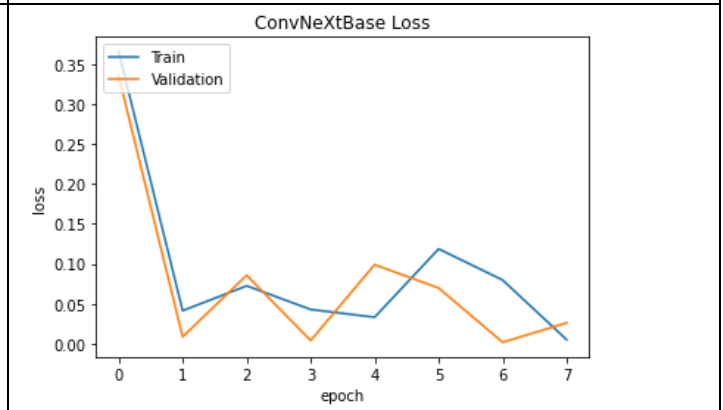
The accuracy steadily increases with each epoch until the fourth epoch, where it reaches its highest value of 0.9979. After that, the accuracy remains consistently high at 1.0 from the fifth epoch onwards. This indicates that the model quickly learns from the training data and achieves near-perfect accuracy in classifying the images.



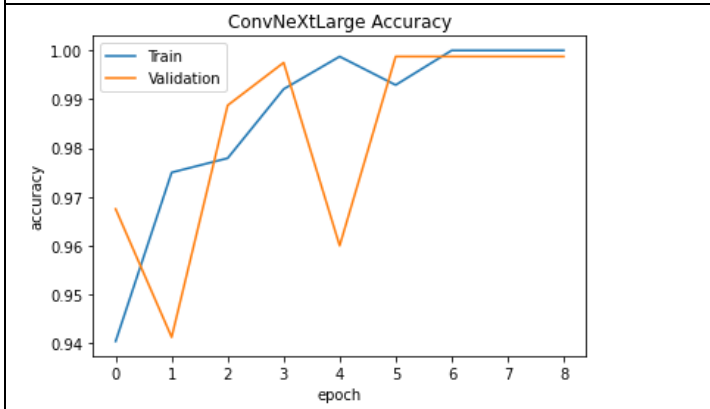
The loss starts at 0.3075 in the first epoch and decreases significantly in the subsequent epochs. It reaches its lowest value of 1.2019e-05 in the eighth epoch. The decreasing loss indicates that the model is effectively minimizing errors and improving its predictive capabilities.



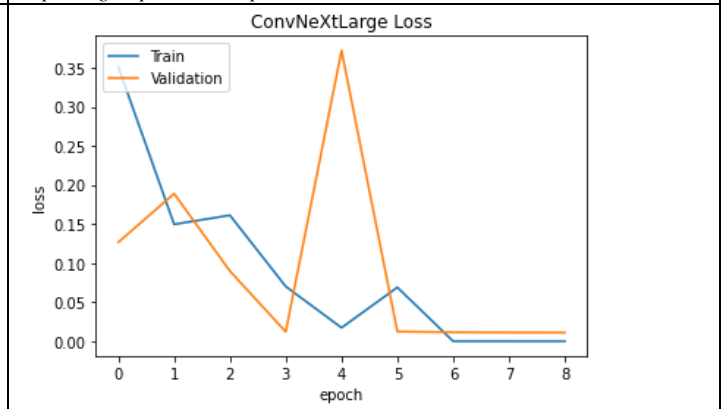
The accuracy steadily increases with each epoch until the seventh epoch, where it reaches its highest value of 0.9986. However, in the last epoch, the accuracy drops slightly to 0.9987. Overall, the model achieves high accuracy throughout the training process, indicating its ability to correctly classify images.



The loss starts at 0.3656 in the first epoch and decreases significantly in the subsequent epochs. It reaches its lowest value of 0.0017 in the seventh epoch. However, in the last epoch, the loss increases slightly to 0.0049. The decreasing loss indicates that the model is effectively minimizing errors and improving its predictive capabilities.



The accuracy steadily increases with each epoch, reaching a high value of 1.0 (100%) for the training dataset. On the validation dataset, the accuracy also shows a steady improvement, reaching a peak value of 0.99875 (99.875%) before the model stopped training due to early stopping.



The loss decreases significantly in the initial epochs, indicating that the model is learning and improving its predictions. After reaching a minimum value of 6.7500e-07, the loss plateaus and remains constant until the end of training.

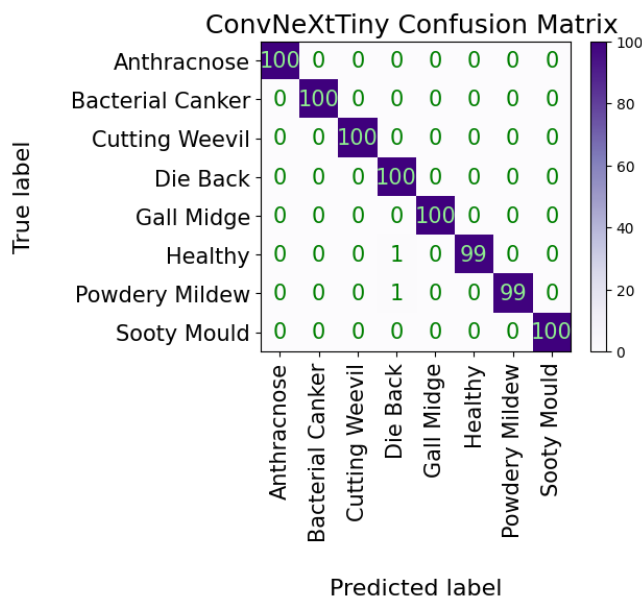
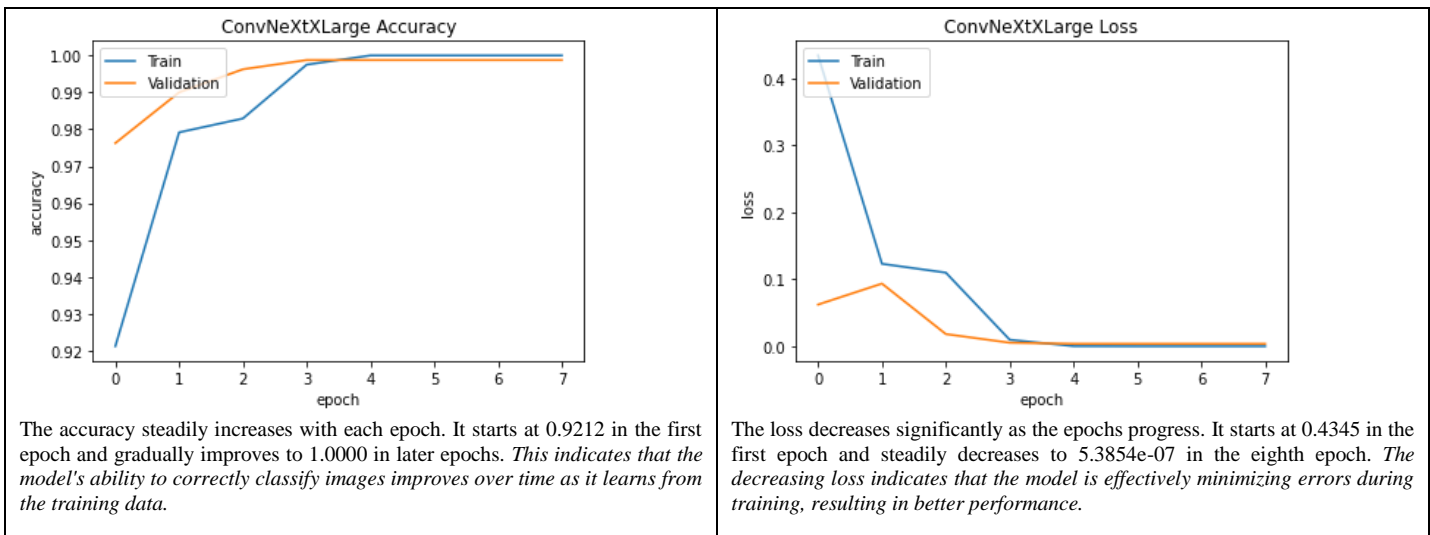


Fig. 2. ConvNeXtTiny confusion matrix for mango pathogen dataset.

Looking at the matrix, we can see that the model performed very well, with perfect accuracy in most of the classes (classes 0 to 5 and class 7). The only class where the model made mistakes is class 6 (Powdery Mildew), where it misclassified 1 instance as class 7 (Sooty Mould). The confusion matrix indicates that the ConvNeXtTiny model achieved high accuracy on the Mango Pathogen dataset, with only a single misclassification out of 800 instances.

### V. CONCLUSION

It can be concluded that all the models have performed well on both the mango pest and pathogen datasets. However, the accuracy of the models on the mango pathogen dataset is higher compared to the mango pest dataset. This is because the pathogen dataset contains images that are more distinct and easier to classify compared to the pest dataset.

In terms of the model architecture, it is seen that larger models, i.e., ConvNeXtBase, ConvNeXtLarge, and

ConvNeXtXLarge, have consistently higher accuracy than the smaller models, i.e., ConvNeXtTiny and ConvNeXtSmall. This suggests that the larger models have more capacity to learn complex features and patterns in the images, which results in better accuracy.

ConvNeXtXLarge Model giving its highest accuracy of 98.786747% for Mango Pest Dataset, 100% for Mango Pathogen Dataset and 99.16654% for Combination of Both Mango Pest and Mango Pathogen Dataset is the best model for Mango Disease Detection.

ConvNeXtTiny Model giving its accuracy of 90.908746% for Mango Pest Dataset, ConvNeXtSmall Model giving 96.97368% for Combination of Both Mango Pest and Mango Pathogen Dataset can be considered as Baseline models for Mango Disease Detection.

The models consistently improve their accuracy with each epoch, reaching near-perfect or perfect accuracy in classifying the mango pests and pathogens. The decreasing loss throughout the epochs demonstrates the models' ability to effectively minimize errors and improve their predictive capabilities.

This work is important in Mango Disease detection using transfer learning and ConvNeXT. The results show the potential of using deep learning models to accurately classify mango diseases, which can lead to more efficient and effective management of mango plantations. This can ultimately help farmers reduce crop losses and increase yields, leading to economic benefits for the agriculture industry.

Overall, the results show that deep learning models can be effective in classifying images of mango pests and pathogens with high accuracy, and larger models tend to outperform the smaller ones. However, it is important to note that the models' performance may depend on factors such as the quality of the dataset, pre-processing techniques and the choice of hyper parameters.

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# A Fine-grained Access Control Model with Enhanced Flexibility and On-chain Policy Execution for IoT Systems

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**Abstract**—Blockchain-based access control mechanisms have garnered significant attention in recent years due to their potential to address the security and privacy challenges in the Internet of Things (IoT) ecosystem. IoT devices generate massive amounts of data that are often transmitted to cloud-based servers for processing and storage. However, these devices are vulnerable to attacks and unauthorized access, which can lead to data breaches and privacy violations. Blockchain-based access control mechanisms can provide a secure and decentralized solution to these issues. This paper presents an improved Attribute-based Access Control (ABAC) approach with enhanced flexibility, which utilizes decentralized identity management on the Substrate Framework, codifies access control policies by Rust programming language, and executes access control policies on-chain. The proposed design ensures trust and security while enhancing flexibility compared to existing works. In addition, we implement a PoC to demonstrate the feasibility and investigate its effectiveness.

**Keywords**—Attribute-based Access Control (ABAC); Internet of Things (IoT); blockchain; substrate framework

## I. INTRODUCTION

Access control is a security approach that governs who or what has access to and uses resources in a computing environment. The primary objective of access control is to reduce the hazards of unauthenticated system access while protecting personal information. Therefore, most computing applications require access control services to control and prohibit unauthorized access to system resources such as networks, devices, files, or sensitive data. Meanwhile, the number of connected IoT devices is rapidly increasing due to the maturation of connecting protocols for IoT (e.g., BLE, LoRa, NB-IoT, LTE, 5G, and 6G). In addition, the growth of Big Data and Artificial Intelligence also motivates data collection from the physical environment by adopting IoT infrastructures. However, this means that security in IoT becomes more critical because IoT systems can yield a lot of sensitive data [1][2][3][4]. For example, a faulty firmware of a camera vendor caused millions of camera devices of clients to be exposed publicly to the Internet, and malicious parties can exploit resources legitimately. Therefore, access control employment is an essential solution to improve the security of IoT systems.

Most conventional access controls for IoT are based on a centralized architecture with many limitations, such as single-point-of-failure, trusted third-party requirements, and low scalability [5][6][7]. Meanwhile, the maturity of Blockchain drives

towards applying to numerous areas beyond cryptocurrencies to solve concerns of trust and security, such as digital certificate [8], smart factory [9], smart parking [10], healthcare [11], and traceability [12]. Additionally, there have been various research studies on the amalgamation of Blockchain to solve problems in existing IoT systems regarding scalability, interaction, security, privacy, and trust [13][14][15][16][17]. However, many aspects must be considered when applying Blockchain to conventional access control methods for IoT systems [18][19]. Due to heterogeneity and scenario variety in IoT, coarse-grained access control schemes, such as Discretionary Access Control (DAC), Mandatory Access Control (MAC), and Role-based Access Control (RBAC), become cumbersome in administration. Nevertheless, fine-grained access control schemes, such as Attribute-based Access Control (ABAC), not only provide flexible administration but also guarantee security [20].

In the ABAC scheme, access control is evaluated by attributes (e.g., subject, object, and environmental attributes) and instructed by codifiable policies. Those features produce ABAC's advantages but make it challenging to design, especially on Blockchain platforms. An ABAC design should consider two main parts: attribute management and policy execution. Besides the scheme aspect, identity management is also crucial in access control. Thanks to the decentralized identity (DID) standard, participants own DIDs associated with their human-readable information on Blockchain, which can be resolved to DID Document (DDO). This standard also facilitates authentication (DID Auth), which is generally necessary before authorization or access validation. Nowadays, existing Blockchain-based ABAC solutions for IoT still have several limitations. They do not ensure both security and flexibility. Moreover, several solutions based on ancient Blockchain platforms, such as Bitcoin and Ethereum, need to be improved in terms of scalability for massive IoT systems.

In this paper, we propose an improved ABAC-based approach developed on the Substrate Blockchain Framework, which ensures trust and security while enhancing flexibility compared to existing ABAC-based works. The main contributions of this paper can be summarized as follows:

- Propose an alternative design of a blockchain-based access control approach that includes improved features compared to similar works.
- Present the implementation of a proof-of-concept in detail to demonstrate the feasibility and evaluate the

effectiveness of the proposed design.

The rest of this paper is organized as follows. Section II summarizes related works to clarify the scope of our study. Then, Section III describes our proposed system. The implementation and evaluation are presented in Section IV. Finally, Section V provides concluding remarks and future works.

## II. RELATED WORKS

### A. Conventional Access Control Approaches

Discretionary Access Control (DAC) [21] is an identity-based access control model that gives users specific permissions to control their resources and data. Data owners can set access permissions for another user or group of users. These permissions are usually stored in an access control list. DAC is a simple and highly granular design because it allows users to freely configure access parameters on each data sample. However, it becomes a disadvantage and makes it for administrators more challenging to operate and maintain a more extensive system with a variety of users, data, and access configurations.

Mandatory Access Control (MAC) is a hierarchical model determined by the security level. In this model, each user is granted a security level, and each object is assigned a security label. A user can only access the according resource with a security label equal to or lower than that user's security level. In addition, this access control model also gives administrators complete control over access while users cannot configure their permissions. Therefore, the MAC model has a very high security. However, MAC-based systems can become quite unmanageable since administrators must configure permissions to all users and objects, leading to being overwhelmed if the system grows too fast.

Role-based Access Control (RBAC) [22] is a model based on user roles and responsibilities. Instead of granting access to users, RBAC gives access to roles that are then used to grant users the rights to access the system resources according to granted roles. RBAC has several variants, including flat RBAC, hierarchical RBAC, and constrained RBAC. The RBAC is suitable for small and medium systems because its static property is unsuitable for systems that grant access according to dynamic parameters.

Attribute-based Access Control (ABAC) [23] provides fine-grained and contextual access control capabilities based on attributes of users, system resources, and environment. The ABAC scheme allows administrators to define access control policies without prior knowledge of specific access objects. In addition, it can provide dynamic access control because it allows the use of environmental attributes, such as time, location, or IP address. Access decisions can be changed between access requests as attributes change. However, the ABAC scheme has low visibility (i.e., it is difficult to determine the privileges of a particular user) because it works based on attributes from many different sources. This also makes it challenging to identify security risks in the whole system.

Capability-based Access Control (CapBAC) [24] is an access control model based on the capability that is a token holding the privileges granted to users. When a user wants to

perform any actions on system resources, he has to send a request with his token to the service provider to check the validity of the token before deciding to allow or deny the request without verifying the requester's privileges because the token was published by a trusted server. This procedure makes the system not needing to maintain the users' list or the access policies list at the access points. However, issuing tokens by authentication servers and validating tokens at service providers might consume time in case of token withdrawal.

Access control models can be selected and deployed according to specific applications and conditions. Historically, centralized systems were often chosen to implement access control systems or through a third-party service provider. However, centralized systems are often limited regarding system scalability and the problem of single-point-of-failure, i.e., the risk at the centralized entity. In the meantime, allowing third parties to manage important security information, such as access control, can lead to information leakage risks and loss of user privacy. In addition, the system administrator has full control over the system, including manipulation of system usage history, which reduces the reliability and transparency of the entire access control system. However, Blockchain can tackle these limitations with prominent characteristics such as immutability, stability, audibility, and reliability.

### B. Blockchain-based Access Control Approaches

Applying Blockchain technology to access control management for IoT systems is a direction with many potential benefits. In [25], the authors proposed an access control solution by adopting smart contracts to define access control contracts (ACC). Each pair of a subject and an object in the system has one ACC that stores the subject's permissions with the object resources. This also means the number of ACCs will increase exponentially as the IoT system expands. Some other works [26][27] proposed blockchain-based authentication and authorization mechanisms for IoT with multiple domains and parties as access control solutions. Meanwhile, in [28], the authors proposed a capability-based access control on Blockchain, which applies the Decentralized Identifier standard to identify the parties involved in the system, including resource owners, resource access requests, and devices. However, this method does not have flexibility in access administration because it is a coarse-grained access control scheme that usually becomes cumbersome in access control management with large IoT systems, especially with many changes.

As mentioned above, fine-grained access control schemes are suitable for IoTs but more complex when developing on Blockchain. The six following works are the most closely related to ours. In [29], the authors proposed a fine-grained access control framework based on Hyperledger Fabric, called Fabric-IoT. Attribute fields for users, devices, and policies are pre-defined, and administrators specify their values. Meanwhile, values of environment attributes are dynamically detected at the request processing time. In this work, a policy definition is limited to only being set values of the pre-defined attribute fields. In addition, policy execution for the relationship between attributes and access decisions is hard-coded in a smart contract. A similar design was presented by Song et al. in [30], but user and device attribute fields in this



work do not need to be pre-defined. These two Blockchain-based approaches are generally simplified from the original ABAC scheme, making them less dynamic and flexible.

In [31], attributes and policies are stored on a Hyperledger Fabric blockchain and an InterPlanetary File System. A policy execution is performed at distributed nodes in a network, called off-chain execution, and its final result is reduced with the Practical Byzantine Fault Tolerance (PBFT) algorithm. This approach does not take advantage of Blockchain for policy execution. Meanwhile, Maesa et al. [32] proposed a manner to transpile ABAC policies with XACML language to smart contracts with Solidity language, which can be executed on EVM-integrated Blockchain. Similarly, in [33], the authors proposed a scheme to interpret ABAC policies with XAMCL language to Blockchain transactions in JSON and scripting-logic expression. Those can be executed as Bitcoin scripts with several extended commands dedicated to collecting attribute information in the ABAC scheme.

Besides policy execution, attribute management is crucial in ensuring the ABAC scheme's security. These above-mentioned works took attributes of subjects and objects provided by third parties or managed by an administrator. However, in [34], the authors proposed a model for endorsing subject attributes on Blockchain. An entity, so-called a trusted entity, can issue or revoke endorsements for other entities' attributes. An attribute's trust is a value accumulated from the trust levels of the entities endorsing it. Trust levels of entities are maintained by a reputation system deployed on Blockchain. Because of focusing on attribute endorsement, this work did not take policy execution in the scope of its study.

To the best of the authors' knowledge, existing ABAC designs for IoTs on Blockchain have yet to ensure trust, security, and flexibility simultaneously. Therefore, this paper proposes an improved ABAC design for IoTs, which utilizes decentralized identity management on Blockchain, applies attribute endorsement to ensure attribute trust and security, and leverage smart contract to codify policy for enhancing flexibility. We define four criteria to highlight the improvement of the proposed design in terms of flexibility compared to six related methods, as shown in Table I.

- C1: Attributes are modifiable.
- C2: Policies are codifiable.
- C3: Policies are executed on-chain.
- C4: Attribute values are endorsed.

TABLE I. COMPARISON OF RELATED WORKS AND OURS

Criteria	[29]	[30]	[31]	[32]	[33]	[34]	Ours
C1	No	N/A	Yes	N/A	Yes	Yes	Yes
C2	No	No	Yes	Yes	Yes	N/A	Yes
C3	No	Yes	Yes	Yes	Yes	No	Yes
C4	No	No	Yes	No	No	Yes	Yes

### III. THE PROPOSED APPROACH

IoT infrastructures typically consist of numerous devices deployed distributedly in the physical world. These devices can be categorized into end-devices, gateway, and IoT devices. As the largest and most distributed part among others, end-devices should be optimized in cost and energy consumption, letting them be neglected with battery power for a long time. In addition, end-devices are usually constrained in computing and storing capability, so they can not efficiently perform heavy cryptographic techniques to consolidate security. Moreover, low-power networks (LPWN) of wireless end-devices also have low bandwidth. Therefore, security methods will be mainly deployed on gateways since they employ electric grid power, high bandwidth internet connection, and more powerful computing and storage capacity. Besides, IoT devices, such as surveillance cameras, robots, or smartwatches, which have more powerful hardware configurations, are also considered to accommodate self-serving cryptographic security techniques. In the proposed design, we choose gateways as end-points for access control service, restricting requests from outside to inside resources for empowering security and privacy.

As the core of the proposed design, critical data and execution of access control are carried out on Blockchain to empower security and trust. We develop the proposed method on Substrate Framework and customize the Blockchain system for the access control services with three major obligations. First, Blockchain is an underlying infrastructure for a decentralized identifying system, facilitating authentication. Second, it provides methods for participants to manage their access control attributes on Blockchain. Third, it provides a distributed computing environment to manage and execute access control policies.

The proposed access control system comprises users with different roles and permissions, who can be divided into three types: regular users, trusted users, and administrators. The regular users include requesters who request access to resources and owners who own shared resources. The trusted users can endorse attributes of regular users, specifically requesters or subjects. The administrators are a minority in the system and are responsible for governing access to IoT resources through policies. With a large or global IoT system, there can be many multiple domains in which several administrators can manage each domain. This access control system is not tied to a specific IoT domain; in other words, it also supports multiple IoT domains. Furthermore, owners are considered to have sovereignty over their own IoT devices, which they may control locally and physically.

#### A. Security Assumptions

A security system is usually designed and built based on specific assumptions. Our proposed system will be developed based on four security assumptions (SA).

- SA1: Regarding physical devices such as IoT devices and gateways, they are assumed to operate reliably to protect themselves. It is noted that a device cannot be secured with only software solutions if a device is physically attacked and manipulated. However, a malicious device will not harm other trusted devices.

- SA2: The connection from IoT devices to the Blockchain system is also considered secure, allowing transactions from devices to reach the Blockchain or events returned from the Blockchain to propagate smoothly.
- SA3: Like other Blockchain systems, participants are responsible for the confidentiality of their Blockchain accounts and other private keys associated with their decentralized identity. In addition, users with special roles, such as administrators, are assumed to be trusted in their authority.
- SA4: Actual deployment conditions might influence Blockchain network topology and the selection of consensus algorithms. However, a Blockchain system must be distributed, immutable, and transparent as inherent characteristics.

Among these four assumptions above, except for the last one (SA4), when other assumptions are violated, it just locally affects; for example, a compromised IoT device or a disclosed Blockchain account, the security problems will be only affected locally.

### B. System Design

An access control system should have flexibility to be easily adopted for numerous scenarios. The flexibility also makes access management more convenient for administrators, particularly in granting or revoking permissions. Hence, we chose the ABAC scheme that a fine-grained access control scheme. In addition, to consider the flexibility of an access control system, we scope our study in two following use-cases.

- In smart agriculture, combining low-power wireless sensor networks with automatic control systems facilitates agriculture precision. Commonly, an agricultural product has to go through many stages before reaching its consumer, such as planting, harvesting, processing, transporting, and retailing, hence the need for traceability. Blockchain technology allows parties from those stages to participate in a system to share data in trust. Each farm or each factory can have numerous IoT devices, employees, several managers, and one possessor. To control access to IoT devices, a possessor can delegate to managers; in turn, they will manage access permissions for employees through ABAC policies. In this use case, managers could endorse employees' attributes or delegate to their assistants as trusted endorsers. Environment attributes like DateTime can grant temporary permissions for seasonal employees. Third parties, such as business partners and inspection centers, may also be granted appropriate permissions to access to monitor activity.
- Another use-case is to manage access controls for an IoT camera system on a campus. These cameras can be rented to students who want to conduct related experiments such as video streaming. A CapBAC-based Blockchain approach has been proposed in [28]. Owners control tenant access by issuing or revoking capability tokens, and each token issuing requires the participation of both the owner and the tenant. When

the system scales up, managing issued and revoked tokens becomes cumbersome and inflexible. Meanwhile, the ABAC design can provide more efficient access management for that case. Surveillance cameras can be divided into groups for easy management by defining attributes in a large system. Owners can grant permissions to tenants by endorsing their corresponding attributes. Note that a pre-defined policy just links the camera group to the tenant group. Besides that, environment attributes can help rent out based on time conveniently.

Fig. 1 depicts the system architecture of the proposed method on Substrate Framework that supports DID management and smart contracts via DID and Contract Pallets, respectively. In addition, we design the ABAC scheme as an **ABAC Pallet** and integrate it into the Substrate Framework. A typical Substrate's Pallet has two main parts: **storage declaration** and external methods (so-called **extrinsic definition**). Extrinsic calls only accomplish each update to pallet storage, and the change is also attached to Blockchain. As the core of the proposed design, the ABAC Pallet has three storage declarations for ABAC Attributes, Endorsements, and Policy Attachments, described as follows.

- The first one is to store attributes (**Attribute Storage**) of subjects and objects according to their decentralized identities. Each ABAC attribute is in the form of key-value pair. With self-sovereign design thinking, an owner of a decentralized identity also owns associated ABAC attributes on Blockchain.
- The second one is to store endorsements (**Endorsement Storage**), which trusted endorsers confirmed for reviewed attributes of subjects. The endorsements make trusty for the current values of the subject's attributes. The endorsers can specify a validity period for their endorsements.
- The third one is storing objects' attachments with ABAC policies (**Policy Storage**), which is in the form of a one-to-many relationship. In the proposed design, an ABAC policy is a deployed smart contract with a unique address on the blockchain system. For those policies to be valid to an object, attachments need to be committed by the corresponding owner or administrators. Each attachment also holds a reminiscent name and logs its author.

Based on the storage declarations above, necessary extrinsic are designed to control ABAC attributes, attribute endorsements, and policy attachments from outside Blockchain. To ensure the caller has authority with corresponding data on Blockchain, these extrinsic all require a decentralized identifier owned by the caller as the first parameter. Other parameters in a specific extrinsic are selected to fit multiple demands.

- There are two extrinsic for users to control attributes associated with their DIDs, including **setAttributes()** and **clearAttributes()**. Extrinsic **setAttributes()** allows users to create and modify one or more attributes on Blockchain. If an attribute with its key does not exist, a creation will occur, and vice versa, and an attribute-value update will be activated. Note that once the

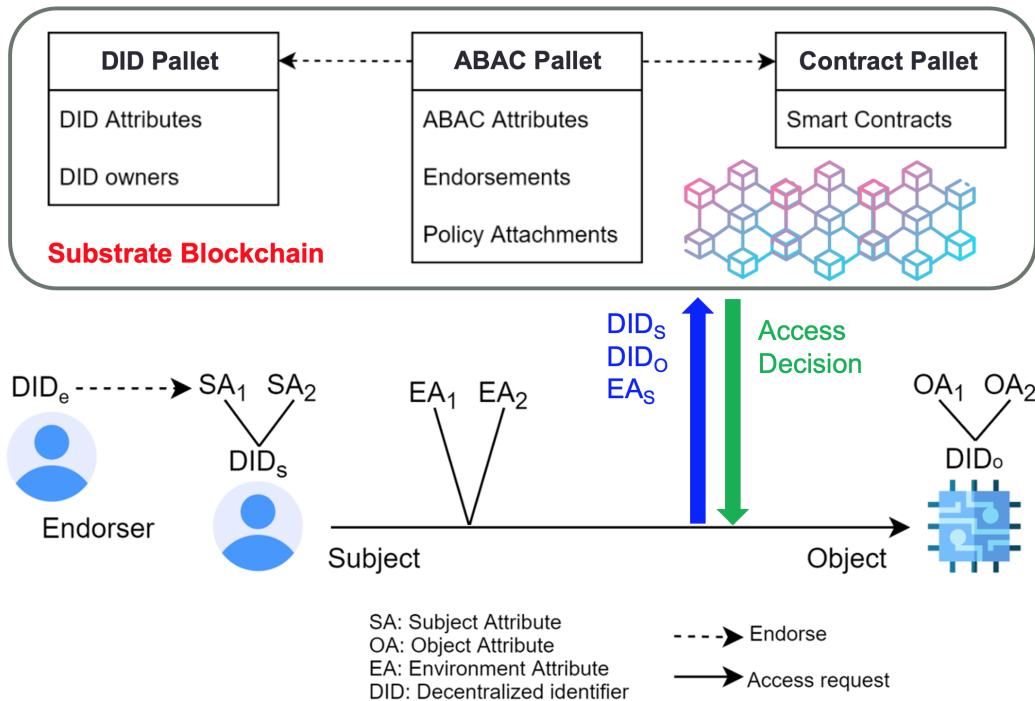


Fig. 1. System architecture.

value of an attribute is modified, all of its previous endorsements will no longer be valid, and then it will be deleted. Otherwise, extrinsic clearAttributes() is to delete the existing attributes of a decentralized identifier by specifying the corresponding attribute names.

- There are two extrinsic for trusted users to control endorsements of subject attributes, including **endorseAttributes()** and **unendorseAttributes()**. Endorsers can use endorseAttributes() to endorse multiple existing attributes of a subject with a specific validity duration. In the Substrate Framework, the value of that validity duration can be represented by a multiplier of the block finalization interval (e.g., 6 seconds by default). Otherwise, unendorseAttributes() allow endorsers to proactively delete their endorsements before expiring.
- There are two extrinsic for owners or administrators to manage policies of corresponding objects, including **attachPolicy()** and **detachPolicy()**. As mentioned above, a policy exists on Blockchain as a smart contract with a unique Blockchain address. Extrinsic attachPolicy() allows owners or administrators to connect an object and a policy. Furthermore, a reminiscent name for the attachment is also enabled, and the caller's DID is logged. Meanwhile, extrinsic detachPolicy() deletes the connection between an object and its policy.

### C. Policy Execution Model

Access control policies define rules executed to make access decisions for requests. The policy execution should

help flexibility in management but ensure security. In our design, the policy execution model coordinates on-chain and off-chain parts as described in Fig. 2. The off-chain part is performed outside the Blockchain system and is usually conducted on gateways. Policy Enforcement Point (PEP) is a middleware for receiving and handling access requests. When receiving an access request, PEP will forward that request to the Off-chain Context Handle (OFF-CH), and the Environment Attribute Detection (EAD) will derive related information as environment attributes. Subsequently, OFF-CH invokes on-chain policy execution, which contains the subject's DID, the object's DID, and environmental attributes. Once on-chain policy execution is completed, access decisions are returned to OFF-CH, which will forward them to the PEP. Based on those decisions, PEP enforces denying or allowing for the corresponding request.

The on-chain part is performed distributedly on Blockchain, where attributes of subjects and objects are stored and managed via distributed identities. Authority participants, including device owners or administrators, define policies of objects, which are also stored and managed on Blockchain. All on-chain data modifications are attached to the blocks. When the system receives an invocation of on-chain policy execution, the On-chain Context Handle (ON-CH) will forward it to Policy Decision Point (PDP) to execute corresponding policies. Note that which policies will be executed can be specified in the invocation or derived from the object's DID. During the execution, the ON-CH is responsible for fetching necessary attributes from the Subject/Object Attribute Authority to the PDP. Once completed, access decisions go from the PDP to the ON-CH and propagate to the OFF-CH through Blockchain events.

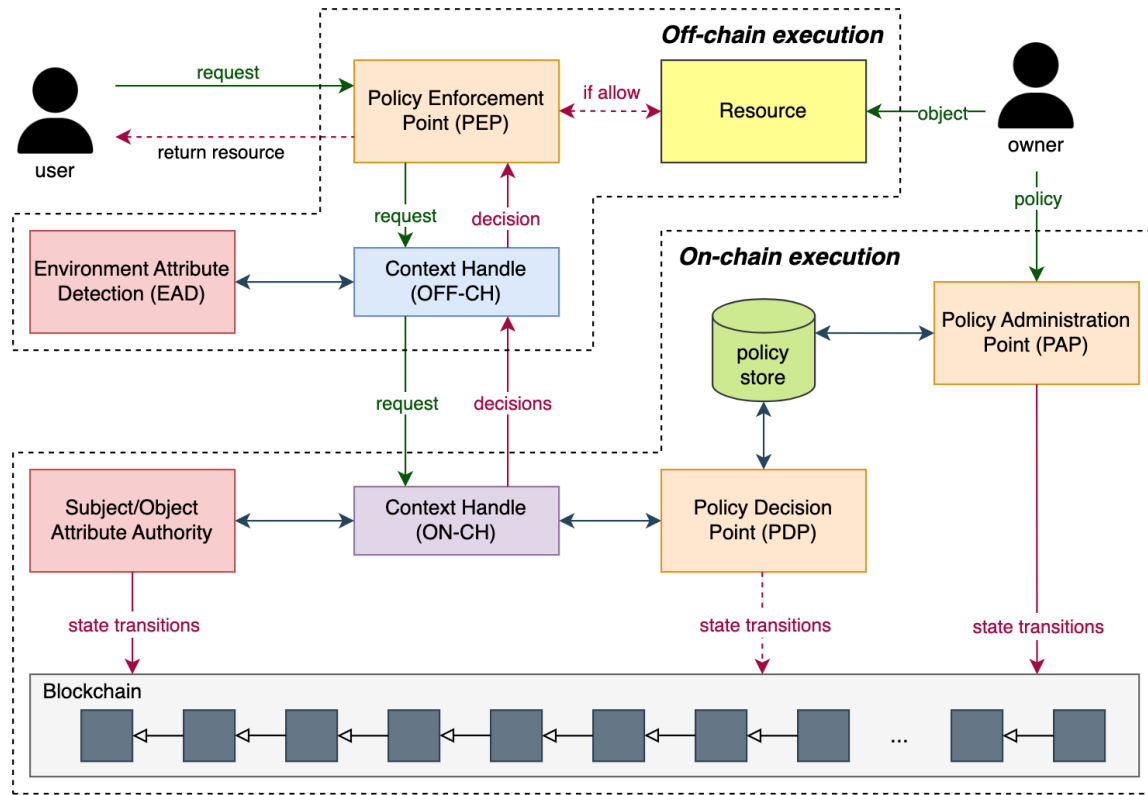


Fig. 2. Policy execution model.

A policy is a combination of programmable logic that defines the relationship among subject, object, environment attributes, and access decisions. In fact, policies can be expressed by procedural programming languages and deployed in appropriate computing environments. However, we leverage smart contracts in Substrate Framework to define policies.

#### IV. IMPLEMENTATION AND EVALUATION

##### A. Implementation

To investigate the proposed design, we implement and deploy a proof-of-concept (PoC) based on Substrate Blockchain Framework. Some abbreviations used to describe our algorithms are described in Table II. As presented in Section III-B, there are six main extrinsic for attributes management, attribute endorsement, and policy management in the proposed design. These six extrinsic belong to the ABAC Pallet (see Fig. 1) as interfaces to allow exterior to manipulate their on-chain data. We implement these extrinsic as Algorithms 1, 2, and 3. Some remarks are summarized as follows:

- In Algorithm 1, if an attribute is modified or deleted, all its endorsements shall be dropped automatically, as in lines 11 and 23.
- In Algorithm 2, before creating an endorsement for an attribute, its existence should be verified as line 6, and its value is calculated as line 7. For example, if  $EV$  is 3600 and the block generation interval is six seconds,

the corresponding endorsements will be valid for six hours.

- In Algorithm 3, the  $checkPerm()$  is used to make sure those who utilize these functions are the object's owner or administrators delegated, and a reminiscent name is also possibly associated with each attachment for later use.

To express the access control policy by a smart contract for general purposes, several rules in development should be proposed to scope it for access validation. Firstly, it needs a list of trusted endorsers so that its administrator can decide who is trusted with them. Secondly, it must have at least one method for access validation. Thirdly, those methods should take necessary arguments (e.g.,  $DID_s$ ,  $DID_o$ , and  $EA$ ), result in access decisions, and express policy logic in its body. Remarkably, there can be multiple policy logic expressions in one access validation method, and an access control template is proposed as Algorithm 4. A typical procedure should have five steps as follows.

- Step 1: Reading necessary attribute values.
- Step 2: Checking validity of the necessary attributes.
- Step 3: Evaluating defined policy logic.
- Step 4: Making a decision.
- Step 5: Saving the decision to the returning list

TABLE II. ABBREVIATIONS

Symbol	Description
$DID$	Distributed Identifier
$DID_a$	Administrator's DID
$DID_e$	Endorser's DID
$DID_o$	Object's DID
$DID_s$	Subject's DID
$ATL$	Attribute List
$AS$	Attribute Storage
$AV$	Attribute Value
$ANL$	Attribute Name List
$ES$	Endorsement Storage
$EV$	Endorsement Validity
$PS$	Policy Storage
$PAddr$	Policy Address
$PRN$	Policy's Reminiscent Name
$EA$	Environment Attribute
$ADL$	Access Decision List
$ACC_s$	The $i$ th Blockchain Account
$AEK$	Authentication's Encrypted Key
$APK_o$	Authentication's Private Key of An Object
$EAC$	Encrypted Authentication Challenge
$DDO$	DID Document

In case of failing to read attribute values or invalid endorsement, the corresponding expression should be bypassed, and no decision should be considered denying access.

Moreover, to demonstrate the feasibility of the entire system based on the proposed design, we also develop an example script of the off-chain access control as Algorithm 5, which works as an Express.js server running on an access control object (e.g., the Gateway) and opens REST API for listening access control requests. This module can communicate with Blockchain via a Web Socket connection manipulated by the Polkadot.js API library to query on-chain storage or listen to Blockchain events. Some remarks are summarized as follows.

- Lines 1 and 2 are to establish a Web Socket connection to Blockchain and to initialize a DID Resolver, respectively. As a service, the infinite loop handles every access request when it comes. The corresponding handler will be triggered based on the incoming request type.
- Lines 8 to 13 are to perform an authentication process between the sender (i.e., a subject) and an object. When this process finishes, an authentication challenge will return to the subject.
- Lines 14 to 20 are to complete the DID Authentication process. The request must include an authentication response corresponding to the previous authentication challenge for the subject. If the response matches the challenge, an encrypted key will be returned to the subject as a successful authentication. Otherwise, an error will be returned as a failed authentication.

### Algorithm 1 Attribute Management

---

**Require:**  $DID, ATL[], ANL[]$

- 1: *%Two extrinsics for users to control attributes associated with their DIDs*
- 2: **function** setAttributes( $DID, ATL[]$ )
- 3:     **for**  $attr$  **in**  $ATL$  **do**
- 4:          $key \leftarrow \langle DID, attr.name \rangle$
- 5:          $value \leftarrow attr.value$
- 6:         **if**  $AS.Exist(key) == true$  **then**
- 7:              $AS.Insert(key, value)$
- 8:         **else**
- 9:              $AS.Mutate(key, value)$
- 10:              $keys \leftarrow \langle DID, attr.name, * \rangle$
- 11:              $ES.RemoveAll(keys)$
- 12:         **end if**
- 13:     **end for**
- 14:     **return Success**
- 15: **end function**
- 16:
- 17: **function** clearAttributes( $DID, ANL[]$ )
- 18:     **for**  $name$  **in**  $ANL$  **do**
- 19:          $key \leftarrow \langle DID, name \rangle$
- 20:         **if**  $AS.Exist(key) == true$  **then**
- 21:              $AS.Remove(key)$
- 22:              $keys \leftarrow \langle DID, name, * \rangle$
- 23:              $ES.RemoveAll(keys)$
- 24:         **end if**
- 25:     **end for**
- 26:     **return Success**
- 27: **end function**

---

### Algorithm 2 Attribute Endorsement

---

**Require:**  $DID_e, DID_s, ATL[], EV$

- 1: *% Two extrinsics for trusted users to control endorsements of subject attributes*
- 2: **function** endorseAttributes( $DID_e, DID_s, ANL[], EV$ )
- 3:     **for**  $name$  **in**  $ANL$  **do**
- 4:          $key_a \leftarrow \langle DID_s, name \rangle$
- 5:          $key_e \leftarrow \langle DID_s, DID_e, name \rangle$
- 6:         **if**  $AS.Exist(key_a) == true$  **then**
- 7:              $value \leftarrow EV + CurrentBlockNumber()$
- 8:              $ES.Insert(key_e, value)$
- 9:         **end if**
- 10:     **end for**
- 11:     **return Success**
- 12: **end function**
- 13:
- 14: **function** unendorseAttributes( $DID_e, DID_s, ANL[]$ )
- 15:     **for**  $name$  **in**  $ANL$  **do**
- 16:          $key_e \leftarrow \langle DID_s, DID_e, name \rangle$
- 17:         **if**  $ES.Exist(key_e) == true$  **then**
- 18:              $ES.Remove(key_e)$
- 19:         **end if**
- 20:     **end for**
- 21:     **return Success**
- 22: **end function**

---

- Lines 21 to 29 are to validate and then access a specific resource if authorized. The subject and policy validity

---

**Algorithm 3** Policy Management

---

**Require:**  $DID_a, DID_o, PAddr, PRN$

```
1: % Two extrinsics for trusted users to manage access control policy
2: function attachPolicy( $DID_a, DID_o, PAddr, PRN$ )
3:   if checkPerm( $DID_a, DID_o$ ) == false then
4:     return Fail
5:   end if
6:    $key \leftarrow \langle DID_o, PAddr \rangle$ 
7:    $value \leftarrow \langle DID_a, PRN \rangle$ 
8:    $PS.Insert(key, value)$ 
9:   return Success
10: end function
11:
12: function detachPolicy( $DID_a, DID_o, PAddr$ )
13:   if checkPerm( $DID_a, DID_o$ ) == false then
14:     return Fail
15:   end if
16:    $key \leftarrow \langle DID_o, PAddr \rangle$ 
17:    $PS.Remove(key)$ 
18:   return Success
19: end function
20:
21: % A helper function to check permission for Policy Attachment
22: function checkPerm( $DID_a, DID_o$ )
23:    $Admins \leftarrow DidPallet.GetDelegates(DID_o, "PolicyAdmin")$ 
24:   if  $DID_a == DID_o$  then  $\triangleright$  self-management
25:     return true
26:   else if  $DID_a \in Admins$  then
27:     return true
28:   end if
29:   return false
30: end function
31:
32:
```

---

must be verified before making an on-chain access validation to get access decisions (ADL) returned from Blockchain. At line 27, *OnChainValidation()* can collect environment attributes (EA) and encapsulate them into invoking on-chain policy execution.

The entire source code are freely shared at <https://github.com/substrate-iot>.

### B. Deployment

We adopt containerization to simulate a Blockchain network as a runtime environment because it is flexible in establishing a more decentralized Blockchain. Currently, we have established a network consisting of 12 Blockchain nodes. Notably, Substrate Blockchain uses a Proof-of-Authority consensus algorithm that does not press on computing capability. Therefore, deploying multiple Blockchain nodes on low-cost desktops or personal computers is convenient for experiments while guaranteeing all Blockchain features.

The deployment process of our implementation on containers in Substrate Blockchain Framework is summarized in four main steps as follows.

---

**Algorithm 4** The template to express the access control policy by smart contract

---

**Input:**  $DID_s, DID_o, EA[]$

**Output:**  $String[]$  (ADL: List of access decisions)

```
1: function validateAccess( $DID_s, DID_o, EA[]$ )
2:   Initialize ADL as an empty array of string
3:
4:   % Start of policy logic 1
5:   ...read attribute values ...
6:   ...check validity of attributes ...
7:   ...evaluate policy logic 1 ...
8:   ...make a decision for evaluation 1 ...
9:    $ADL.Push(\text{the result for logic 1})$ 
10:  % End of policy logic 1
11:
12:  % Start of policy logic 2
13:  ...
14:  ...  $ADL.Push(\text{the result for logic 2})$ 
15:  % End of policy logic 2
16:  ...
17:  % Start of policy logic n
18:  ...
19:   $ADL.Push(\text{the result for logic n})$ 
20:  % End of policy logic n
21:  return ADL
22: end function
```

---

- Step 1: Create a docker image (DI) which includes the executable file (EF) of the Blockchain node by compiling the source code (SC).

$$SC \xrightarrow{\text{compile}} EF \xrightarrow{\text{copy}} DI$$

- Step 2: Generate Blockchain accounts (ACC) for every node in the networks.

$$EF \xrightarrow{\text{generate}} \{ACC_1, ACC_2, \dots, ACC_{12}\}$$

- Step 3: Update the Default Chain Specification file (DCS), which would be loaded each the executable file boots up. A node must be aware of all other nodes and be updated with all other nodes' Blockchain addresses. Then, each particular node will have an Updated Chain Specification (UCS).

$$EF \xrightarrow{\text{generate}} DCS \xrightarrow{\text{modify}} UCS$$

- Step 4: Activate containers according to the number of Blockchain nodes from the docker image with the updated chain specification and their associated Blockchain account.

$$\{DI, UCS, ACC_i\} \xrightarrow{\text{activate}} BlockchainNode_i$$

### C. Evaluation

We conduct experiments to investigate the timing problem, a common design metric in most IoT systems. It measures how long it takes to complete a transaction, especially when many users utilize the Blockchain simultaneously. If it is too long, it will negatively affect to real-time demand and scalability of the IoT system. Therefore, our experiments investigate the amount of time elapsed to thoroughly submit transactions



---

**Algorithm 5** An off-chain access control JavaScript

---

**Input:**  $DID_o$ ,  $APK_o$

```
1:  $api \leftarrow PolkadotJS.ConnectTo(Blockchain)$ 
2:  $DidResolver \leftarrow BuildDidResolver(api)$ 
3: while true do
4:    $\langle req, type, data \rangle \leftarrow GetRequest()$ 
5:   if  $req == null$  then
6:     continue
7:   end if
8:   if  $type == "AuthRequest"$  then
9:      $DDO \leftarrow DidResolver(data.DID)$ 
10:     $publicKey \leftarrow GetAuthPublicKey(DDO)$ 
11:     $EAC \leftarrow GenerateEncryptedChallenge($ 
12:       $publicKey)$ 
13:     $CacheChallenge(data.DID, EAC)$ 
14:    return  $Response(EAC)$ 
15:   else if  $type == "AuthResponse"$  then
16:     $authRe \leftarrow data.authReponse$ 
17:     $result \leftarrow VerifyAuthResponse($ 
18:       $data.DID, authRe)$ 
19:     $Ensure(result == true)$ 
20:     $encryptedKey \leftarrow GenerateEncryptedKey()$ 
21:     $CacheEncryptedKey(data.DID, encryptedKey)$ 
22:    return  $Response(encryptedKey)$ 
23:   else if  $type == "AccessResourceX"$  then
24:     $encryptedKey \leftarrow data.encryptedKey$ 
25:     $PAddr \leftarrow data.policyAddress$ 
26:     $avRe \leftarrow VerifyAuthValidity($ 
27:       $data.DID, encryptedKey)$ 
28:     $pvRe \leftarrow VerifyPolicyValidity($ 
29:       $DID_o, PAddr)$ 
30:     $Ensure(avRe == true \& \& pvRe == true)$ 
31:     $ADL \leftarrow OnChainValidation($ 
32:       $data.DID, PAddr)$ 
33:     $Ensure("allow_resource_X" \in ADL)$ 
34:    return  $Response(current\ data\ of\ resource\ X)$ 
35:   end if
36:   return  $Response(Error)$ 
37: end while
```

---

for seven main functions, including six extrinsic, as above-presented, and one for executing access policies. In each testing process, transactions have been submitted consecutively until a specific number of times is reached. The number of transactions for each process is increased by x10 times. Each testing process is performed five times to eliminate the effect of the natural unexpected random factor, and the final result is averaged. Fig. 3 summarises the experimental results, in which a logarithmic scale is utilized to present the value clearly due to the large differences.

Some findings are discussed based on the experimental results as follows:

- A single transaction's elapsed time, called response time, is roughly 1.0 to 1.5 on the logarithmic scale, equivalently from 10 to 30 milliseconds.
- When the number of transactions increases by x10 times, the elapsed times will also rise linearly by x10 times because it is equivalent to one unit on the logarithmic scale.

- At a specific number of consecutive transactions, the period of testing processes in different transaction types are almost the same, but one's  $validateAccess()$  is slightly greater than others. This is because invoking  $validateAccess()$  is a policy execution that leads to a smart contract execution behind the scenes, which is more complex than a normal extrinsic transaction.
- For application aspects, the average response time of 15 milliseconds is appropriate for the soft real-time IoT system. Besides, it can handle a vast number of transactions at a time, up to 10000, without any problems such as significant transaction failures or starvation. Therefore, the proposed design could meet the requirements of the IoT systems in terms of response time and accommodate more transactions compared to popular Blockchains like Bitcoin or Ethereum.

#### D. Security Analysis

The proposed design is trusted since it is inherently achieved by Blockchain compared to centralized systems. However, there is a trust-sharing model that is not mentioned before but exists implicitly in the proposed design. Device owners are considered the root of trust and can share it with other policy administrators through DID delegation. These administrators can manage ABAC policies of delegated devices or objects; in turn, they can specify who are trusted endorsers for ABAC policies. These trusted endorsers can endorse ABAC attributes of users or subjects to make them valid for access validation. The trust-sharing model makes access management more convenient but still maintains trust.

Additionally, the security of the proposed system is discussed on three typical security aspects of a software system: confidentiality, integrity, and availability (so-called CIA triad).

- **Confidentiality** is considered at IoT resources that should only be accessed by subject requests satisfying the requirements in the object's policies. For a malicious subject to access an IoT resource of an object, it has to modify its own ABAC attributes on blockchain to meet the object's policy. Nevertheless, such forged ABAC attributes have no meaning for access validation because they are not endorsed by one of the trusted endorsers specified in the policies. Furthermore, there are accident cases, for example, leakage of the blockchain account's private key. The previous trusted blockchain account and its DID become malicious. In such cases, endorsers can revoke their endorsements for that blockchain account. Similarly, device owners can also revoke delegations for policy administration in case administrators become malicious.
- **Integrity** is considered in on-chain data and policy execution. The data in the pallets' storages, such as ABAC attributes, attribute endorsement, ABAC policy attachment, etc., can only be modified by extrinsic signed by their owner's blockchain account. Regarding ABAC policies, once a smart contract is instantiated, the hash of both its source code and argument values passed into its constructor will be saved to the Pallet Contract's storage. This means that access validation

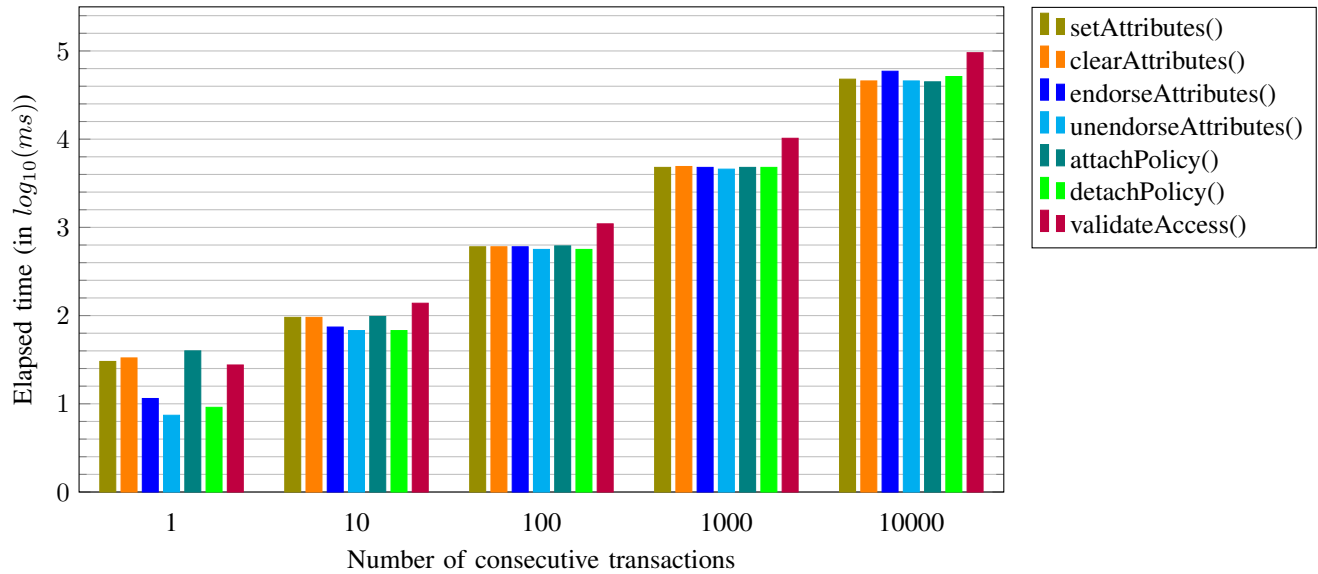


Fig. 3. Experimental results in terms of response time.

expressions of policy in the source code and trusted endorsers specified at the instantiating stage via the constructor are guaranteed to be consistent. Furthermore, policy execution can be distributedly conducted, and the result, which is access decisions, can be logged in the respective smart contract's storage. Generally, the integrity of policy execution is ensured by the smart contract. Moreover, in accident situations such as Blockchain account leakage, transactions originating from those leaked accounts are traceable because all transactions are kept in blocks.

- **Availability** is achieved by relying on a decentralized architecture with Blockchain technology. A decentralized system solves the single-point-of-failure problem in a centralized system; it can withstand a certain number of nodes failing simultaneously, and that number depends on the blockchain network topology and consensus algorithm. Each transaction has a certain fee in a blockchain system integrated with cryptocurrencies, so DoS or DDoS attacks by spamming transactions to disrupt the system are expensive for attackers.

As such, our proposed design achieves trust and security. However, these properties are also affected by the factors of a Blockchain system, such as network topology, consensus algorithm, and the number of honest nodes. Nonetheless, there is a horizontal scaling solution for the trust and security of a system by increasing the number of its Blockchain nodes. Meanwhile, consensus algorithm selection for a Blockchain is a trade-off between performance and security level, depending on assumptions of trust and security.

## V. CONCLUSION

This paper presents details of a Blockchain-based ABAC model that includes two main parts: attributes management and policy execution. Each decentralized identifier (DID) can be associated with attributes to verify access permission,

where attributes may need to be authenticated by trusted users (e.g., endorsers) via their DIDs. In our proposed model, the resource (e.g., IoT device or document) owner is considered the center, root-of-trust, who can delegate the authority to other administrators. Resource owners and administrators can also specify trusted endorsers for an access control policy for a particular object. Access control policies are codifiable by smart contracts, enhancing flexibility in access control management. Besides, policy validation is also executed on-chain, guaranteeing security in terms of the CIA triad. Therefore, our proposed design has demonstrated improved features compared to similar works based on four criteria, as shown in Table I. Furthermore, we also implemented the proposed model to investigate the performance regarding response time. The experimental results show that the proposed model could meet the soft real-time requirement for IoT systems.

In future work, intensive experiments be conducted to investigate other essential metrics, such as workload at the Blockchain node, storage cost, and transaction fee, before deploying it to practical applications.

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# DeLClustE: Protecting Users from Credit-Card Fraud Transaction via the Deep-Learning Cluster Ensemble

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**Abstract**—Fraud is the unlawful acquisition of valuable assets gained via intended misrepresentation. It is a crime committed by either an internal/external user, and associated with acts of theft, embezzlement, and larceny. The proliferation of credit cards to aid financial inclusiveness has its usefulness alongside it attracting malicious attacks for gains. Attempts to classify fraudulent credit card transactions have yielded formal taxonomies as these attacks seek to evade detection. We propose a deep learning ensemble via a profile hidden Markov model with a deep neural network, which is poised to effectively classify credit-card fraud with a high degree of accuracy, reduce errors, and timely fashion. The result shows the ensemble effectively classified benign transactions with a precision of 97 percent. Thus, we posit a new scheme that is more logical, intuitive, reusable, exhaustive, and robust in classifying such fraudulent transactions based on the attack source, cause(s), and attack time gap.

**Keywords**—Fraud transactions; fraud detection; deep learning ensemble; credit card fraud; cluster modeling; financial inclusion

## I. INTRODUCTION

The rise in the adoption of computing devices to aid effective data processing and resource sharing has continued to attract adversaries. This has necessitated the deployment of systems to avert such threats. The growth in these attacks has also resulted in higher costs associated with the safeguarding of valuable resources shared across networks [1]. Attackers have become more proficient at exploiting flaws with access to privileges, aimed at financial gains – even with advances made in the medium of data sharing [2]. This remarkable evidence advances a digital revolution such that day-to-day living is impacted therein with the proliferation of buying/selling via such mode, platform(s), and adoption of credit cards that have consequently, exposed many users to more clever and complicated methods to steal considerable money [3]–[5]. The growing complexity of ICT and the frequency of threats have also increased the data required to successfully detect them. There is also a rise in the adoption of multi-staged, subterfuge attacks targeted at various levels of security as provisioned in many organizations. Another barrier to detection is that adversaries often disguise the true forms and nature of their assault – and rarely, take up abrupt spurts of suspicious behavior that are easily recognized by simple intrusion detection schemes [6]–[9].

Previous studies have continued to acknowledge the rise in trend/alarming growth in credit card fraud, which has continued to lower user trust (irrespective of the rise in the adoption of credit cards) [10]. Studies also note that such fraudulent activities have caused greater losses to the financial services industry. This has thus, positioned as imperative – many researchers that adopted statistical models in detecting malicious credit card transactions [11]. Implementing a stochastic model has its bottleneck – as malicious transactions are aimed to evade detection, and their respective performance is often hindered by model over-fitting, parameter selection, etc [12].

The limited availability of data and ‘censored’ results from previous studies – have also led to difficulties to advance this field as datasets contain ambiguities, partial truth, and noise. These, have led to improper selection of features, data encoding, poor learning convergence, and incorrect results from over-parameterizing, overfitting, and overtraining. This increases false-positives and true-negatives error rates. We resolve this via a robust search that will effectively classify observations and yield the expected values [13]–[16].

The continued complexity in credit-card fraud detection has left us all in a frenzy with the continued quest to tweak methods to evade detection (for adversaries) as well as means to curb all attacks/threats (for security experts). This, in turn, has made and left such task and business, both a continuous and inconclusive feat [17]. In the quest therein for improved frameworks, some studies have shown that such tasks also, yield models whose performance is continually degraded at intervals due to improper selection of features within the used dataset for training and testing therein [18]–[20]. Even with the use and adoption of intelligent, stochastic, and dynamic classifiers, credit-card fraud persists as adversaries continue to evolve their techniques.

Thus, our study seeks to explore the use of feature selection [21]–[23] that is capable of addressing the issues of optimization with appropriate feature(s) selection, and adequately training the framework to avoid pitfalls from over-parameterization and overfitting of the model using deep learning. We propose a deep-learning cluster model to aid credit-card fraud detection. This will help to explore, exploit and use observed data as well as seek the underlying stochastic

feature of interest to yield a robust output and ensure qualitative knowledge.

## II. METHODS AND MATERIALS

### A. Credit-Card Fraud Detection: Review of Literature

The cost of financial crimes (globally) was estimated to be about \$ 42 billion in 2018. With this, is constantly on the rise – the financial services industry must employ systems that implement innovative fraud mitigation and prevention modes. Many methods for detecting abuse of a technical system [24], [25], are required. Fraud detection seeks to detect cases of fraud from logged data and user behavior [26]. Fraud *management thus* advances a step further to set up preventive measures. Oracle offers real-time detection and correlation capabilities of complex user behavior with use-case management – to result in its early detection and prevention via complex, multi-channel with reduced risk [27]. Fraudsters continue to seek effective means with improved complexity and circumvent border systems, which profile behavior at the point of access [28], and internal hacks that seek to steal client data and defraud valuable clients. Fraud monitoring should offer combined risk monitoring and detection analytics [29]. The system must intelligently correlate event alerts from various channels to offer optimal solutions via early fraud detection of multi-channel, and complex fraud, enhance client protection, and minimize risks [30]–[32].

Fraud is an unlawful act of possessing a valuable asset via intended misrepresentation. It is also associated with criminal cases such as embezzlement, theft, and larceny. It posits that an unknowing victim depends largely on a criminal's bogus claims for gains. It is committed by either an internal/external user. Today, credit cards have not only enhanced their usefulness in financial inclusion, but they have also attracted malicious attacks for gains [33], [34]. With credit cards easily targeted – crimes perpetrated with them are only discovered days afterward. Successful credit-card fraud techniques include (not limited to): (a) card-cloning and acquiring user's data, and (b) vendors' over-charge without cardholder's awareness [35], [36]. When banks lose money to card fraud, a cardholder is partly or wholly made to pay for such loss via many means that include higher interest rates, and reduced benefits. Thus, it is in both cardholders' and banks' interest to reduce fraudulent acts on a card [17], [37], [38].

In [39], the RBF model used 7 features and the trained RBF recognizes a packet as an attack, it is sent to a filter alarm. Else, it is classified as a normal packet. Profiles were constructed via stream sampling. Results showed that we can: (a) accurately profile packets, and (b) identify anomalies in low false-positive and false-negative. As routers exchange data, they capture key-feats in each packet – allowing them to profile the packets, and increase their rate and confidence in detection. Also [40] posited a distributed change aggregation trees (CATs) detection scheme. It lets the router detect minor shocks in data – which is then investigated and events correlated at the different sessions. The router then proactively terminates the session (if it detects an attack is imminent). In [41], the supervised memetic rule-based model used 7-feats to monitor, inspect and detect packet rates. However, [1] sought to extend the work [41] via deep learning, an unsupervised modular

network that captures a packet's key feats used as a profile to help analyze and classify packet patterns in a traffic session as either the normal or a DDoS attack.

### B. Data Gathering / Sample Population

Datasets are transactions generated through the Central Bank of Nigeria e-channel having 41,667 records with 15 feats as in Table I, which shows a description of the collected dataset including cardholder and transaction data. We split the dataset into training (70%) and Testing (30%) as in [18], [42], [43].

TABLE I. DATASET DESCRIPTION, DATA TYPES, AND FORMAT

Features	Description of Features	Data Type	Format
User Name	Account Holder's Name	Object	abcd
Bank Name	Bank of Account Holder	Object	abcd
NUBAN Account	Nigerian Universal Bank Number e-channel Trans.	Int	1234
Billing Address	Account holder's local bank address of withdrawal, hotel	Object	abcd
Transaction Amount	Amount of transactions adjusted in the bank's currency	Float	12.34
Transaction Type	Local, International, and/or e-Commerce as type	Object	Abcd
Date/Time	Transaction Date and Time	Float	M:D:Y
Transaction Channel	Channel (payment terminal and/or merchant application)	Object	Abcd
Merchant	Hotels, Restaurants, etc	Object	Abcd
Transaction Gap Time	Duration from last transaction to the current transaction	Float	M:D:Y
Daily Transaction	Daily average transactions performed by a cardholder	Int	1234
Daily Tran. Limit	The daily limit of the amount that cardholders can do daily	Float	12.34
Weekly Transaction	Weekly average transactions performed by the cardholder	Int	1234
Monthly Transaction	Monthly average transactions by the cardholder	Int	1234
Freq. Trans. Types	Average frequency of transactions by cardholder	Int.	1234

### C. Parameter / Features Tuning

A critical issue in machine learning is the formatting of data, the selections of feats/parameters of interest to understudy, properly encode the chosen dataset, and tuning the parameters to avoid model overfitting and overtraining to mention a few. Datasets are often riddled with inconsistencies, ambiguities, partial truths, and noise – such that selecting optimal parameters for a model, and encoding it by mapping to the required form a model understands – is a herculean feat and task. To transform our parameters and map them to the dataset, we use the Pandas data type Library as in the listing 1 algorithm [44]–[46].

**Algorithm 1: Data Description for DeLClustE Algorithm**

**Input:** Features are Selected  
**Output:** Features are Converted to Appropriate Data Type  
 Initialize DeLClustE with Select Parameters  
**For Each Selected Parameter do**  
     **if** Feature Selected is Non-Numerical **then**  
         Category for the Data Type is Generated  
     **End if**  
**End For**

**D. Experimental DeLClustE Ensemble**

Fig. 1 details our hybrid ensemble leveraging the work of [47]. The ensemble leans on two-components namely: the profile Hidden Markov model and deep-learning neural network. The selected training data forms a cluster of parameters that are passed via a PHMM represented as thus: (a) circles are delete-states for unclassified rules, (b) rectangles as accurately matched states that classify rules into class types, and (c) diamonds are insert-states to update the rules knowledgebase. As PHMM moves between the states, its insert and match states observe the emission state with probabilities corresponding to B. Thus, computes the probabilities via a forward algorithm, and computes the frequency of the number of rules each state emits [48]. Lastly, the delete state lets a PHMM pass through the gaps in the model to reach other emission states. The gaps in the model prevent it from over-fitting and over-parameterization [47], [49], [50].

DNN in its bid to learn, and adapt useful selected parameters via a carefully constructed deep, multilayer net that aims to improve forecast precision. Its hidden layer often transforms [51] data non-linearly and passes it on from a previous layer to its next [52]. With learning handed over to the DNN, [53] stressed that the DNN trains itself using 2-stages namely pre-training, and fine-tuning. It learns and resolves each task posed to it thus: (a) first, it groups all training data into cliques, to find the center point of each clique, (b) it then trains each clique of the DNN [54], learning the various features of each data subset, (c) third, it then applies a test data to previous clique centers to detect the outlier(s) in the pre-trained DNNs, and (d) lastly, it aggregates the output of each DNN as the final result of outliers [40]. A detailed description of the benchmark DNN is described in [55]. Also, the experimental ensemble yields a 3-phase model as in Fig. 1 [56]–[59].

The stages are as thus [14], [52], [53], [60]–[62]:

- Step 1:** Separates the data into clusters (train and test). DNN computes cluster centers and uses them as initialization centers to yield test datasets. The data attributes are structured as data points and aligned to meet the classes [63]. The model revises the cluster counts and sigma to improve its performance. The shortest distance between a data point and each cluster center is measured, and a data point's proximity to a cluster classifies it. DNNs use the training sets created by clusters as input. The number of DNNs in training equals the number of cliques. Each DNN consists of 5 layers (input, 2-hidden, softmax, and output). Each training subset is used to train the hidden layer, and the top layer is a 5D output vector. Each training created by the *k*th-clique center is sent back to the *k*th-DNN.

And each sub-DNN is trained, and labelled from 1 to *k* [64], [65].

- Step 2:** Generates a *k*-dataset of data via previous clique center obtained from clusters in Step 1. Test sub-datasets are represented by the letters Test-1 via Test-*k* [56].
- Step 3:** The test dataset is then, fed to the *k*-sub-DNNs that are trained as in step 1. Each DNN output is combined as the final result to analyze the positive detection [62].

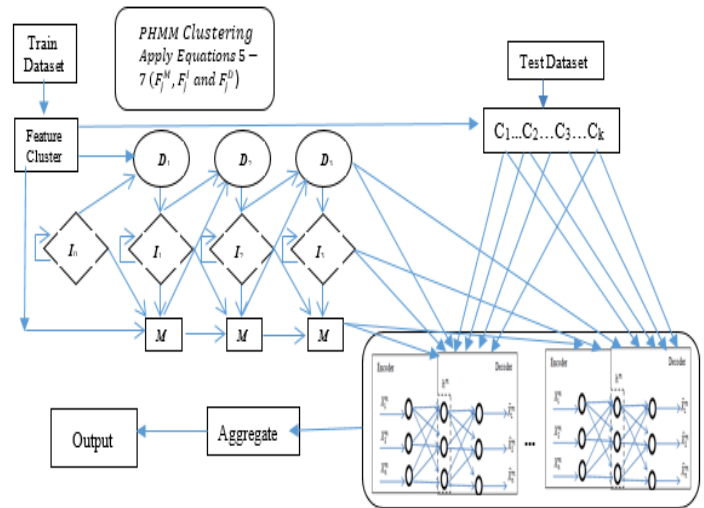


Fig. 1. DeLClustE: deep learning cluster hidden markov model trained deep learning neural network) ensemble.

**Algorithm 2: The DeLClustE Algorithm**

**Input:** Selected Features, **Output:** Converted Feature Data Type  
 Initialize DeLClustE with PHMM; states;  
 Discrete HMM with Random multinomial draw for each step  
 K-means cluster fits on *k*-sub DNNs  
**For Each Selected Parameter do**  
     Sample states using Forward Filtering  
     Compute Backward Sampling algorithm on states  
     Sample each transition parameters  
      $T_i = Mult(n_{ij} \setminus T_i) Dir(T_i \setminus c_k)$   
**End For Each**

**E. Hyper-Parameter and Ensemble Optimization**

A critical issue is that of tuning the parameters with values beyond the ensemble. They ripple across the model as hidden elements (hyper-parameters) [66]–[68] to impact its behavior – via targeted learning to optimize. Thus, we adopt the modular neural network [69]. As the model learns these feats directly via training data, it resolves the issues of over-parameterization, poor generalization, and model over-fitting [1], [70]–[72].

Handling these hyper-parameters is detailed in [57] thus:

- Learning Rate hyper-feat regulates what weight and how much of it on the network must be modified for gradient loss. A smaller value yields a slower slope. This feat defines how easily a network abandons learn beliefs, in favor of new ones. A small learning rate value implies that a network can quickly distinguish



between important feats and unimportant ones. A faster learning rate allows the net to adapt to change, more easily. To minimize over-fit and overtraining, the learning rate is suitably adjusted.

- 2) Batch Size defines the size of training used in iteration. There are three-modes namely: (a) batch is when its iteration and epoch values are equal, (b) Mini-batch denotes when the iteration size is greater than its epoch size, and (c) stochastic is when the gradient and network feats, which are updated after each iteration.

An epoch is the number of times when all training values were used to update a weight. A network can be trained in a single step. Training a network in a single pass, on a training dataset – implies that an epoch has been reached or exhausted. Training can span multiple iterations and/or eras. Thus, in batch training – a learning model process all samples simultaneously in one epoch, and update all the weights; While sequential training – adjusts all the weights after a training session.

### III. RESULTS AND FINDINGS DISCUSSION

#### A. Result Findings

We modeled the network's input layer with one neuron for each parameter to yield a total of 8 neurons; And used two neurons (to represent each possible outcome) for our output layer. The Deep learning parameters include the learning rate, our activation function, the hidden layer structure, and the number of epochs. We used the Rectified Linear Unit Activation Function with 500 epochs (optimal values reached 100, 300, and 500 epochs) – accounting for train convergence time and accuracy). Also, we note that there are no best practices for determining the number of neurons cum hidden layers – and additional hidden layers will give the ensemble capability to undertake more sophisticated functions on the data.

TABLE II. FIRST HIDDEN LAYER CONFIGURATION ANALYSIS

Hidden Layers	Precision	Recall	F1	Iteration	Train Loss	Epoch
1	0.94	0.94	0.92	18	1.400	500
2	0.86	0.53	0.63	4	2.230	500
3	0.90	0.84	0.86	16	2.071	500
4	0.92	0.93	0.92	18	1.140	500
5	0.92	0.92	0.90	16	1.779	500
6	0.88	0.91	0.89	7	2.134	500
7	0.91	0.92	0.89	8	2.320	500
8	0.87	0.87	0.87	13	2.006	500
9	0.92	0.92	0.90	8	1.970	500
10	0.92	0.92	0.90	5	1.730	500
11	0.85	0.85	0.85	10	1.540	500
12	0.90	0.84	0.86	15	2.320	500
13	0.91	0.92	0.90	8	1.440	500
14	0.92	0.93	0.90	14	2.160	500
15	0.91	0.91	0.91	5	1.772	500

We choose the number of neurons vis-à-vis the hidden layers via a trial-and-error mode that analyzes the results to achieve its best fit with the least amount of training error. The best number of layers to be used was discovered by first conducting experiments on a single layer with 1-to-15 neurons to determine which produces the highest f-score with the least (constant) amount of training loss time (see Table II)

As in Table III, the addition of a second hidden layer with the greatest number of neurons to generate the highest f-score resulted in the overall best feasible hidden layer arrangement.

TABLE III. SECOND HIDDEN LAYER CONFIGURATION ANALYSIS

Hidden Layers	Precision	Recall	F1	Iteration	Train Loss	Epoch
9, 1	0.91	0.92	0.89	10	1.996	500
9, 2	0.84	0.92	0.88	24	0.281	500
9, 3	0.93	0.93	0.92	11	1.884	500
9, 4	0.92	0.92	0.89	12	1.590	500
9, 5	0.90	0.92	0.90	12	1.731	500
9, 6	0.95	0.94	0.93	14	0.390	500
9, 7	0.93	0.93	0.91	12	1.130	500
9, 8	0.91	0.92	0.91	20	1.929	500
9, 9	0.92	0.93	0.90	13	2.237	500
9, 10	0.94	0.94	0.92	7	1.765	500
9, 11	0.85	0.52	0.62	7	2.010	500
9, 12	0.94	0.94	0.94	6	1.620	500
9, 13	0.93	0.94	0.92	7	1.760	500
9, 14	0.86	0.74	0.79	13	2.059	500
9, 15	0.92	0.92	0.89	8	2.421	500

#### B. Discussion of Findings

To evaluate how well the ensemble performed against known benchmarks, a comparative result(s) is seen in Table IV – with detection accuracies of 0.89 for PHMM, 0.78 for GANN, 0.91 for MNN, 0.96 for DNN, and 0.92 PHMM-DNN respectively. We also have that Fig. 2 shows the mean-time convergence for the various ensembles. We created a total of 22 rules. Table IV shows that rules can effectively identify/detect more than 60-to-82 percent of the cases in the dataset.

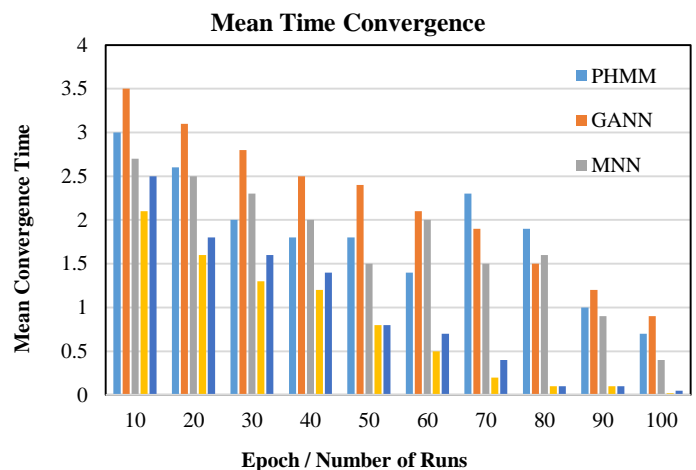


Fig. 2. Mean convergence time for experimental ensemble.

TABLE IV. CONFIGURATION ANALYSIS

Ensemble	Precision	Redundancy	Recall	F1	Average Support	Cost Estimate
DNN	0.92	0.52	0.94	0.92	12.449	140
PHMM	0.89	0.71	0.83	0.83	11.410	130
MNN	0.91	0.56	0.92	0.89	11.411	140
GANN	0.78	0.79	0.74	0.92	11.408	120
DeLClustE	0.96	0.52	1.00	0.97	12.500	140

That is, the test phase of the model with 12,500 records reveals that we accurately identified the majority of the models, 11,411 benign cases as agreed by [73], [74]. The result showed 11,410 benign threats from the test dataset are correctly grouped (i.e. true-positives). The result showed that 31-detected cases were erroneously labeled and agreed with [75]–[77] as false-positive; Also, 776 wrongly detected threats (i.e. false-negative) and 283-correctly recognized malicious instances labeled as true-negative. Thus, for true-positive cases, the model predicted positive (correctly) and also predicted negative (correctly) for true-negative cases. Conversely, sensitivity and specificity rates were computed with standardized tests for our test data [78], [79]. These proved, to be more efficient.

#### IV. CONCLUSION

We created a total of 22 rules, with classification accuracy range and fitness [0.6, 0.82] for the top rules (i.e. 60% of generated rules can sufficiently categorize the dataset). Thus, the ensemble effectively/correctly identifies fraudulent transactions and simultaneously improves the generality of rules to allow new datasets and their associated produced rules, to be added to the knowledgebase. Detection often filters all requests on a network, analyses all to separate compromised clients from those that are uncompromised, and also, provides security measures as appropriate actions. The performance of these ensembles may be hampered by error rates for erroneously classified and misidentified data points generated by the scheme and/or model.

Through trade-offs between the frequency of false positives and false negatives, an ideal approach correctly classifies all requests with nearly zero error rates of false positives or false negatives. With the increasing trend of intrusion threats and activities, it is critical to develop new methods and updated security monitoring systems that provide a high chance of detection and timely warning of intruder attacks. The goal of this research is to adapt a hybrid ensemble to monitor cardholder transaction flow patterns on a network, predict possible fraudster and adversary behaviors, and boost the effectiveness of banking platform (e-channel) network security when and if the level of threat changes.

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# Proof of Spacetime as a Defensive Technique Against Model Extraction Attacks

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**Abstract**—When providing a service that utilizes a machine learning model, the countermeasures against cyber-attacks are required. The model extraction attack is one of the attacks, in which an attacker attempts to replicate the model by obtaining a large number of input-output pairs. While a defense using Proof of Work has already been proposed, an attacker can still conduct model extraction attacks by increasing their computational power. Moreover, this approach leads to unnecessary energy consumption and might not be environmentally friendly. In this paper, the defense method using Proof of Spacetime instead of Proof of Work is proposed to reduce the energy consumption. The Proof of Spacetime is a method to impose spatial and temporal costs on the users of the service. While the Proof of Work makes a user to calculate until permission is granted, the Proof of Spacetime makes a user to keep a result of calculation, so the energy consumption is reduced. Through computer simulations, it was found that systems with Proof of Spacetime, compared to those with Proof of Work, impose 0.79 times the power consumption and 1.07 times the temporal cost on the attackers, while 0.73 times and 0.64 times on the non-attackers. Therefore, the system with Proof of Spacetime can prevent model extraction attacks with lower energy consumption.

**Keywords**—Proof of spacetime; model extraction attacks; machine learning; security

## I. INTRODUCTION

In recent years, services known as Machine Learning as a Service (MLaaS), which utilize platforms such as Microsoft Azure and Amazon Machine Learning, have become increasingly popular. MLaaS enables users to pass input data to models stored on servers and receive corresponding output. In order for businesses to profit from MLaaS, they must allocate considerable resources towards training models on servers. However, there is a risk of model theft through attacks that target server-based models. These types of attacks, such as model extraction attacks that may not require training data [1], are increasing in frequency and severity.

Model extraction attacks involve repeatedly inputting data to a pre-trained machine learning model, obtaining many input-output pairs, and then training a local model based on that information in an attempt to replicate the original model. If a model is stolen, the MLaaS that was targeted could suffer a decline in revenue, and depending on the type of service, it may even be used as a foothold for other attacks.

There are various types of model extraction attacks, including Copycat CNN [2] and Knockoff Nets [3]. Copycat CNN involves creating a mimicked dataset by linking input data and their corresponding output from the targeted model,

and then using it to train a local model to steal the model. On the other hand, Knockoff Nets use reinforcement learning to efficiently select input images. There are also methods that steal the model by aligning the gradients of the targeted model and the local model [4].

As defense mechanisms against model extraction attacks, there are active defense, passive defense, reactive defense, and proactive defense.

Active defense is a method of hindering the training of the attacker's local model by altering the output of the targeted model. For example, it is possible to distort the probability of the output without changing the most probable class in the last activation layer of the targeted model [5] or intentionally poisoning the output to prevent the attacker from obtaining accurate output and obstructing the training of the local model [6]. However, these methods also affect the output accuracy of the model, which is a problem that also affects the output obtained by non-attackers.

Passive defense is a defense mechanism that protects the targeted model by truncating its output or detecting attacks. For example, there are methods that analyze the distribution of data that users have previously queried to detect attackers. However, existing methods are limited to research results based on assumptions such as the small distance between natural data and synthetic data [7] or the distribution of the attacker's dataset showing significant deviations as anomalies [8].

Reactive defense methods are techniques that aim to prove that the attacker's local model has stolen the victim model, rather than detecting the attack itself. There are methods that use digital watermarks [9] or verify whether the model suspected of theft has a certain level of common knowledge with the victim model [10]. However, these methods cannot prevent the theft of the model, and there is no guarantee that the stolen model will not be used for other attacks.

Proactive defense is a technique that increases the attacker's burden by imposing some form of cost on the users who query the model. For example, there are techniques that use Proof of Work [11,12], which requires computation, to demand costs in terms of electricity or time from attackers. This technique makes it difficult for attackers to acquire many input-output relationships at a low cost and is a method that does not affect output accuracy for non-attackers. Furthermore, since this defense technique does not require any changes to the learning model itself, there is no need to train the model with specialized data or retrain a pre-trained model, making the cost of introducing the defense technique relatively low.

However, the calculation required in the Proof of Work consumes a significant amount of electricity, which is not sustainable from the perspective of the United Nations' Sustainable Development Goals (SDGs). As a solution, applying the Proof of Spacetime into the defense method against model extraction attacks is proposed in this paper. The Proof of Spacetime aims to limit access by attackers without repeating high load calculation and can reduce the unnecessary consumption of electricity.

## II. LITERATURE REVIEW

Firstly, we describe the method of the Proof of Work and the Proof of Spacetime.

### A. Proof of Work

Proof of Work is mainly used in cryptocurrencies such as Bitcoin [13], where a reward can be received in exchange for solving a given problem through computation. Generally, a hashcash [14] is used in Proof of Work, which imposes a calculation to find a string of characters that has a certain number of zeros in the upper bits when the hash is converted. The difficulty of the calculation can be determined based on the number of zeros required.

By using Proof of Work's hashcash, it is possible to inhibit an attacker from obtaining the input-output relationship of a model by making MLaaS users perform calculations to obtain the model's output. However, since non-attackers also use MLaaS, it is necessary to increase the difficulty of hashcash, i.e., the number of consecutive zeros, as the suspicion of the attacker increases.

As a result, the attacker needs to perform many computations to obtain the output of the model, which imposes time and power consumption constraints. Additionally, because the computation occupies the CPU or GPU, it prevents the attacker from evading time constraints by using multiple accounts. However, Proof of Work calculations force unnecessary computations and power consumption, which leads to the consumption of fossil fuels, making it environmentally unfavorable.

### B. Differential Privacy

In a defense method using Proof of Work, it is necessary to distinguish between attackers and non-attackers, which can be achieved using differential privacy [15] as an indicator. Differential privacy is a concept that originally aims to protect personal information on a database and make statistical analysis possible. Differential privacy considers the privacy is secured if it is impossible to distinguish between the results obtained using a dataset that contains personal data and the results obtained using a dataset that excludes the personal data.

PATE [16] is a method for measuring differential privacy. PATE trains multiple models including personal data and builds a model that adopts the majority vote of their outputs. Then, the output of this model with noise added is used to train another model without using personal data. Through this process, the final model is trained without directly using personal data and with noise added, leading to the protection of differential privacy.

In our method, the differential privacy is used to judge the user whether or not an attacker and to determine how much cost to impose the user.

### C. Merkle Tree

Merkle tree [17] is a technique that uses hash functions to summarize and verify data. Multiple data are hashed and then the hash values are added together in pairs, which are then hashed again. This process is repeated until a tree is created with hash values on each node. Fig. 1 shows an example of a Merkle tree generated from four data sets. The root node,  $h_{ABCD}$ , is called the Merkle root. The hash values  $h_A$  and  $h_C$  that are needed to calculate the Merkle root from data  $B$  are called the Merkle path of data  $B$ .

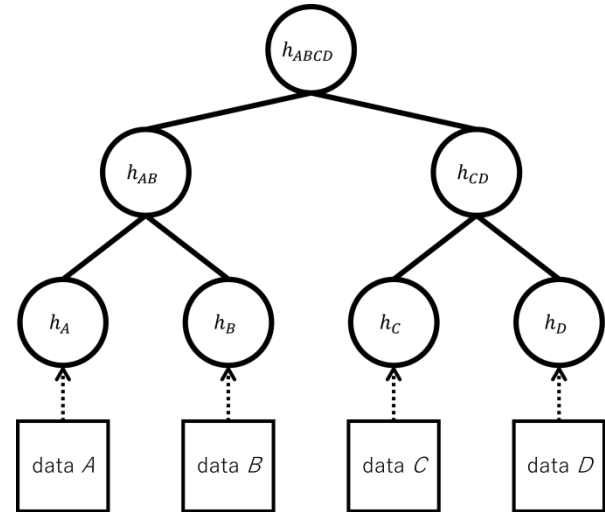


Fig. 1. Example of Merkle tree.

### D. Proof of Spacetime

Proof of Spacetime [18] is a consensus algorithm used in virtual currencies such as Spacemesh. It is a method that occupies a certain amount of memory space for a certain amount of time. Specifically, it generates initial data in advance using a hash cache and considers the memory space and time occupied by that initial data as the cost.

Proof of Spacetime is a consensus algorithm used in virtual currencies such as Spacemesh. It is a method that occupies a certain amount of memory space for a certain period of time. It generates initial data using a hash cache and considers the memory space and time occupied by the initial data as costs. The Proof of Spacetime flow can be divided into initialization, proof, and verification stages. In the initialization stage, users save all hash-transformed data using a hash cache. In the proof stage, users create proof data using a Merkle tree. In the verification stage, the server verifies whether the proof data created in the proof stage is correct. The power consumed to build a Merkle tree is smaller than the power consumed to generate data in the initialization stage, because the hash transformation used to construct the Merkle tree is a repeated hash function that is faster than the hash function used in the initialization stage. The user-side cost in Proof of Spacetime can be represented as a monetary cost using (1) and (2),

$$C_{init} = p \times n \times C_p, \quad (1)$$



$$C_{proof} = s \times t \times C_{st}, \quad (2)$$

where  $C_{init}$  and  $C_{proof}$  are the cost in the initial and the proof stage, respectively. The cost in initial stage can be said also the cost of hash cash. Note that  $p$  is the amount of power consumed for one hash transformation,  $n$  is the number of times the hash is performed,  $C_p$  is the cost per power consumption,  $s$  is the size of occupied storage,  $t$  is the occupied time, and  $C_{st}$  is the cost per second for occupying 1 MB. A general flow of Proof of Spacetime is shown in Algorithm I.

The Proof of Work requires the user to perform a high-load calculation and continues until it is solved, whereas the Proof of Spacetime requires a relatively simple calculation and keeping the "evidence" of the calculation. In other words, the Proof of Spacetime does not require the user to keep moving at high power all the time, and power consumption can be suppressed.

#### Algorithm I:

1. function `init_stage(id)`:
2.      $\sigma = \text{hashcash}(id)$
3.     for  $i = 0 \dots t$ :
4.          $G[i] = \text{hash\_init}(i, \sigma)$
5.         if  $G[i]$  has  $\log_2 t$  or more leading zeros:
6.             return True
7.     return False
8. function `proof_stage()`:
9.      $\text{tree} = \text{Merkle}(G)$
10.     $\text{path\_list} = \text{all of the Merkle paths from all of leaves}$
11.    transmit  $G$  and  $\text{path\_list}$  to the server
12. function `verification_stage()`:
13.    for  $i = 0 \dots t$ :
14.       if  $G[i]$  has  $\log_2 t$  or more leading zeros:
15.           reconstruct tree from  $\text{path\_list}$
16.           return if tree is equivalent to  $\text{Merkle}(G)$
17.    return False

### III. METHODS

When using Proof of Work as a defense mechanism against model extraction attacks, excessive energy consumption and its negative impact on the environment have already been noted. Therefore, this study proposes a method using Proof of Spacetime. Specifically, the following steps STEP 1 to STEP 5 are taken:

STEP 1: Measure the differential privacy of the user that is

considered a non-attacker, denoted as  $D_n$ .

STEP 2: Measure the differential privacy of the current user,

denoted as  $D_c$ .

STEP 3: Calculate the difference  $D$  between  $D_n$  and  $D_c$ .

STEP 4: Calculate the temporal and spatial cost based on  $D$ .

STEP 5: Impose the temporal cost and spatial cost on the

current user using Proof of Spacetime.

The temporal cost reduces the efficiency of attackers obtaining input/output data, and the spatial cost prevents attackers from obtaining input/output data by parallel processing, i.e., using multiple accounts. However, there is a possibility that even non-attacker users may use the service multiple times, so it is desirable to minimize the initial hashcash as much as possible, which will also reduce unnecessary energy consumption. Therefore, the spatial cost for storage is fixed.

Compared to using the defense method with Proof of Work, using Proof of Spacetime provides the following four benefits:

- Power consumption can be reduced.
- Time costs imposed on users can be adjusted with little
- Change in computational complexity.
- Fine-tuning of costs is also possible.
- Costs can be demanded regardless of differences in machine resources.

The first benefit comes from the fact that Proof of Spacetime can reduce power consumption by using proof stages that require less power consumption than repeating hash calculations. This is because, as mentioned earlier, the hash conversion used for constructing a Merkle tree in the proof stage is a repetition of a high-speed hash function. Similarly, the second benefit is due to the small computational complexity of the proof stage, making it possible to adjust time costs without worrying too much about computational complexity.

The third benefit is due to the difficulty of adjusting difficulty levels when increasing the number of zeros in a hash cache from  $n$  to  $n + 1$ , as increasing the number of zeros results in an average computational complexity increase of  $2^n$ . With Proof of Spacetime, it is easy to simply change the occupied time.

The fourth benefit is that while costs that depend on computational complexity such as hash caches can be relatively reduced by increasing the performance of the attacker's machine, the time cost of Proof of Spacetime is not affected by the performance of the machine, and the space cost can be easily increased accordingly.

#### IV. EXPERIMENTS

Comparing the power consumption between Proof of Work and Proof of Spacetime:

##### A. Experimental Procedure

We prepared a target model for the attack: a ResNet34 for classifying cifar10 data (95.60% accuracy). Both of attackers and non-attackers randomly selected data from dataset not used for training the model to query. The number of queries is 5000 for each experiment. For the classification server, we implemented a defense method using Proof of Work and a defense method using Proof of Spacetime. We conducted the following measurements for a total of four servers:

- Power consumption of non-attackers.
- Power consumption of attackers using Knockoff Nets.
- Power consumption of attackers using Copycat CNN.

Power consumption was measured by measuring the overall power consumption of a computer shown in Table I with the minimum required processes running for program execution. In addition, the average power consumption during normal times when the program was not running was also measured.

TABLE I. COMPUTER USED FOR EXPERIMENTS

CPU	Core i5-9400F BOX
Memory	64GB
OS	Ubuntu Desktop 22.04

##### B. Results

The experimental results are shown in Table II. Fig. 2 to Fig. 4 illustrate the power consumption during program execution, where the vertical line shows the elapsed time from the query threw and the horizontal one shows the cumulative power consumption. Note that the power consumption while the computer is in idled for 30 minutes was  $3.0 \times 10^{-2}$  kWh and an average wattage is 60W.

TABLE II. RESULT FOR PROOF OF WORK

Client	Defence Method	Erapsed Time [Sec]	Power consumption [kWh]	Average wattage [W]
Non Attacker	PoW	48047	2.40	180
Knockoff	PoW	299563	9.36	112
Copycat	PoW	374146	11.52	110
Non Attacker	PoST	30685	1.75	205
Knockoff	PoST	360930	8.44	84
Copycat	PoST	358576	8.13	82

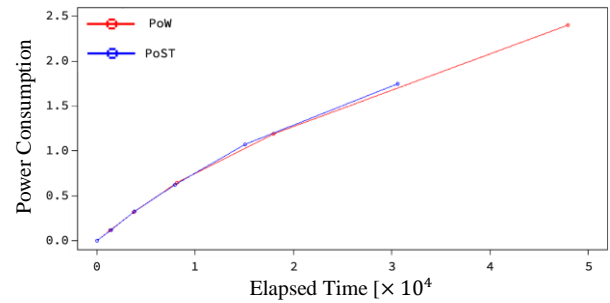


Fig. 2. Power consumption for a non-attacker.

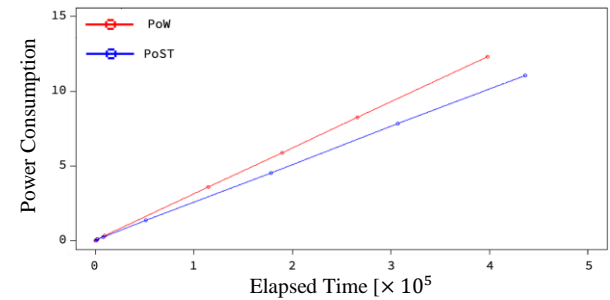


Fig. 3. Power consumption for an attacker with knockoff nets.

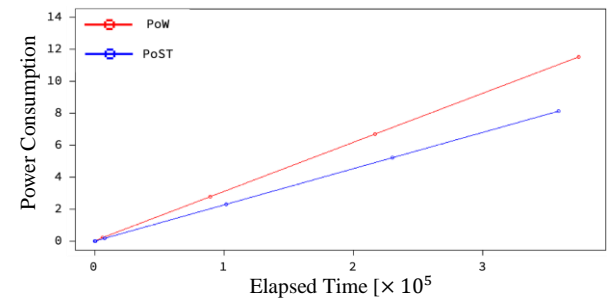


Fig. 4. Power consumption for an attacker with copycat.

Fig. 5 to Fig. 7 show the monetary cost for each attack. Note that the unit prices in (1) and (2) were set to  $C_{st} = 2.50 \times 10^{-10}$  and  $C_p = 31$  [19-21], respectively. The vertical line shows the elapsed time from the query threw and the horizontal one shows the monetary cost.

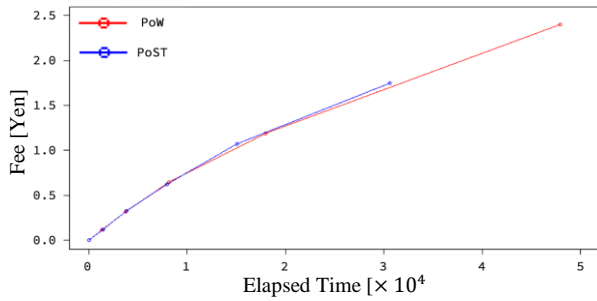


Fig. 5. Monetary cost based on the online storage services for a non-attacker.

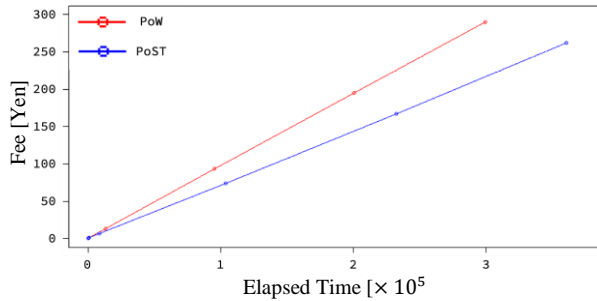


Fig. 6. Monetary cost based on the online storage services for an attacker with knockoff nets.

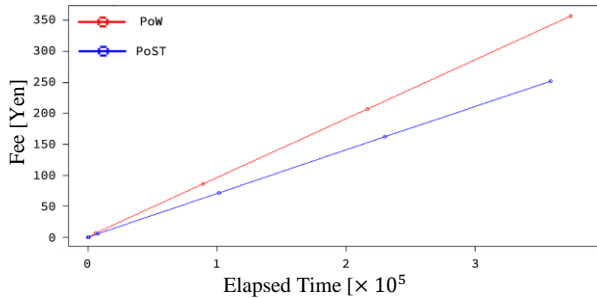


Fig. 7. Monetary cost based on the online storage services for an attacker with copycat.

## V. CONSIDERATION OF RESULTS

Now, we consider the results obtained from the experiment from the viewpoint of temporal cost and power consumption.

### A. Temporal Cost

According to Table I, the average time required per query for the defense mechanism using Proof of Work was 9.61 seconds for non-attackers and 67.4 seconds for attackers. On the other hand, when using Proof of Spacetime, the times were 6.14 seconds for non-attackers and 72.0 seconds for attackers. Therefore, the defense mechanism using Proof of Spacetime requires 0.64 times the temporal cost for non-attackers while

1.07 times for attackers, indicating its high performance as a defense mechanism.

### B. Power Consumption

For non-attackers, it can be seen that Proof of Spacetime reduces the total power consumption by 0.73 times compared to Proof of Work, but the average power required is 1.14 times higher. This is because Proof of Spacetime requires more computation in the initialization phase, which occupies a larger portion of the non-attacker's time cost.

For attackers, it can be seen that Proof of Spacetime reduces the total power consumption by 0.79 times compared to Proof of Work, and the average wattage required is also reduced by 0.75 times.

### C. Comprehensive Perspective

Comparing the defense mechanisms using Proof of Work and Proof of Spacetime, it was found that the latter has the following characteristics:

- Higher average power consumption for non-attackers
- Lower total power consumption for non-attackers
- Lower time cost for non-attackers
- Lower average power consumption for attackers
- Lower total power consumption for attackers
- Higher time cost for attackers

Since the goal of this study was to reduce unnecessary power consumption while preventing attacks, these results indicate that the goal was successfully achieved.

In addition, since the graphs of the monetary cost in Fig. 5 to Fig. 7 have a similar shape to the power consumption graphs in Fig. 2 to Fig.4, respectively. That means that it can be seen that storage costs are negligible compared to power costs. In other words, in terms of monetary cost, there is a trade-off between time cost and space cost in Proof of Spacetime. While storage was assumed to be the target of space cost in this study, cost-effectiveness can be improved by storing data in main memory.

When choosing between Proof of Spacetime and Proof of Work as defense mechanisms, the following points should be considered. Specifically, Proof of Work should be used to impose costs on attackers when the suspicion of an attack is low due to differential privacy. Proof of Spacetime should be used when the suspicion of an attack is high, to reduce power consumption while imposing time and space costs. By doing so, the costs imposed on non-attackers can be kept small, while the costs imposed on attackers can be increased.

## VI. CONCLUSION

This paper proposed the use of Proof of Spacetime as a defense mechanism against model extraction attacks. The existing defense method, Proof of Work, is effective in preventing attackers from obtaining the input-output relationship of the model for model extraction attacks. However, it imposes unnecessary power consumption, which is not environmentally preferable. With our method, the user has

to calculate a relatively simple calculation and keeps the "evidence" of the calculation, so the total power consumption decrease compared to Proof of Work. The cost to impose to the user is determined according to the differential privacy.

The only drawback of Proof of Spacetime is the large average wattage for the non-attackers. As the future work, it is necessary to consider efficient ways to use Proof of Work and Proof of Spacetime for attackers and non-attackers separately.

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# Deep Learning-based Intrusion Detection: A Novel Approach for Identifying Brute-Force Attacks on FTP and SSH Protocol

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**Abstract**—As networks continue to expand rapidly, the number and diversity of cyberattacks are also increasing, posing a significant challenge for organizations worldwide. Consequently, brute-force attacks targeting FTP and SSH protocols have become more prevalent. IDSes offer an essential tool to detect these attacks, providing traffic analysis and system monitoring. Traditional IDSes employ signatures and anomalies to monitor information flow for malicious activity and policy violations; however, they often struggle to effectively identify unknown or novel patterns. In response, we propose a novel intelligent approach based on deep learning to detect brute-force attacks on FTP and SSH protocols. We conducted an extensive literature review and developed a metric to compare our work with existing literature. Our findings indicate that our proposed approach achieves an accuracy of 99.9%, outperforming other comparable solutions in detecting brute-force attacks.

**Keywords**—Artificial neural networks; machine learning; deep learning; intrusion detection system; detecting brute force attacks on SSH and FTP protocols

## I. INTRODUCTION

Over the past decade, network security has emerged as a major research area due to the growing interest and advancements in internet and communication technologies. The security of networks and their connected assets in cyberspace is primarily protected by various technologies, such as firewalls, antivirus software, and Intrusion detection systems (IDSes) [1]. However, as attacks become more sophisticated, non-traditional techniques are required to detect them. Consequently, existing IDSes have proven to be ineffective at detecting a wide range of threats, including zero-day attacks, and at reducing false alarm rates (FARs) [2].

Researchers have investigated the potential application of machine learning (ML), including deep learning, to aid in detecting these attacks. ML aims to extract valuable information from large volumes of data [3] and serves as a powerful approach for gathering useful data from network traffic and predicting normal and abnormal events based on learned patterns. Machine learning models rely heavily on feature engineering to learn essential information from network traffic [4]. Due to their structure, deep learning models do not require feature engineering and are capable of automatically learning complex features from raw data [5].

Although deep learning models are still in their early stages, there is considerable potential for advancing this technology. Recently, researchers have begun proposing deep

learning models to improve the effectiveness of attack identification. Among the most well-known attacks on networks are brute-force attacks on Secure Shell (SSH) protocol and File Transfer Protocol (FTP). The SSH protocol is used for secure remote login over an insecure network [6], while the FTP protocol is employed to transfer data between a client and a server [4].

Therefore, in this paper, we propose a deep learning-based model for detecting brute-force attacks on FTP and SSH protocols. Brute-force attacks targeting these protocols have become increasingly significant security risks to organizations. By leveraging the capabilities of deep learning, our model aims to overcome the limitations of traditional IDSes and improve the accuracy and efficiency of brute-force attack detection on FTP and SSH protocols. Through an extensive evaluation and comparison with existing literature, our findings demonstrate that the proposed model achieves an accuracy of 99.9%, outperforming other comparable solutions in detecting brute-force attacks.

The remainder of this paper is organized as follows: Section II provides a review of the literature. Section III presents the research methodology. Section IV discusses the proposed model. Section V presents the findings and analysis of the proposed model. Finally, Section VI concludes the paper.

## II. RELATED WORKS

Cybersecurity is a vast field designed to combat various attack pathways [7]. Since 2009, research has focused on utilizing artificial neural networks (ANNs) to improve anomaly detection and IDS identification. As a result, the application of ANNs in IDS and malware detection is still a relatively new concept [8]. Previous researchers have attempted to address issues related to overfitting, excessive memory utilization, and high overhead associated with traditional IDS detection. A two-layer, feed-forward ANN was suggested for this purpose. According to the authors, their method produced outcomes similar to traditional procedures but required less computational effort. This technique was tested using the benchmark dataset KDD'99. Since the machine requires time to process the data, the paper concluded that having fewer data points was preferable [9]. Researchers evaluated pruning an ANN as part of network optimization, which involved removing neural nodes from the input or hidden layers. As a result, their ANN became faster due to fewer computations

needing to be processed. When tested as an IDS, the ANN in [9] showed promising performance.

Rather than delivering the inputs directly from the dataset, [10] used principal component analysis (PCA) as a feature representation before feeding the data to the ANN. As the paper illustrated, this reduced the memory resources needed and the amount of training time required. In terms of accuracy, the two tested approaches produced similar results, making PCA the better alternative. Although using a kernel PCA improves ANN training time, it consumes significantly more memory than standard PCA, which is a drawback. Since the accuracy measures for both techniques are similar, the authors of [11] discussed the use of a combination of techniques as a superior alternative. Because GPUs are well-suited for ANN computations, research has explored using them to accelerate ANN-based IDSes. A performance boost has been demonstrated in [12]. The authors of [13] compared a support vector machine (SVM), Naïve Bayes (NB), and a C4.5 classifier to an ANN with one hidden layer. The ANN yielded equivalent or better results in attack detection than the other algorithms evaluated by the paper, and it did so with fewer computations due to the simplified structure of a three-layered ANN model. The tests were conducted on the NSL-KDD database, which replaced KDD'99 as the current benchmark.

Artificial intelligence-based IDS models continue to face two major issues. Traditional machine learning (ML) algorithms are generally fast but have a high false positive rate (FPR). Deep learning, on the other hand, offers excellent accuracy and low FPR but requires significant computation time. As a result, the authors of [14] proposed a solution that provided the best of both worlds. The suggested solution was an OS-based monitoring algorithm that used standard ML as a quick monitoring device, referred to as the standard stage; when a classification falls into the borderline state, the method's second stage is initiated. The second stage, dubbed uncertain, employs deep learning as the final decision-maker on a process. The authors of [15] examined malware detection flow based on a convolutional neural network (CNN). They found that detection approaches were overly reliant on specific packet elements, such as the port number, which created a blind spot in security, as some malware uses unpredictable port numbers and protocols. Instead of these packet elements, they proposed 35 features derived from the Stratosphere IPS project's data. To address the data balance problem, 2000 data points were selected in each class. Nestmate was used to extract 35-flow static features that were then fed into a CNN and three different machine learning methods for evaluation, including SVM, random forest (RF), and multi-layer perceptron (MLP). Data from the Stratosphere IPS project was used to train the models, as it is publicly available. The CNN architecture consisted of one input layer, five feature map layers, a flatten layer, two hidden layers, and one output layer. The authors concluded that the RF algorithm outperformed other approaches on all three examined indicators: accuracy, specificity, and sensitivity [16].

Table I and Table II display supervised algorithms, as well as autoencoder and deep belief network architectures used for intrusion detection, respectively.

TABLE I. COMPARISON OF INTRUSION DETECTION SCHEMES USING ANN AND CNN ARCHITECTURES

Scheme	Data used	Model architecture	Result in %
[17]	CICIDS 2017, UNSW-NB15, NSL-KDD, Kyoto, WSN-DS	ANN + ReLU activation	Accuracy: 78.5, 95.6, Precision: 81.0, 96.2, Recall: 78.5, 95.6, F1- score: 76.5, 95.7
[18]	ISCX VPN	CNN	accuracy: 99.85
[19]	NSL-KDD	ANN + ReLU activation	Accuracy: 86.35, Precision: 81.86, Recall:77.32, F1-score: 73.89, FAR: 0.1619
[20]	NSL-KDD	ANN	accuracy: 98.27, recall:96.5, FAR: 0.0257
[21]	KDD 99	ANN + ReLU activation	Accuracy: 99.01, Recall:99.81, FAR: 0.0047
[22]	USTC-TFC2016	CNN	Accuracy: 99.17, Precision: 99, Recall:98, F1-score: 98
[23]	Network data Simulated by IoT	ANN + Sigmoid activation	Accuracy: 99

TABLE II. COMPARISON OF INTRUSION DETECTION SCHEMES USING LSTM RNN AND OTHER DEEP LEARNING ARCHITECTURES

Scheme	Data used	Model architecture	Result in %
[8]	NSL-KDD	LSTM	Accuracy: 98.94, Recall:99.23, FAR: 9.86
[24]	ISCX 2012, AWID	embedding + LSTM + sigmoid	Accuracy: 99.91, Precision: 99.85, Recall:99.96
[10]	KDD 99, NSL-KDD	GRU + BGRU	Accuracy: 99.24, Recall:99.31, FAR: 0.84
[12]	Vehicle network data	LSTM	Accuracy: 86.9
[25]	NSL-KDD, binary and 5-class classification	RNN	Accuracy: 81.29
[15]	KDD 99	LSTM network	Accuracy: 97.54, Precision: 97.69, Recall:98.95, FAR: 9.98
[26]	CSE-CIC-IDS2018	Broad Learning System	Accuracy: 97.08 F1- score: 77.89 Precision: NA Recall: NA
[27]	CSE-CIC-IDS2018	LSTM+ SMOTE algorithm	Accuracy :96.2 F1- score: NA Precision :96 Recall :96
[28]	CSE-CIC-IDS2018	Spark ML + Conv-AE	Accuracy: 98.20 F1- score: 98 Precision: NA Recall :98



### III. METHODOLOGY

The methodology section outlines the process followed in developing the intrusion detection model using deep learning techniques. The chosen algorithm is based on previous studies, and the model utilizes ANNs with ReLU and SoftMax activation functions. The CSE-CIC-IDS 2018 dataset, specifically the FTP/SSH brute-force attacks, serves as the basis for the model. The entire process is broken down into distinct stages, as detailed below:

- 1) *Obtain the proposed benchmark dataset:* The CSE-CIC-IDS 2018 dataset is acquired, containing eight different attack types. Only FTP/SSH brute-force attacks are used in this study.
- 2) *Prepare the data:* Data preprocessing involves correcting issues such as missing values and outliers, ensuring that the dataset is clean and ready for analysis.
- 3) *Use exploratory analysis:* This step involves understanding the dataset's content and selecting the most suitable algorithm for the given problem.
- 4) *Train the model:* The best-performing algorithm from the literature review is used to train the model on the prepared dataset.
- 5) *Evaluate the model:* Evaluation techniques are employed to assess the model's performance and ensure that it meets the desired accuracy and detection standards.
- 6) *Optimize the model:* If the model's performance is unsatisfactory, alternative algorithms are considered or the current model's parameters are adjusted to improve its effectiveness.

The model is implemented using Google Colab, Python programming language, and the Scikit-learn library. The algorithm implementation is divided into four stages:

Stage 1: Input features are generated from the data preprocessing and representation stages and supplied to the neural network's input layer.

Stage 2: Neural network layers are initialized with random weights, which are used throughout the training phase.

Stage 3: The network accepts the input and begins the training process. The feature identifies the output probabilities by going through the forward propagation phases (dense, ReLU, and operations, as well as the forwarding propagation of hidden layer 3).

Stage 4: The intended output error value is computed and compared to the produced output. Validation is performed after every 50 iterations to assess the model's performance and make adjustments as needed.

This methodology provides a systematic approach to developing an effective intrusion detection model, from obtaining the dataset to training and evaluating the model.

### IV. PROPOSED MODEL

To implement the proposed algorithm, it is crucial to obtain the CSE-CIC-IDS2018 benchmark dataset. The data is organized in a CSV file with columns such as FlowID, Destination-IP, Source-Port, and Protocol. The dataset includes

over 80 network traffic features representing various attack types, including denial-of-service, Heartbleed, web attacks, botnet, and infiltration attacks.

Brute-force attacks are prevalent against networks as they exploit weak login and password combinations. Our model focuses on identifying SSH and MySQL accounts on the primary server targeted by dictionary brute-force attacks.

The following steps outline the data preprocessing:

- 1) *Data cleaning and normalization:* Convert all required features to nominal values and clean the data, depending on the created features.
- 2) *Normalization of data:* Normalize numeric feature values to a chosen scale, such as the [0, 1] range, to decrease data scale and improve model accuracy and processing time.
- 3) *Splitting data:* Divide the data into three parts: a training set with 60% of the data, a validation set with 20%, and a testing set with the remaining 20%.

Fig. 1 displays the architecture of the proposed model, while Fig. 2 shows the neural network architecture of our multiclass detection model. The ANN aims to minimize the number of information parameters needed by employing equivariant representation, parameter sharing, and sparse interactions. The network consists of multiple hidden layers, as well as an input and output layer.

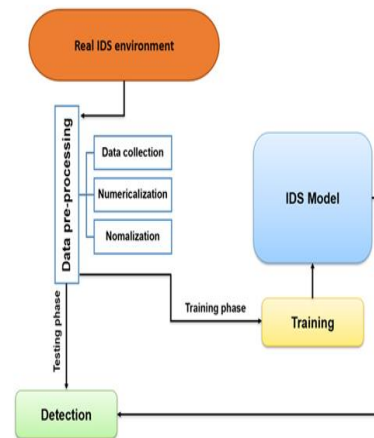


Fig. 1. Architecture of the proposed model.

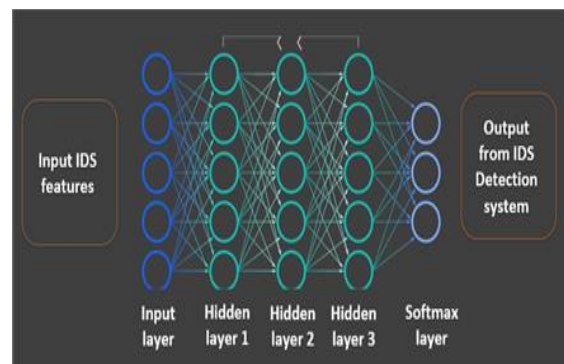


Fig. 2. Proposed neural network architecture of our multiclass detection model.

The model parameters are as follows:

- Input layer: Contains neurons equal to the number of input data features, utilizing the ReLU activation function.
- Hidden layers (1, 2, and 4): Dense layers with a specified number of neurons, also employing the ReLU activation function.
- Output layer: A softmax layer for classification with three output classes.

In this model, we use a softmax classifier for multiclass classification of brute-force attacks targeting SSH and FTP. The softmax layer effectively represents category distributions by normalizing the exponent of output values. It is primarily used in the output layer, providing a differentiable function that reflects the probability of the output.

### V. FINDINGS AND ANALYSIS

In the Findings and Analysis section, we present the performance of our proposed model and compare it with current research. Our proposed model achieved superior results with over 99.9% accuracy in comparison to the existing literature. Fig. 3, which shows the learning curves during the training process, demonstrates the performance of our proposed model.

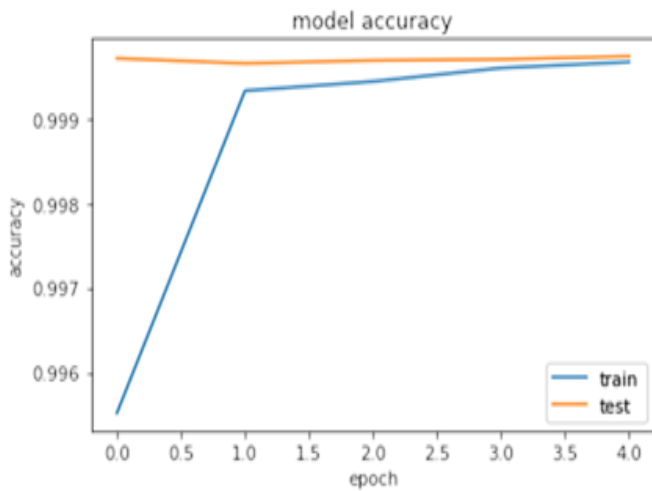


Fig. 3. The accuracy of the proposed model.

Table III compares our proposed model with current research based on accuracy, precision, recall, and F-score. Our model produced superior results, with 99.9% accuracy, 98.3% F-score, 100% precision, and 98% recall.

The results of the proposed model, which employs an Artificial Neural Network (ANN) on the CSE-CIC-IDS2018 dataset, demonstrate a significant improvement in performance compared to existing research. With an accuracy of 99.9%, F1-score of 98.3%, precision of 100%, and recall of 98%, the proposed model outperforms other methods in the literature.

TABLE III. COMPARISON BETWEEN THE PROPOSED MODEL AND CURRENT RESEARCH

Scheme	Dataset	Model Architecture	Result in %
[26]	CSE-CIC-IDS2018	Broad Learning System	Accuracy: 97.08 F1- score : 77.89 Precision :NA Recall :NA
[27]	CSE-CIC-IDS2018	LSTM+ SMOTE algorithm	Accuracy :96.2 F1- score : NA Precision :96 Recall :96
[28]	CSE-CIC-IDS2018	Spark ML + Conv-AE	Accuracy : 98.20 F1- score : 98 Precision :NA Recall :98
Proposed Model	CSE-CIC-IDS2018	ANN	Accuracy : 99.9 F1- score : 98.3 Precision : 100 Recall : 98

In comparison, the Broad Learning System (BLS) achieved an accuracy of 97.08% and an F1-score of 77.89%, while the model using LSTM with SMOTE algorithm reached an accuracy of 96.2% and a precision and recall of 96%. Finally, the model employing Spark ML with Conv-AE obtained an accuracy of 98.20%, F1-score of 98%, and a recall of 98%. These results show that the proposed ANN model is significantly more accurate than other models, particularly in terms of precision.

The high precision of the proposed model indicates that it is particularly effective at correctly identifying true positives (i.e., correctly detecting attack instances) and minimizing false positives (i.e., misclassifying benign instances as attacks). This is an essential aspect of an intrusion detection system, as it ensures that genuine threats are identified while minimizing the risk of false alarms.

The recall rate of 98% for the proposed model, while slightly lower than its precision, is still noteworthy. This indicates that the model can successfully identify a high proportion of true positive instances from the total number of actual positive instances. In the context of intrusion detection, this means that the proposed model is effective at detecting most of the attacks in the dataset.

### VI. CONCLUSION AND FUTURE WORK

In this research, we introduced a novel model for detecting network intrusions using a deep neural network. Our proposed model demonstrates superior performance compared to other existing approaches, as evidenced by the results obtained.

We utilized the comprehensive CSE-CIC-IDS2018 dataset to train our powerful neural network model, taking advantage of Google Colab's computational resources. The model effectively defends against SSH/FTP brute-force attacks and is designed to closely emulate real-world scenarios. By employing a hidden real-time test dataset throughout its training and development, the model's performance can be more accurately assessed. Comparison of our model's results with various evaluation metrics reveals its superior ability to

detect brute-force attacks, outperforming other recent research studies. The key metrics obtained are 99.9% accuracy, 98.3% F1-score, 100% precision, and 98% recall.

Future work could focus on refining the artificial neural network model and comparing its performance with other machine learning models, such as Support Vector Machines (SVM), logistic regression, decision trees, and random forests. These comparisons would provide valuable insights into the model's performance and potential for further enhancement. Additionally, future research may explore the applicability of the proposed model to a wider range of cyberattacks, contributing to the ongoing development of robust intrusion detection systems.

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# Method for Characterization of Customer Churn Based on LightBGM and Experimental Approach for Mitigation of Churn

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**Abstract**—A method for customer churn characterization based on LightBGM (Light Gradient Boosting Machine) is proposed. Additionally, experimental approaches for mitigation of churn are conducted through churn prediction. The experiments reveal several churn characteristics such as age dependency, gender dependency (with a high divorce rate among female customers), number of visits dependency (with a higher churn rate for customers with fewer visits), unit price (per hair salon visit) dependency (with a higher withdrawal rate for lower-priced services), date of first visit dependency (with a high churn rate for recent customers), date of last visit dependency, and menu dependency (with low attrition rates for gray hair dye and high attrition rates for school and child cuts) and so on. Through the experiments, these dependencies are clarified. It is found that the first visit date is the most significant factor for churn customer character. Also, it is found that “distance to hair salon” dependency may be related to the availability of parking lots, although this factor has insignificant impact on the churn rate.

**Keywords**—Churn; LightBGM; churn characteristics; linear regression

## I. INTRODUCTION

The method for predicting the characterization of churn customers is an important aspect of customer retention and marketing strategies. By understanding the characteristics of customers who are likely to leave or churn, businesses can take proactive measure for them. Predictive modeling techniques, such as machine learning algorithms, can be used to identify patterns and relationships in customer data, allowing businesses to predict which customers are most likely to churn and why.

Overall, the effectiveness of this method depends on the quality of data used for analysis, the accuracy of the predictive models employed, and the ability of businesses to act on the insights generated. It is important to continuously refine the models and update them with new data to ensure accuracy and relevance. Additionally, churn predictions can help develop appropriate customer retention strategies. Acquiring new customers is usually more expensive than retaining existing ones. Therefore, churn forecasting is becoming increasingly common to aim for a more profitable business.

There are two types of churns:

1) Customer churn (e.g., monthly churn customers / the number of customers at the beginning of the month).

2) Revenue churn refers to the decrease in Monthly Recurring Revenue (MRR) over a given period, typically a month. It is calculated by dividing the reduction in MRR by the MRR at the start of the month.

While customer churn specifically pertains to customers canceling a service or subscription, revenue churn encompasses not only customer churn but also instances where customers downgrade to a lower-tier service or product. Therefore, revenue churn is a more comprehensive measure than customer churn.

There are four MRR changes, each with a name:

- 1) *New MRR*: MRR from new customers.
- 2) *Expansion MRR*: MRR obtained from existing customers with increased transaction value.
- 3) *Downgrade MRR*: MRR obtained from existing customers whose transaction amount has decreased.
- 4) *Churn MRR*: MRR that would have been obtained from churned customers.

MRR changes can be classified into the following two categories:

- 1) *Increased MRR*: New MRR + Expansion MRR.
- 2) *Decreased MRR*: Downgrade MRR + Churn MRR

The Quick Ratio, which is the ratio of Increased MRR to Decreased MRR, is used as an index to measure growth potential. A Quick Ratio of less than 1 is considered bad, while a Quick Ratio of over 4 is considered great.

The churn prediction (departure prediction) model created by machine learning can be applied in two situations:

- 1) Complete churn (transaction amount 0).
- 2) Downgrade (change to lower service/product).

In the case of complete churn, it becomes a binary classification problem of "detachment or continuation." In the case of downgrading, it becomes a binary classification problem of "downgrade or maintenance." However, if there are multiple services to be downgraded, it becomes a multi-class classification problem.

When constructing a churn prediction (departure prediction) model, the process follows a similar framework to building a typical machine learning model. Firstly, the business

problem and objectives are defined. Then, the model and necessary data for analysis are specified. This data is often sourced from transaction histories or CRM (Customer Relationship Management) systems. Subsequently, the dataset is generated, prepared, and subjected to EDA (Exploratory Data Analysis), as well as essential preprocessing steps like data normalization and standardization, to create suitable datasets for machine learning algorithms. Predictive models are then trained and evaluated. Churn prediction models utilize various machine learning algorithms, including deep learning, for classification problem-solving. Lastly, the trained prediction model is deployed and monitored to validate its effectiveness.

Reducing customer churn is of utmost importance. Therefore, it is crucial to analyze the differences between churned customers and those who remain (non-churned). To understand the behavior of churned customers, a method based on LightGBM (Light Gradient Boosting Machine) is proposed. While there are several linear prediction algorithms available, LightGBM demonstrates relatively high prediction accuracy. The factors contributing to churn are categorized, and churned customers are characterized based on these factors. By employing the proposed method, the importance of customer churn prediction can be assessed. LightGBM offers a functionality that identifies the key factors influencing churn prediction. Consequently, appropriate measures can be taken to reduce customer churn.

In the following section, some of the related research works are described, followed by the proposed method. Then, some of the simulation studies are described, followed by a conclusion with some discussions.

## II. RELATED RESEARCH WORKS

Database marketing has been successfully introduced [1]. The book "Enterprise One to One: Tools for Competing in the Interactive Age" has also been published [2]. An attempt has been made to apply the concept of CLTV (Customer Lifetime Value) to FMCG (Fast-Moving Consumer Goods) [3]. Furthermore, several studies on CLTV have been introduced and reviewed, with each paper presenting different definitions of customer lifetime value, target industries, business models, and conditions for calculation [4].

Instances of COCA (Cost of Customer Acquisition) have been described, which refers to the cost of acquiring customers [5]. CLTV models and applications for marketing have been proposed and their applicability discussed [6]. Marketing study guides have been published and well-reviewed [7].

The book "Customer Profitability and Lifetime Value" has been published and extensively discussed [8]. Managing customers profitably has also been investigated and discussed [9]. Additionally, the analysis and discussion of "Performance management, which includes integrating strategy execution, methodologies, risk, and analytics," has taken place [10].

The paper "RFM (Recent Frequency Monetary) and CLTV: Using iso-value curves for customer base analysis" has been published, proposing and validating a method for marketing research [11]. Similarly, the paper "Autonomous CRM control via CLTV approximation with deep reinforcement learning in

discrete and continuous action space" has been published, attempting to use CLTV approximation for CRM control [12].

On the other hand, CLTV has been well defined and discussed [13]. The paper "EDA of predictive modeling with "R" (a software tool for statistics) for risk management using machine learning" has been published, proposing and validating the use of EDA for predictive modeling [14]. Meanwhile, it is widely acknowledged that EDA is an important and useful technique in data science for analyzing and understanding data better. EDA involves exploring and visualizing the data to identify patterns, relationships, and anomalies.

EDA helps identify missing values, outliers, and other inconsistencies in the data, which can then be addressed before building predictive models. By visualizing the data, EDA also facilitates communicating insights to stakeholders and guiding further analysis. Furthermore, EDA is increasingly recognized as a critical step in any data analysis project as it enables a better understanding of the data, identification of potential issues, and provides insights for further analysis and decision-making. The concept of EDA has also been proposed and discussed [15]. Data analysis and regression have been well proposed for EDA analysis [16].

The paper "Suitability of random forest analysis for epidemiological research: Exploring sociodemographic and lifestyle-related risk factors of overweight in a cross-sectional design" has been published, studying and reporting on the suitability of random forest analysis for epidemiological research [17]. Additionally, EDA has been well defined, described, and investigated for its usefulness [18].

The paper "Customer Profiling Method with Big Data based on BDT and Clustering for Sales Prediction" has been published, proposing and validating a method for sales prediction using big data [19]. Meanwhile, the paper "Modified Prophet+Optuna Prediction Method for Sales Estimations" has been published, also proposing and validating a prediction method for sales using actual sales data [20].

## III. PROPOSED METHOD

The objective of this paper is to clarify the behavior of churned customers, identify the reasons for churn, and propose strategies to mitigate churn. We aim to discover significant feature values for predicting customer behavior and leverage the insights obtained through Exploratory Data Analysis (EDA) to predict customers who are likely to churn using decision tree models like LightGBM and logistic regression. LightGBM is a popular open-source gradient boosting framework widely used for various machine learning tasks, including classification, regression, and ranking. Its high accuracy, efficiency, and scalability make it an excellent choice for analyzing churn customer behavior.

LightGBM utilizes a histogram-based algorithm to efficiently partition data into discrete bins, reducing memory usage and speeding up the training process. This feature, along with its gradient-based one-sided sampling technique that prioritizes data contributing the most to the loss function, further enhances training speed. Both processing speed and loss function minimization are essential factors. Additionally,

LightGBM provides advanced features such as handling categorical features and missing values, early stopping, and cross-validation. These capabilities facilitate the handling of real-world datasets, prevent overfitting, and improve model performance. Overall, LightGBM is a powerful and efficient tool for building accurate and scalable machine learning models, especially for large-scale and high-dimensional datasets.

The definition of estrangement and output are as follows: The format of the final churn prediction output is shown in Table I.

TABLE I. SPECIFICATION OF CHURN PROBABILITY

Customer ID	Churn Probability
1	5%
2	50%
3	30%
...	...

We aim to predict the probability that each customer will churn in the next three months (definition of churn customer). A customer who visited the hair salon in the previous three months and did not return to the hair salon in the next three months, and a customer who did not visit the hair salon was defined as churn. The example of churn customer definition is as follows, "out of the customers who visited the hair salon between January and March, the customers who visited between April and June returned, and the customers who did not visit the hair salon were considered as having churned".

#### IV. EXPERIMENT

##### A. Data Used

The data used in the experiment targeted approximately 65,000 customers who visited all hair salons between January and March 2021. Customers who visited the hair salon between April and June were considered repeat customers, while those who did not visit the hair salon were considered as churn customer. These are illustrated in Fig. 1. In the figure, "0" is recurrence, "1" is withdrawal, and the withdrawal rate was about 42%. Table II shows the features used for churn analysis.

TABLE II. FEATURES USED

Schema name	Description
customer_id	Customer ID
visits_count	Number of visits
unit_price_ave	Average unit price per hair salon
first_visit_date	Customer's first visit date
last_visit_date	Customer's last visit date
gender	Male or Female
Age	Age (customers who do not enter are 0)
distance	Distance to the hair salon calculated from the zip code
Menu	Categorization by menu
unit_price_per_visit_s_count	Average unit price per visit / the number of visits

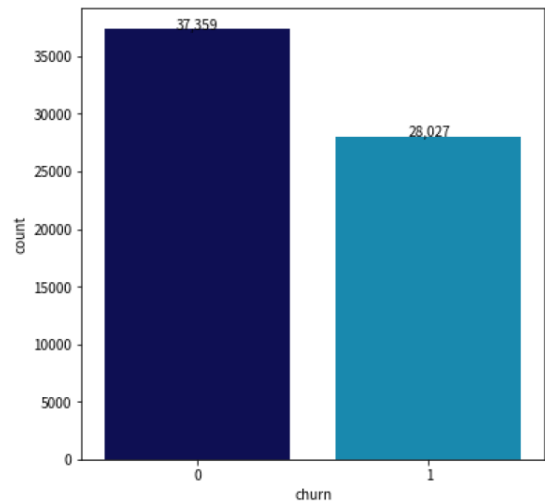


Fig. 1. Data used for churn analysis.

##### B. Experimental Results

Difference between churn and non-churn customers.

1) *Number of visits*: The total number of visits is displayed in Fig. 2. In subsequent graphs, orange color represents churn, while blue represents retention, as shown in Fig. 2. There is a notable difference in the attrition rate, with a higher number of visits resulting in lower attrition rates and vice versa for a lower number of visits.

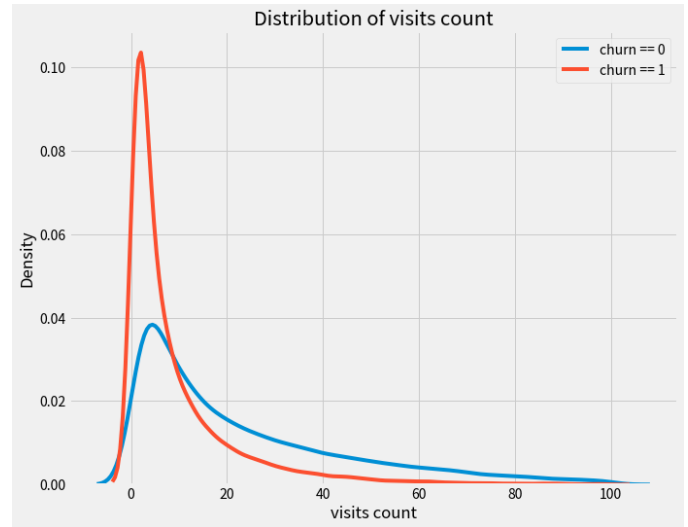


Fig. 2. The number of visits.

2) *Average unit price per visit*: The average unit price per visit is shown in Fig. 3. Customers with a low unit price have a high churn rate, whereas customers with a high unit price have a low churn rate. There is not much difference between the two.

3) *Customer's first visit date*: Fig. 4 displays the date of the customer's first visit to the hair salon. The horizontal axis represents the number of days before the first visit from the analysis point. In this analysis, we focused on customers who visited the hair salon between January and March. Hence,



March 31st corresponds to the day before the analysis period's end. Notably, customers who recently made their first visit exhibit a higher churn rate, while those who visited the hair salon in the past show a lower churn rate. These differences are statistically significant.

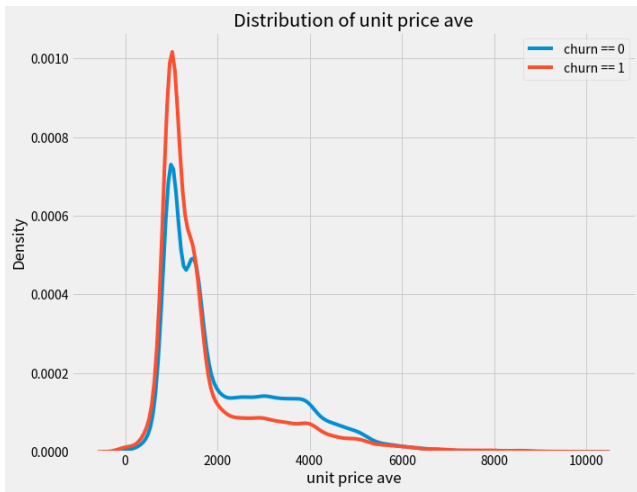


Fig. 3. Averaged unit price per visit.

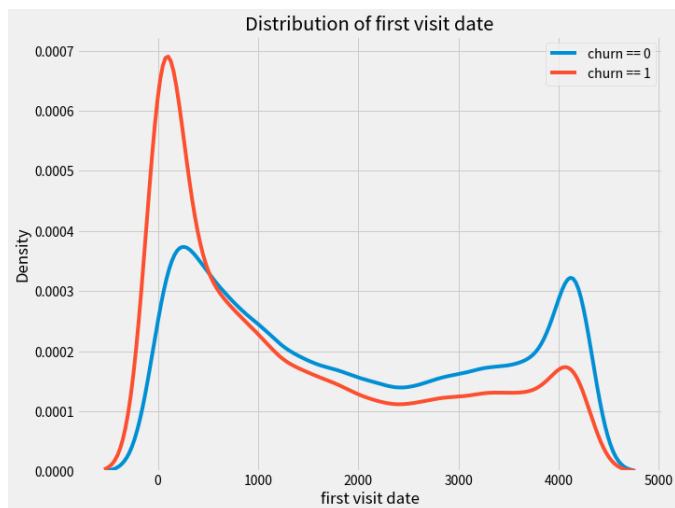


Fig. 4. Customer's first visit date.

4) *Customer's last visit date*: Fig. 5 illustrates the date of the customer's last visit. Similar to the first visit date, the horizontal axis indicates the number of days before the last visit from the analysis point. In this analysis, we examined customers who visited the hair salon between January and March, with March 31st being the obvious day before the analysis period's end. Interestingly, the churn rate is lower for customers who have recently visited the salon. However, customers whose last visit was more than 50 days ago exhibit a high churn rate, as depicted in Fig. 5.

5) *Gender*: As shown in Fig. 6, males have a lower attrition rate than females. The attrition rate for customers identified as female exceeds 60%, but it is slightly over 50% for males. Customers whose gender is unknown (not entered) have an extremely low attrition rate.

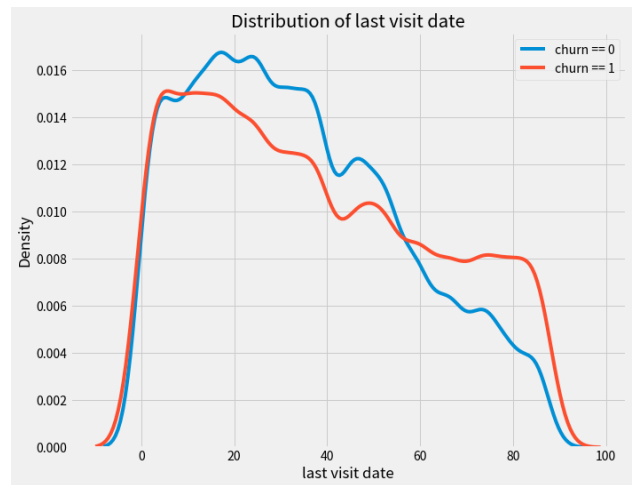


Fig. 5. Customer's last visit date.

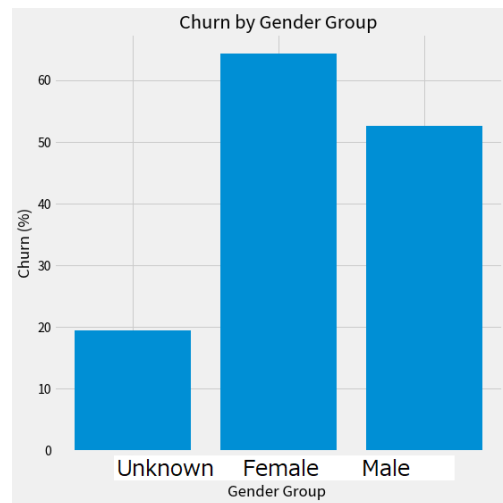


Fig. 6. Churn rate against gender.

6) *Age*: As shown in Fig. 7, the churn rate is high for those in their 20s and 30s, and decreases for those in their 50s.

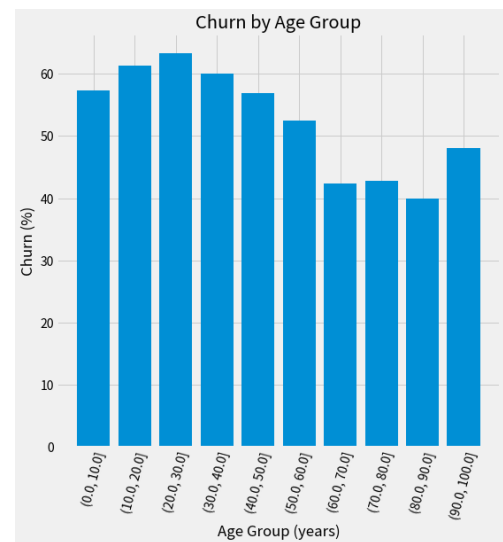


Fig. 7. Churn rate against age.

7) *Service menu*: We classified customers based on their most frequently ordered menu and examined the churn rate, as presented in Fig. 8. The churn rate for customers who selected "dyeing white hair" is notably low, at approximately 30%. However, there is a high churn rate observed for "child cuts" and "school cuts".

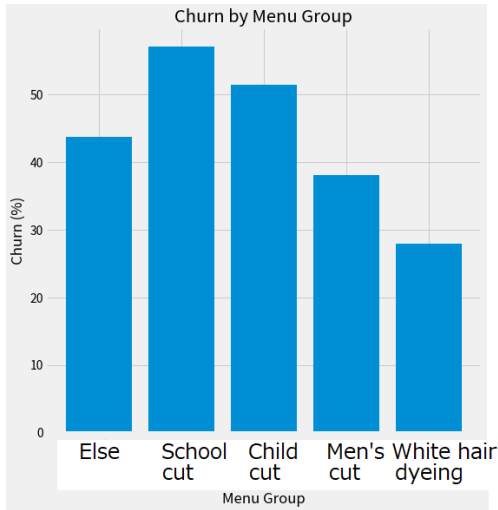


Fig. 8. Menu dependency on churn rate.

8) *Average cost per visit / Number of visits*: Fig. 9 displays a Kernel Density Estimation (KDE) plot for individuals with an average unit price per hair salon visit of over 2,000 yen. It is noticeable that customers with a value of 6,000 yen or more exhibit a slightly higher churn rate. This suggests that despite visiting the hair salon less frequently, individuals who opt for expensive menu options have a higher likelihood of churning.

KDE is a non-parametric method used to estimate the probability density function of a random variable based on a sample of observations (KDE in Python: Kdeplot is a KDE Plot which depicts the probability density function of the continuous or non-parametric data). KDE is in some senses an algorithm which takes the mixture-of-Gaussians idea to its logical extreme. The basic idea behind KDE present the probability density function as a weighted sum of kernel functions centered at each observation in the sample. The kernel function is a smooth, symmetric, and non-negative function that integrates to one, and its shape determines the smoothness of the estimated density.

KDE is often used in data analysis, machine learning, and statistics to visualize and estimate the probability density function of a dataset, especially when the underlying distribution is unknown or complex. It is a powerful tool for data exploration, pattern recognition, and outlier detection, and it can be applied to one-dimensional, two-dimensional, or higher-dimensional data. Some of the popular kernel functions used in KDE include Gaussian, Epanechnikov, and triangular kernels, and the bandwidth parameter determines the width of the kernel function and the smoothness of the estimated density.

KDE is a nonparametric method for estimating the probability density function of random variables in statistics. It is also known as the Parzen window, named after Emmanuel Parzen. In simple terms, kernel density estimation can be used to estimate data from a population, given data from a sample of that population.

9) *Customer churn prediction*: For customer churn prediction, Fig. 10 shows the results of using the above feature values (excluding distance to the hair salon). The top 6 features are displayed in the figure, with the menu features following. The feature value order of customer churn prediction using LightGBM is shown below, with the number of hair salon visits on the first day being the most influential feature.

In this churn prediction using LightGBM, the ROC curve is shown in Fig. 11 and the relationship between churn rate and its count is shown in Fig. 12 as a PCT.

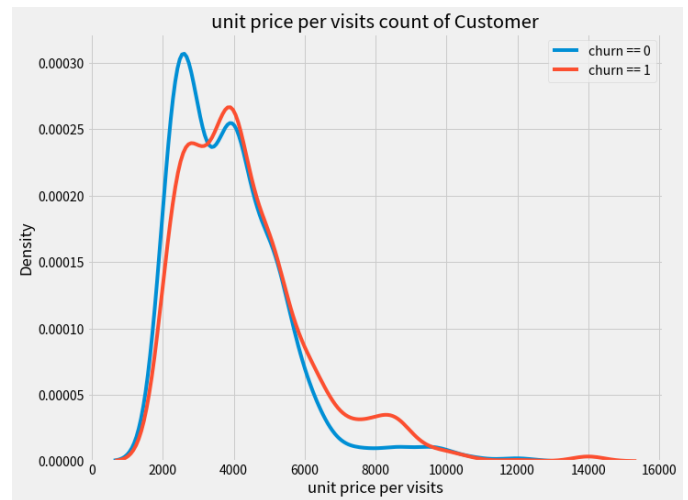


Fig. 9. Average cost per visit / Number of visits.

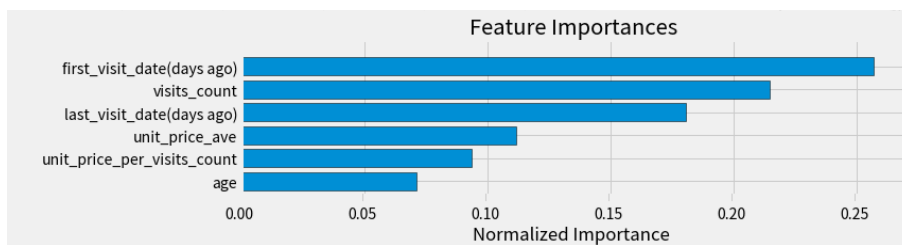


Fig. 10. Feature importance for the customer churn prediction.

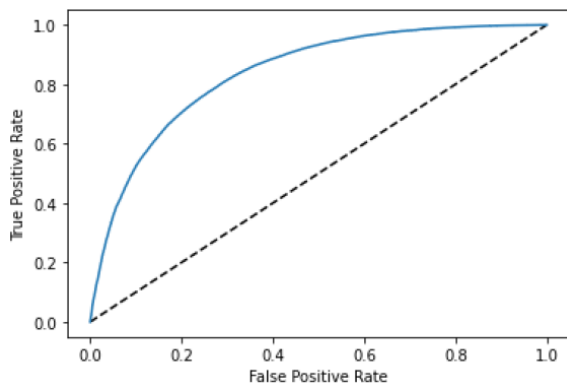


Fig. 11. ROC curve.

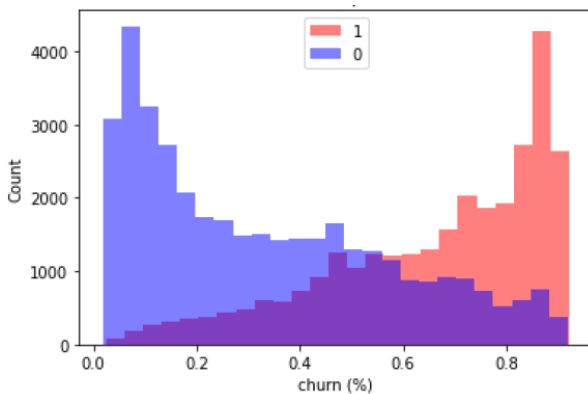


Fig. 12. PCT.

From the ROC curve, the AUC (Area Under Curve) is calculated as 0.837. ROC curve and AUC are commonly used to evaluate the performance of binary classification models. The ROC curve is a graph of the true positive rate (sensitivity) against the false positive rate (1 - specificity) for various threshold values, and it shows how well the model can distinguish between positive and negative samples. A perfect model would have an ROC curve that passes through the top left corner (100% true positive rate and 0% false positive rate), while a random guessing model would have an ROC curve that follows the diagonal line.

AUC is a single number that summarizes the ROC curve by calculating the area under the curve. AUC ranges from 0 to 1, where a score of 0.5 indicates a random guessing model and a score of 1 indicates a perfect model. A model with an AUC score of 0.7 or higher is considered to have good predictive power. ROC curve and AUC are useful tools for evaluating the performance of binary classification models, and a higher AUC score indicates better predictive power. Additionally, a logarithmic function of loss is found to be 0.496.

The results of the customer churn analysis and prediction are summarized as follows:

- 1) *Age*: Younger customers have a higher attrition rate, while those in their 60s to 80s have a lower attrition rate.
- 2) *Gender*: The churn rate is higher for female customers.
- 3) *Number of visits*: Customers with a lower number of visits have a higher churn rate.

4) *Unit price (per hair salon visit)*: Customers with lower unit prices have a higher withdrawal rate.

5) *Date of first visit*: Customers who have recently visited for the first time have a higher churn rate.

6) *Date of last visit*: The churn rate is lower for customers who have recently visited.

7) *Menu*: Gray hair dye customers have a low attrition rate, while school and child cuts have a high attrition rate.

8) *Distance to hair salons*: The presence or absence of parking lots seems to have little impact on the churn rate.

Based on real-time database referencing (having your own database provides quicker results), the following countermeasures are implemented:

"Sending direct messages (DMs) and coupons to customers with a 90% chance of churning."

To improve churn prediction accuracy, ensemble models such as RandomForest and logistic regression will be attempted in addition to LightGBM, further enhancing accuracy. Additionally, if analyzed for each hair salon without narrowing down the period, different results may emerge, as mentioned in the previous section (churn characterization depends on the definition of churn).

## V. CONCLUSION

In conclusion, this paper proposes a method for analyzing churn customer characteristics and conducts experimental approaches to minimize churn through churn prediction using LightGBM. The experiments revealed the following churn characteristics: age dependency, gender dependency (higher churn rate for females), dependency on the number of visits, dependency on unit price per visit, dependency on the date of first visit, dependency on the date of last visit, menu dependency, and distance to hair salons dependency. While the proposed method aids in characterizing churn customer behavior and identifying churn reasons, further considerations are required to devise effective countermeasures against churn.

## VI. FUTURE RESEARCH WORKS

We should conduct further investigation to identify alternative prediction methods that may lead to more accurate results. In particular, nonlinear prediction method has to be considered because the LighGBM used is essentially linear regression method and there must exist nonlinear behavior for churn customers.

## ACKNOWLEDGMENT

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# Artificial Intelligence-based Detection of Fava Bean Rust Disease in Agricultural Settings: An Innovative Approach

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**Abstract**—The traditional methods used to identify plant diseases mostly rely on expert opinion, which causes long waits and enormous expenses in the control of crop diseases and field activities, especially given that the majority of crop infections now in existence have tiny targets, occlusions, and looks that are similar to those of other diseases. To increase the efficiency and precision of rust disease classification in a fava bean field, a new optimized multilayer deep learning model called YOLOv8 is suggested in this study. 3296 images were collected from a farm in eastern Morocco for the fava bean rust disease dataset. We labeled all the data before training, evaluating, and testing our model. The results demonstrate that the model developed using transfer learning has a higher recognition precision than the other models, reaching 95.1%, and can classify and identify diseases into three severity levels: healthy, moderate, and critical. As performance indicators, the needed standards for mean Average Precision (mAP), recall, and F1 score are 93.7%, 90.3%, and 92%, respectively. The improved model's detection speed was 10.1 ms, sufficient for real-time detection. This study is the first to employ a new method to find rust in fava bean crops. Results are encouraging and supply new opportunities for crop disease research.

**Keywords**—Fava bean disease; deep learning; YOLOv8; real-time detection

## I. INTRODUCTION

Humanity faces a severe problem with food security, and one of the main challenges to agricultural output is the occurrence of plant diseases [1]. These diseases generate significant losses, making early identification of these situations crucial. Accurate diagnosis of plant diseases is essential to minimizing economic losses imposed on them. The three approaches now in use are manual inspection of a plant's leaves to determine its health condition and the sort of illness it is affected, which has time, efficiency, and high professional needs issues; pathogen testing [2], which is correct but time-consuming and unsuitable for field detection, and plant protection expert diagnosis [3], which is subject to personal interpretations and has low accuracy.

Development of artificial intelligence and machine vision in various sectors, including agriculture is required. It states that many researchers prefer hyperspectral images due to their capacity to provide continuous spectral information and the spatial distribution of plant diseases [4]. Near-infrared spectroscopic digital images are also used for plant disease

detection [5]. However, the tools needed to capture spectral images are costly and not easily accessible. Digital cameras and mobile phones are within everyone's reach; on the other hand, they make it simple to capture visible light images, making them a more practical choice for image recognition research.

Deep learning (DL) is a crucial technique to remedy this problem. While resolving complex issues like feature extraction, transformation, and image classification, this technology helps implement new tools, methods, and technologies in agriculture. By proposing detection models based on convolutional neural networks (CNN) and using photos taken by cameras, many researchers have used deep learning to identify crop diseases in real time. Therefore, DL has enormous potential to increase the effectiveness of agricultural output and lower losses brought on by plant diseases [6].

To detect rust disease on fava bean pods, this study used the convolutional neural network's enhanced version, You Only Look Once (YOLO). It is commonly used in computer vision tasks, including object segmentation and image classification [7]. A grid divides images into cells, with each cell responsible for object detection in the YOLO object identification approach. For the first time, a bean crop rust disease was detected using the innovative system named YOLOv8 in this study. This research aimed to identify and correctly classify rust disease according to three different severity levels: healthy, moderate, and critical, using images obtained with the camera.

The YOLOv8 method has many advantages over traditional object identification techniques. We want to solve the limitations of current methods and offer a more efficient and accurate solution for the recognition of rust disease in our study. One of the main advantages of the YOLOv8 approach is its excellent level of precision, making it ideal for operations involving identifying small objects. It locates items of interest more precisely by utilizing innovative techniques, including bounding boxes, multi-scale prediction, and feature fusion. This increased accuracy is crucial for applications requiring reliable and precise detection results. Real-time performance is one of this strategy's key benefits. In our application, which tracks the progression of plant diseases in real-time, accurate recognition of small objects in real-time video streams is critical. This is made possible by YOLOv8's exceptional



processing rates, which are made possible by an efficient network design and parallel processing. Additionally, YOLOv8 shows that it can manage various environmental factors, including occlusions, changing illumination, and crowded backdrops. The method's adaptability in the real world, where environmental variables are frequently unpredictable, is enhanced by its capacity to retain dependable detection performance in challenging settings. The suggested solution's streamlined operational model is shown in Fig. 1.

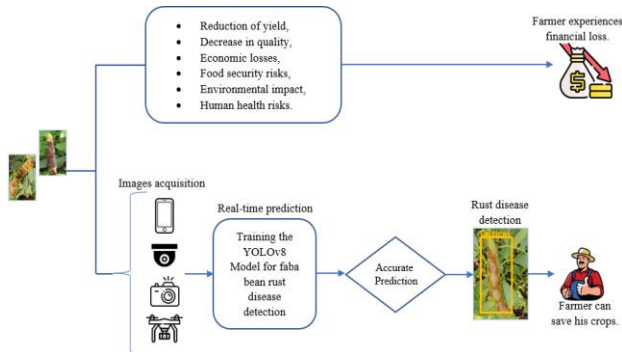


Fig. 1. Creation of the operational model for crop health monitoring.

The context of deep learning algorithms in plant disease detection is discussed in Section II of the seven sections of the research paper—the background in Section III. We outline the methods and materials in Section IV. In Section V, we outline our contribution and the experiment results. The results are discussed in Section VI; Section VII is where we conclude and outline our next steps.

## II. RELATED WORKS

In this section, we summarized some algorithms proposed by researchers and are recently used for disease detection in crops. We can cite Dai et al. [8] work as an example. They merged the CBAM attention mechanism, HRNet, and ASPP structure to enhance the R-CNN. With an average identification rate of 88.78%, a detection algorithm was presented to remove tiny target pests of diverse sizes in citrus.

Karthik et al. [9] recommended a two-level deep-learning method to detect tomato leaf disease. The second deep learning model was applied as an attention mechanism on top of the first model after the first was used to learn critical features via residual learning. The authors identified the late blight, early blight, and leaf diseases in tomatoes using the PlantVillage dataset.

To identify the unhealthy region on tea leaves with an average accuracy of 83%, Mukhopadhyay et al. [10] suggested a new approach based on image processing technology. Zhao et al. [11] proposed a YOLOv5s-based model for crop disease detection. To enhance global and local feature extraction and address the issue of scaling the prediction frame during model learning, the model uses an upgraded CSP structure, CAM structure, additional grid, and DIOU loss function. The model has a recall of 87.89%, an F1 score of 0.91, and an average accuracy (mAP) of 95.92%. The model also has a 40.01 FPS detecting speed. When employed by Alita et al. [12] to find plant leaf diseases, the EfficientNet deep learning model outperformed other cutting-edge deep learning models in terms

of accuracy. To show and detect insects in soybean crops in real-time; the authors Tirkey et al. [13] of this research suggest a deep learning-based approach. They used YOLOv5, InceptionV3, and CNN to achieve 98.75%, 97%, and 97% accuracy as they investigated the viability and dependability of transfer learning models. With YOLOv5, the suggested solution runs at 53 frames per second.

## III. BACKGROUND

Fava bean rust disease presents a severe risk to fava bean crops worldwide, significantly decreasing crop quality and productivity. Traditional approaches to rust disease detection and control rely on visual examination and human observation, which can be time-consuming, labor-intensive, and prone to mistakes. Computer vision and machine learning developments have made deep learning models that can automatically detect and classify rust diseases possible. The YOLOv8 (Fig. 2) object identification method is one such model. This model is a development of the YOLOv4 model, renowned for its object detection speed and accuracy. With the help of a deep neural network and several convolutional layers, the YOLOv8 model can recognize and categorize objects in real time. The YOLOv8 algorithm can quickly and effectively identify this disease since it was trained on a large dataset of healthy and rust-infected fava bean leaf images. The model can evaluate the severity of an infection, which may be used to choose the best preventative actions. The YOLOv8 model, which may decrease reliance on human inspection and improve the speed and accuracy of diagnosis, significantly advances the detection and control of fava bean rust disease.

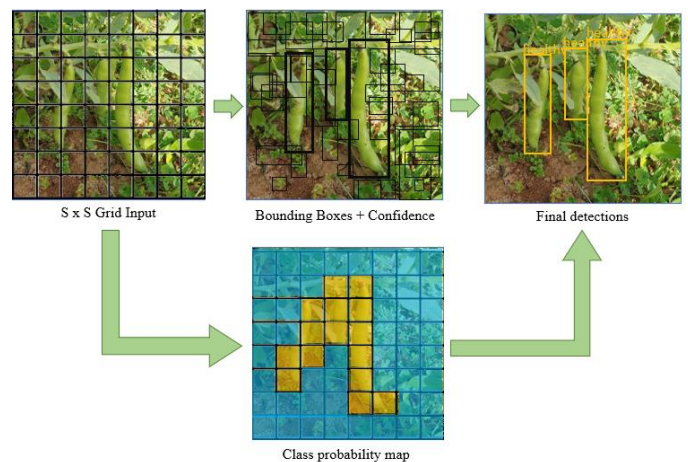


Fig. 2. Pipeline of YOLOv8 algorithm.

## IV. MATERIALS AND METHODS

A model for fava bean rust disease detection in crops is presented in this paper. To do this, an AI-based image recognition system is created. The suggested technique will help farmers apply pesticides precisely and quickly, cut operating costs, and enhance crop output and quality. The settings, data collecting, data pre-processing, Data annotation, and deep learning model training are just a few components of the system's structure. The system uses the trained model to identify rust diseases and validate the developed models based on the results obtained. The suggested strategy is expected to



give farmers precise information for effectively managing crop disease. Fig. 3 depicts the proposed method's flowchart.

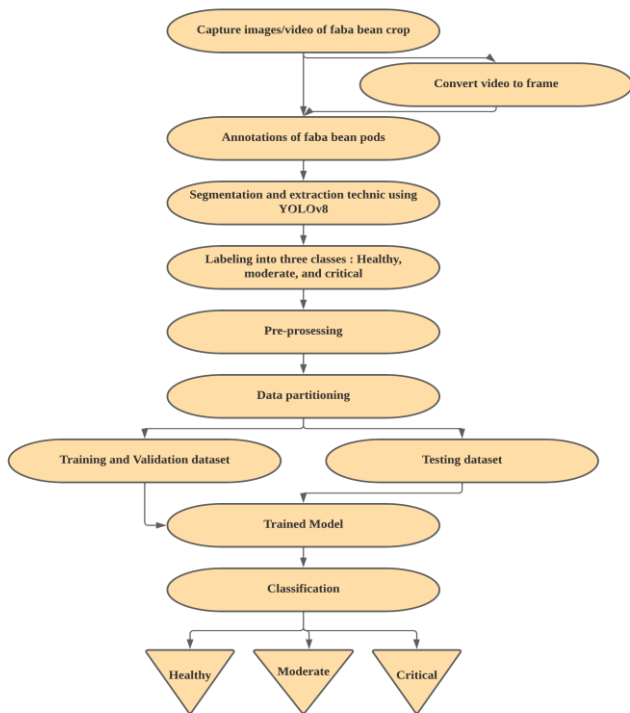


Fig. 3. Diagram showing the proposed model's workflow.

#### A. YOLOv8 for Object Detection

The YOLO family of detection models, which has become famous for their precise detection and segmentation abilities [14], now includes the new YOLOv8 model. This new model's architecture comprises a backbone, head, and neck. Given its transformed architecture, enhanced convolutional layers (backbone), and more sophisticated detecting head, it is an excellent solution for real-time object detection.

One of its strong characteristics is this model's ability to recognize many objects in an image or video faster and more accurately than prior iterations. Because of the model's giant feature map and enhanced convolutional network, which boosts accuracy and speed and are supported by our results, it is more effective than prior versions. The architecture and

framework of the best-trained model YOLOv8 are shown in Fig. 7 and divided into multiple vital parts, each of which is outlined below:

- **Backbone network:** used by the YOLOv8 model to extract features from the input images. YOLOv8 uses the cross-stage partial network (CSPNet) design for the backbone network to lower the computing cost of the network while keeping its accuracy [15].
- **Neck:** The neck acts as a connecting point between the backbone and the detection head. The channel is specifically constructed using the spatial pyramid pooling (SPP) module, which uses different-sized pooling processes to collect multi-scale information [15].
- **Detection head:** Predicting the bounding boxes and class probabilities of things seen in the input image is the responsibility of the detection head. It does this by predicting each item's bounding boxes and class probabilities using a series of convolutional layers, followed by a cluster of anchor boxes [15].

#### B. Research Site

The experimental location was examined at a farm in Ahfir, Berkane province, eastern area of Morocco, at coordinates 34°57'58.9 "N 2°07'42.5 "W shown in Fig. 4. The Fava bean crop was the subject of the investigation, and the picture capture plots were chosen randomly.

#### C. Images Acquisition and Data Collection

To capture images, a Sony DSLR-A230 camera was used. In Table I, the camera settings are displayed. Horizontally aligned pictures were taken. The position of the lens was between 30 and 50cm away from the faba bean pods during image collecting, having a pixel resolution of 3872 x 2592. Throughout March and April 2023, pictures were shot every three to four days.

Three types of faba bean pods—healthy, moderate, and critical—are included in the dataset used for this research; in Fig. 5, samples of each class are displayed. These photos were taken in several spots within the same agricultural area. 1124 images are included in the healthy pod, and 1279 in the moderately infected pod—893 photos of the pods with severe infections. There are 3296 images in all in the data collection.

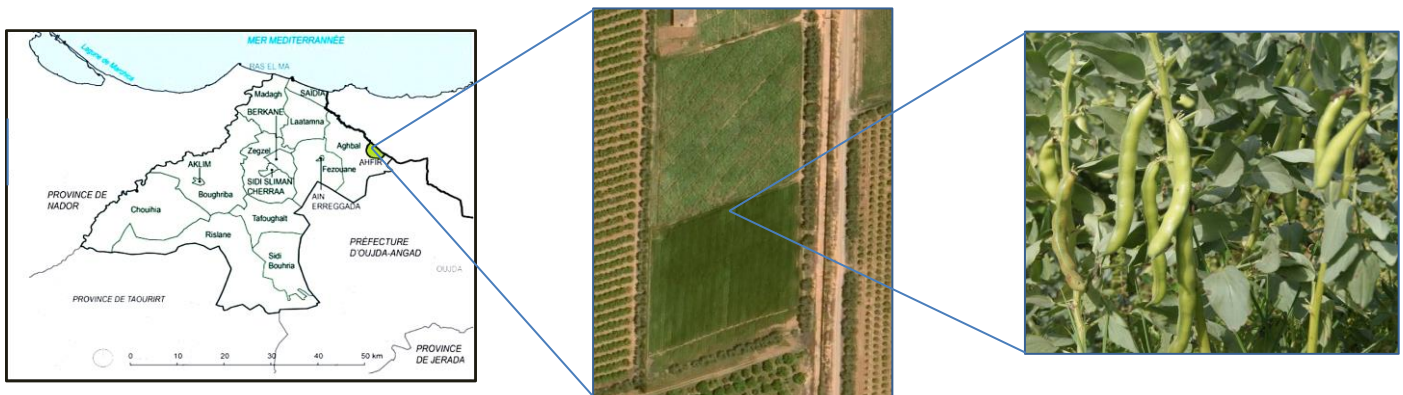


Fig. 4. Research area located in Ahfir, Berkane province, Morocco.

TABLE I. SONY DSLR – A230 CAMERA

Camera Lens	ISO Speed	Resolution	Max Aperture
Sony/Minolta Alpha APS-C 18- 55MM Lens	ISO 3200	3872 x 2592	9.4 feet at f/3.5



Fig. 5. A sample of each class in our database.

D. Data Annotation

Before training our model, it is crucial to complete this step, which requires carefully labeling the images from the resized and obtained data set. This technique is executed via the Python-written "LabelImg" graphical image annotation program [16], which was used for image normalization. The training and validation set images were annotated in VOC format to obtain XML and Txt files with the image names, sizes, class names, target image positions, and other data. Fig. 8 displays the data for the annotations.

The accuracy of the training dataset has a significant effect on how well a machine-learning model performs. An agricultural specialist who helped us find the various lesions present in the farm field to take captures and assisted us with the computer annotation was crucial in our study's dataset annotation. We identified 4468 lesion boundary boxes from a collection of 3296 images. Particularly, healthy, moderate, and critical pods totaling 1540, 1682, and 1246 labels were identified, respectively, (Fig. 6). Since all annotation files were saved in ".txt" format, the model can readily access and understand them.

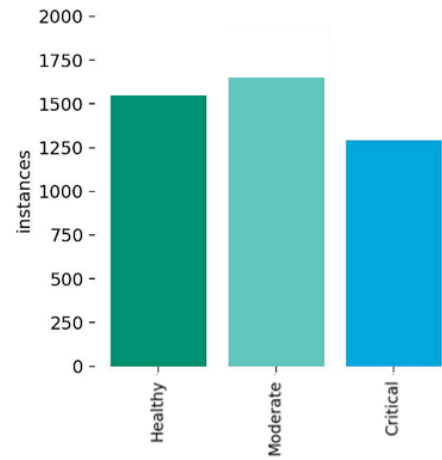


Fig. 6. Number of instances per class. There are labels for 1540 healthy, 1682 moderate, and 1246 critical pod samples.

According to this stringent, expert-guided annotation procedure, the YOLOv8 model can now be trained on high-quality data. This also increases the model's accuracy and efficiency in finding rust diseases in fava bean crops.

E. Augmentation of Dataset and Data Preprocessing

Fig. 6 shows a slight disparity between the healthy and critical classes and the middle class, which might lead to overfitting and impact our model's ability to identify and classify data accurately. Therefore, the training set for healthy and critical pods is increased using simple adjustments like rotation, zoom, brightness, and color saturation of the images to balance our dataset. Additionally, adaptive scaling and filling procedures were conducted on the pictures of the various fava bean pod instances before training our model. The input image size was 640x640 pixels.

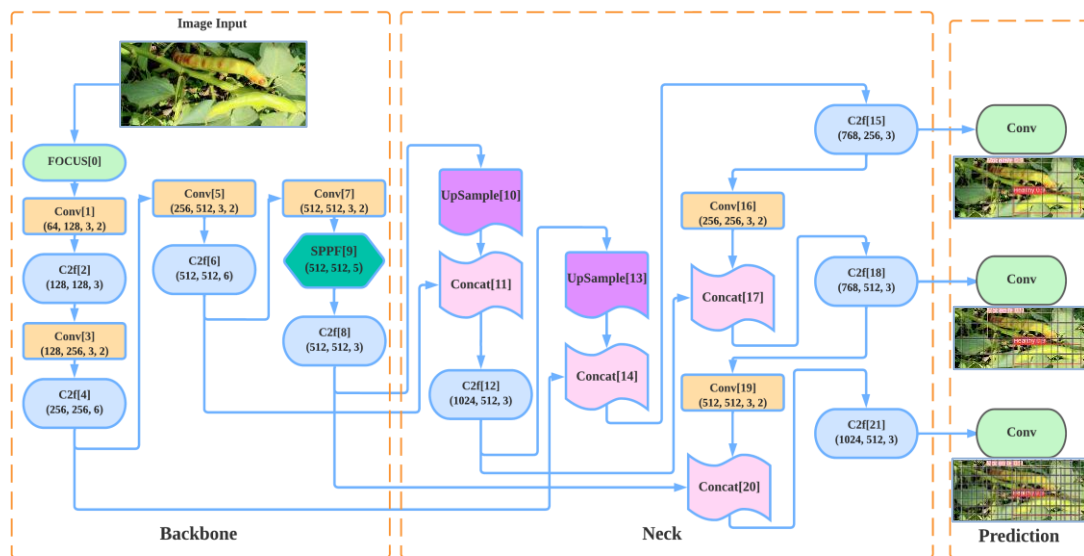


Fig. 7. Architecture of YOLOv8l – best-trained model.

### F. Experimental Setup

The processing platform was a desktop PC with Windows 10 Professional running. The Torch version was 1.13.1, the CUDA version was 11.6, and the Python version was 3.9. The hardware consisted of an Intel® Xeon® W-2223 CPU with a 3.6 GHz core clock, 16 GB of RAM, and an NVIDIA GeForce Quadro P1000 graphics card.

The dataset was divided into training and validation sets in a 4:1 ratio after each image, and the status of the bean pods was manually annotated. Six distinct architectures, including YOLOv8s, YOLOv8l, YOLOv8x, YOLOv5s, YOLOv5l, and YOLOv5x, were modeled using the training set. Four batches of 8 photos each were used for the training procedure. The goal was to evaluate the performance of each architecture and identify the most effective identification model for rust disease detection in fava bean crops. The best model for rust disease detection in fava bean crops was chosen based on the architecture with the highest performance. Fig. 7 shows the selected model's architecture.

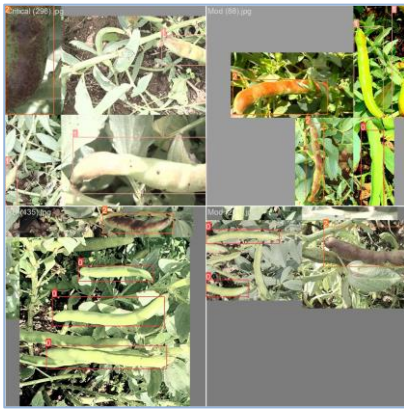


Fig. 8. Images annotation result.

The best hyperparameters were used in the training models. The momentum parameter for the SGD optimizer, which was used in the model learning process, was set at 0.937. This study uses the SGD optimizer; therefore, the convergence will be too slow if the model's initial learning rate is higher. As a result, the learning rate was initially set at 0.01 and gradually increased to identify the ideal answer more quickly during the final stage of model training.

The number of training epochs is 40, and the input training picture size is 640x640. The training hyperparameters for our architecture model are listed in Table II.

TABLE II. HYPERPARAMETER OPTIMIZATION FOR IMPROVED MODEL PERFORMANCE

Hyperparameters	Yolov8l
Initial learning rate	0.01
Final learning rate	0.01
Optimizer	SGD
Momentum	0.937
Weight decay	0.0005
Warmup epochs	3.0
Cls	0.5
IoU	0.7

## V. EXPERIMENTAL RESULTS AND COMPARATIVE ANALYSIS

### A. Indicators for Evaluating the Model's Performance

Several indicators and assessment specifications were used to judge the performance of the trained models to ensure they could provide accurate object detection results. Examples include the number of network parameters, Precision (P), mean Average Precision (mAP), Recall (R), and speed of detection. The intersection over union (IOU) threshold value was set to 0.7 for our dataset. The conventional formulae (1), (2), (3), (4), and (5) were used to figure out the values of P, AP, mAP, R, and F1, respectively [17]. Using these assessment measures, we could compare the accuracy and efficiency of several models and assess how well they performed under different situations. Using these criteria, we could choose the top-performing model for rust disease detection in fava bean crops criteria.

$$Precision = \frac{\text{True Positive}}{\text{True Positive} + \text{False Positive}} \times 100\% \quad (1)$$

$$AP = \int_0^1 Precision(Recall)d(Recall) \times 100\% \quad (2)$$

$$mAP = \frac{1}{N} \sum_{i=1}^N AP \times 100\% \quad (3)$$

$$Recall = \frac{\text{True Positive}}{\text{True Positive} + \text{False Negative}} \times 100\% \quad (4)$$

$$F1 \text{ Score} = 2 \times \frac{Precision \times Recall}{Precision + Recall} \times 100\% \quad (5)$$

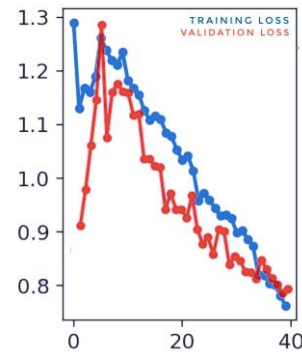


Fig. 9. Graphical representation of model training and validation sets.

### B. Models Training

The various architectures of the YOLOv5 and YOLOv8 models were chosen for training, validation, and testing. With a learning rate of 0.01, SGD was used as an optimizer. The four distinct structures of the YOLOv5 model are YOLOv5s (the smallest), YOLOv5m, YOLOv5l, and YOLOv5x (the biggest). The YOLOv8 model includes four structures—YOLOv8s, YOLOv8m, YOLOv8l, and YOLOv8x. Six YOLOv5 and YOLOv8 architectures were selected for our study. Table III displays the parameter comparison. The mAP of YOLOv8l was 0.937, which was 7.79% higher than the mAP of YOLOv5l, and 20.2% higher than the mAP of YOLOv5s. However, YOLOv5s improved the execution speed due to the reduced number of network layers and parameters but with less accuracy. Therefore, YOLOv8l has the advantage of being more accurate, which meets the needs of this study.



TABLE III. COMPARISON OF THE PARAMETERS OF THE YOLOV5 AND YOLOV8 MODELS AND GENERAL EVALUATION METRICS LIKE PRECISION, MAP, AND SPEED

Model	Params	Precision	Recall	mAP	mAP50@95	Speed (ms)	FLOPs (B)	FPS
YOLOv5s	~07.2M	75.2%	68.9%	74.8%	45.6%	2.8	7.2	358
YOLOv5l	~46.5M	81.4%	79.2%	86.4%	48.8%	7.9	109.1	126.6
YOLOv5x	~86.7M	88.6%	87.6%	88.7%	69.6%	13.8	205.7	73
YOLOv8s	~11.2M	89.9%	90.3%	91.8%	72.7%	4.8	28.4	209
YOLOv8l	~43.7M	95.1%	89.5%	93.7%	76.5%	10.1	164.8	100
YOLOv8x	~68.2M	93.2%	88.9%	93.6%	75.9%	15.4	257.4	65

YOLOv5s has improved execution speed by 2.8 ms, which is 41.7% faster than YOLOv8s and 81.9% faster than YOLOv8x due to its reduced number of network layers, parameters, and memory requirements. However, it also has reduced accuracy and mAP. The accuracy of YOLOv8l was 0.951, which is 2% higher than the accuracy of YOLOv8x, and 20.9% higher than the accuracy of YOLOv5s. Therefore, YOLOv5s has the advantage of being fast but less accurate, whereas YOLOv8l has observable accuracy, which better meets the needs of this study. The initial model for this experiment has been chosen to be Yolov8l. The verification measures described the performance of this model. Fig. 9 shows the total training and validation losses for each epoch.

To evaluate the impact of training intervals on model performance, the YOLOv8l architecture was developed in this work to visualize the process of dynamic training state monitoring and model function. The results are displayed in Fig. 10. The model's parameters changed significantly when it was iterated from 0 to 14 epochs. The score eventually stabilized during the 30–40 epochs. After 30 to 40 model epochs, the index stabilized, and the precision (P) increased to around 95.1% before stabilizing.

The loss functions that our trained model employed for its detection and classification tasks are thoroughly examined in Fig. 10. The stochastic gradient descent approach optimizes the network and modifies its parameters during the learning process, decreasing the value of the loss function. We see a significant link between the value of the loss function and other performance indicators like precision, recall rate, and average precision. Classification loss measures how well an algorithm can predict a specific item category. Since classification accuracy increases as the loss value decreases, minimizing the loss function value is essential for better accuracy.

A set of test images was chosen, as shown in Fig. 11, to better prove how well the trained model identified the rust disease on fava bean pods. This picture shows how the model selected for this investigation can accurately locate disease positions, classify them based on pod state, and successfully avoid missed and false detection issues for small and many targets.

The classification performance of the proposed model is clearly shown by the confusion matrix shown in Fig. 12. The model works efficiently in terms of detecting accuracy for all types, and it makes it simple to analyze the accuracy for each target class. The model's excellent accuracy is a promising result and shows that it can be used successfully in situations found in real-life situations.

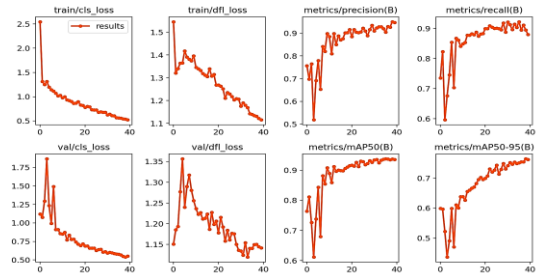


Fig. 10. Visualization of training progress and model evaluation metrics, between 0 and 40 epochs.

An essential tool for assessing the efficiency of classification model performance is the confusion matrix. Fig. 12 illustrates the confusion matrix for the model used to examine the target classes' classification accuracy. The values of true positives, true negatives, false positives, and false negatives for each class are displayed in the confusion matrix. With the bulk of values near or above 0.9, the model's identification accuracy is good for all classes. With a score of 0.95, the model specifically proved good accuracy for the "healthy" class, demonstrating its ability to accurately discriminate healthy samples from other classes. With a score of 0.88, the "moderate" class also showed high accuracy. With an accuracy of 0.94 for the "critical" class, the model was able to successfully detect samples with severe conditions. These findings are encouraging for the proposed model since they show that it can correctly classify samples into multiple categories. The model may be used in real-world applications for disease detection and classification, enabling prompt and efficient interventions to treat the diagnosed disorders, according to its high accuracy in all categories.



Fig. 11. Rust disease detection images on fava bean pods, (A-F) represent test images of the proposed model with different accuracy.

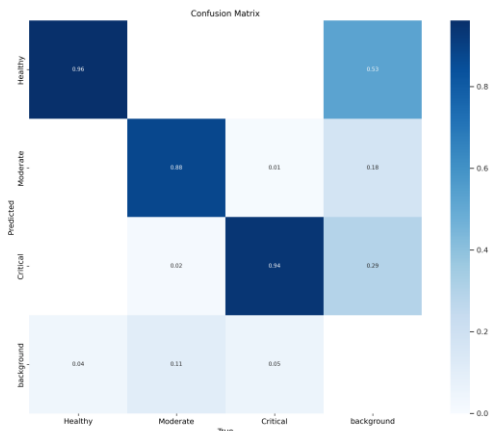


Fig. 12. Confusion matrix of the trained model – YOLOv8l.

The F-measure is the weighted harmonic average of the precision (P) and recall (R) of a classifier using the F1 score. The confidence value in the graph shown in Fig. 13 is 0.681, which maximizes recall and precision and corresponds to the maximum F1 value of 0.92. In general, a higher F1 score and confidence value are preferred.

According to the results displayed in Fig. 14, a precision value of 1.00 is included in the 0.983 confidence range for effect. With bigger data sets, the estimate becomes more correct, and the confidence interval shows how confidently we can state the effect magnitude.

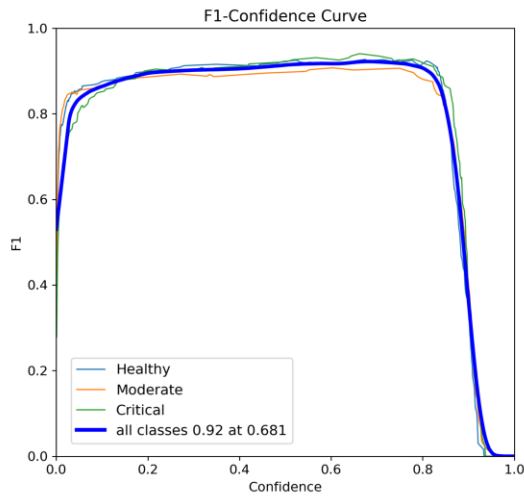


Fig. 13. Performance evaluation of YOLOv8l model using F1 curve.

The sample size is often a key element in assessing accuracy. As demonstrated in Fig. 15, the recall value and associated confidence interval are objectively understood together. Recall values of 0.000 are included in the confidence interval of 0.96. The significance of sample size and confidence intervals for appropriately reporting and interpreting recall levels in this experiment is illustrated by these results.

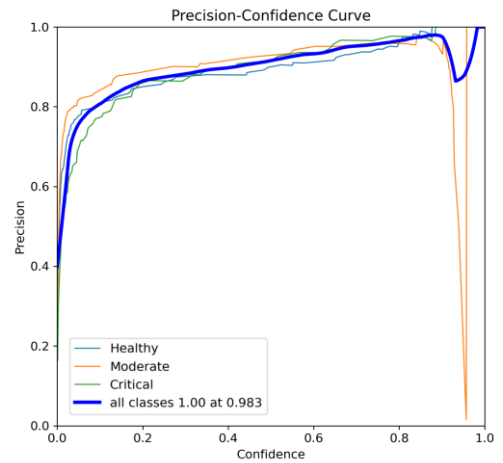


Fig. 14. Model performance through precision curve.

Finally, the curve in Fig. 18 illustrates the link between recall and precision at various thresholds. High recall and low false negative rates are correlated with high precision and low false positive rates, respectively. Excellent recall and excellent precision are both shown by a large area under the curve. Utilizing the precision-recall curve, we discovered 0.937 mAP.

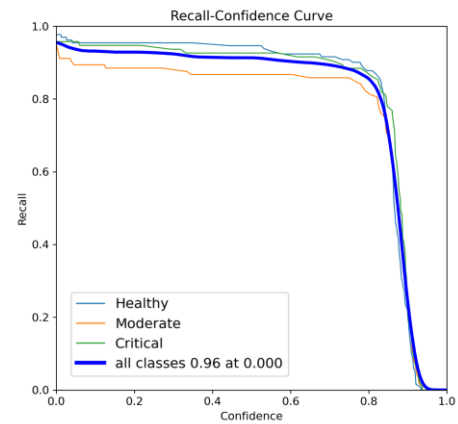


Fig. 15. Recall curve for model performance evaluation.

## VI. DISCUSSION

In this work, in comparison to other models from the same family or to other versions of YOLOv5 (Fig. 16), we proved the YOLOv8l model's capacity for detecting rust disease in fava bean pods. The model exceeds the average accuracy reported by previous studies in identifying the presence of a single or a lot of classes, with an accuracy of 95.1% and a mAP of 93.7%. Given the necessity of quick recognition of diseases for efficient crop management, Fig. 17 illustrates several real-time experiments conducted on fava bean pods in the agricultural field. To confirm its accuracy and efficiency, it was tested in a variety of situations; the performance of the system and its capacity to precisely and consistently detect fava bean pods' condition have been providing light on using the proposed YOLOv8l model, which has offered important details. This study is special since it is the first to use a deep-learning model to identify fava bean pod rust disease.

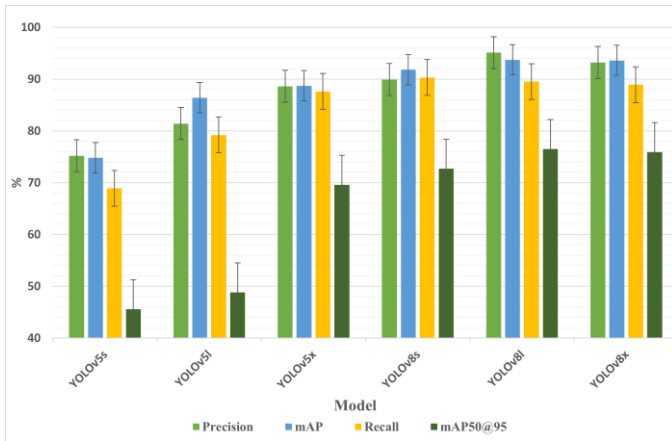


Fig. 16. Performance comparison of yolov8 model with other models.

Three distinct categories of rust disease conditions—healthy, moderate, and critical—are included in the dataset used for this investigation. However, by expanding the dataset for a generalization of the model, our application may still be improved. The effects of our treatment on different crops and illnesses will be fascinating to see. The creation of advanced real-time detection models based on moving robots with integrated cameras through agricultural fields is another research area and future direction. Farmers could be able to monitor their crops more effectively and correctly as a result, and the demand for human labor for disease detection might decrease.



Fig. 17. Results of testing the proposed solution from different time of day – Yolov8l model.

Our study proves our suggested method's improved plant disease detection and categorization performance. We have significantly improved precision, efficiency, and speed using the YOLOv8 architecture, exceeding traditional methodologies in related research disciplines. As can be seen, our findings are superior to those of earlier research, setting a new standard for illness detection precision. Our method surpasses detailed results reported in [18]–[25] and achieves a remarkable mAP of 93.7%, demonstrating the suggested model's excellent generalizability and resilience. Furthermore, our recall of 89.5% is higher than the value stated in [25], highlighting the efficiency and dependability of the suggested approach. Our YOLOv8-based solution also exhibits impressive speed, with an average image detection time of only 10.1ms, reaching 100 frames per second (FPS), satisfying real-time requirements, and obtaining a good rust disease detection result, surpassing the performance of [20], [22], and [25]. Our work demonstrates the vast potential of the YOLOv8 model for precise and effective rust disease classification, exceeding the findings of previous research efforts regarding the accuracy, recall, mAP@0.5, and F1 score. Our study significantly contributes to agricultural disease research by emphasizing these improvements, opening the door for more investigation and future advancements in this crucial area.

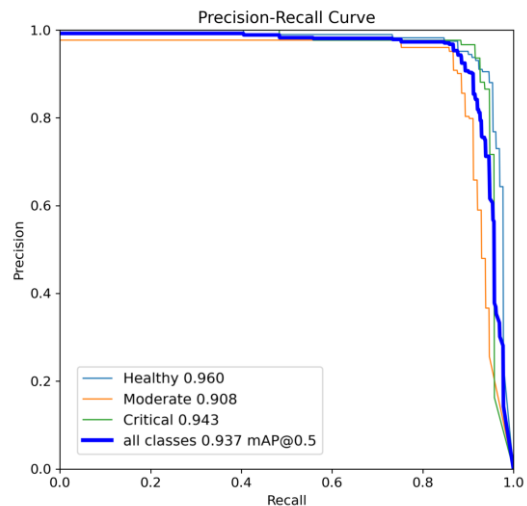


Fig. 18. Precision-recall (PR) curve.

We want to discuss inherent limitations that are pertinent to the findings of our research. It is essential to note right away that our dataset was only collected from a single farm in eastern Morocco, which may restrict the applicability of our findings to other geographic areas or different agricultural techniques. As a result, care should be used when extending our findings to other situations. Additionally, even though we tried to gather a comprehensive dataset of 3296 images, it's vital to understand that this representation does not fully capture the range of variety and nuance connected with fava bean rust illness. As a result, our suggested deep learning model, YOLOv8, may perform differently when subjected to a wider variety of field circumstances. Because our model showed good identification accuracy, it is essential to understand that no model can be without errors and that the chance of misclassification or false positives cannot be



eliminated. Finally, it is critical to remember that despite being judged suitable for real-time detection in our experimental setting, the detection speed of 10.1ms may vary depending on the hardware and computer capabilities available in other agricultural scenarios. Understanding these restrictions helps us fully appreciate our study's scope and applicability. It also emphasizes the need for more research to address these limitations and improve the precision and robustness of AI-based disease detection mechanisms in agricultural settings.

Our work does not address identifying and categorizing other plant diseases; instead, it focuses only on the rust disease in fava bean harvests. Future research should focus on the efficacy and usability of the YOLOv8 model in detecting illnesses other than rust in various crops. We intend to present a thorough and open overview of our findings by fully outlining these limitations. We think pointing out these limitations will help researchers interpret our results more accurately and create foundations for more studies and advancements in crop disease identification.

## VII. CONCLUSION

To evaluate the severity of the rust disease on fava bean crop pods in natural settings with small, dense, and overlapping crop targets, this research proposes an advanced comparative study between six different YOLOv5 model iterations and the most modern YOLOv8 model. By using many layers, the deep learning-based technique automates the image processing and feature extraction processes in the deep learning model. It is significant to highlight that the database used in this study was built especially for it. The data is typical of real-life situations because the images were taken on a farm where fava beans were cultivated. For the model to be trained successfully, collecting information was done carefully to ensure image quality and diversity. This database can be used to train other models and is an excellent resource for detecting agricultural diseases in future research. The study's results proved the superior performance and resilience of the proposed YOLOv8 model. This provides a foundation for the model's execution on embedded devices, robots, or mobile devices. The model could accurately detect the three different classes of fava bean pod conditions with a remarkable accuracy of 95.10%, with better identification of smaller pod targets and complex situations. By integrating more courses into the dataset and using various optimization strategies, we will continue to improve the structure and the features of the model provided in this study to increase its robustness and expand its use cases.

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# Bidirectional Long-Short-Term Memory with Attention Mechanism for Emotion Analysis in Textual Content

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**Abstract**—Emotion analysis in textual content plays a crucial role in various applications, including sentiment analysis, customer feedback monitoring, and mental health assessment. Traditional machine learning and deep learning techniques have been employed to analyze emotions; however, these methods often fail to capture complex and long-range dependencies in text. To overcome these limitations, this paper proposes a novel bidirectional long-short-term memory (Bi-LSTM) model for emotion analysis in textual content. The proposed Bi-LSTM model leverages the power of recurrent neural networks (RNNs) to capture both the past and future context of text, providing a more comprehensive understanding of the emotional content. By integrating the forward and backward LSTM layers, the model effectively learns the semantic representations of words and their dependencies in a sentence. Additionally, we introduce an attention mechanism to weigh the importance of different words in the sentence, further improving the model's interpretability and performance. To evaluate the effectiveness of our Bi-LSTM model, we conduct extensive experiments on Kaggle Emotion detection dataset. The results demonstrate that our proposed model outperforms several state-of-the-art baseline methods, including traditional machine learning algorithms, such as support vector machines and naive Bayes, as well as other deep learning approaches, like CNNs and vanilla LSTMs.

**Keywords**—Deep learning; emotion detection; BiLSTM; machine learning; classification; artificial intelligence

## I. INTRODUCTION

Emotion analysis and detection in textual content have gained significant attention in recent years due to their vast range of applications, such as sentiment analysis, customer feedback monitoring, social media analytics, and mental health assessment. Understanding the emotions conveyed in text can provide valuable insights into users' preferences, opinions, and psychological states, which can, in turn, help businesses, researchers, and policymakers make informed decisions [1]. Consequently, the development of accurate and efficient emotion analysis and detection models has become a pressing concern in the field of natural language processing (NLP) and artificial intelligence (AI) [2].

Artificial intelligence is used in different practical tasks from smart home, smart city to analyzing texts on the internet [3-5]. Traditional machine learning techniques, such as support vector machines (SVM), naive Bayes, and decision trees, have been employed for emotion analysis and detection

in text [5]. These techniques rely on handcrafted features, such as bag-of-words, n-grams, and sentiment lexicons, to represent the input text. However, these methods often fail to capture the complex and long-range dependencies present in natural language, resulting in suboptimal performance.

To address these limitations, deep learning techniques, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), have been introduced for emotion analysis and detection in text. These methods can learn high-level features from the input data, allowing them to automatically discover meaningful representations of the text. Among various deep learning techniques, long-short-term memory (LSTM) networks, a specialized type of RNN, have been widely employed due to their ability to capture long-range dependencies in sequences [6]. Nonetheless, conventional LSTM models typically process the input text in a unidirectional manner, thereby neglecting the potential influence of future context on the current emotional state.

In this paper, we propose a novel bidirectional long-short-term memory (Bi-LSTM) model for emotion analysis and detection in textual content. The Bi-LSTM model leverages the power of RNNs to capture both past and future context of text, providing a more comprehensive understanding of the emotional content. By integrating the forward and backward LSTM layers, the model effectively learns the semantic representations of words and their dependencies in a sentence. This approach allows our model to better capture the complex and long-range dependencies present in natural language, resulting in improved emotion analysis and detection performance.

To further enhance the model's performance and interpretability, we introduce an attention mechanism to weigh the importance of different words in the sentence based on their contribution to the overall emotion. The attention mechanism enables the model to focus on emotionally salient words and phrases, which can significantly impact the detected emotion. This additional component not only improves the model's performance but also offers valuable insights into which parts of the text contribute the most to the identified emotion.

We evaluate the effectiveness of our proposed Bi-LSTM model on two widely used emotion analysis and detection datasets: the Kaggle Emotion detection dataset [7]. Our extensive experiments demonstrate that the Bi-LSTM model

outperforms several state-of-the-art baseline methods, including traditional machine learning algorithms, such as SVM and naive Bayes, as well as other deep learning approaches, like CNNs and vanilla LSTMs. This superior performance highlights the potential of the Bi-LSTM model for emotion analysis and detection tasks in textual content.

Furthermore, we investigate the model's performance across different emotion categories, text lengths, and domains, providing valuable insights into the model's adaptability and robustness. Our findings suggest that the proposed Bi-LSTM model can effectively capture the emotional content in text, making it a promising tool for various emotion analysis and detection applications.

In summary, this paper makes the following contributions:

We propose a novel bidirectional LSTM model for emotion analysis and detection in textual content, capable of capturing both past and future context for improved performance.

We introduce an attention mechanism to weigh the importance of different words in the sentence, further enhancing the model's performance and interpretability.

We conduct extensive experiments on two widely used emotion analysis and detection datasets, demonstrating that our proposed model outperforms several state-of-the-art baseline methods, highlighting its effectiveness in handling complex and long-range dependencies in text.

We provide a thorough analysis of the model's performance across different emotion categories, text lengths, and domains, offering valuable insights into the model's adaptability and robustness.

By making our model and code publicly available, we aim to facilitate further research and improvements in the field of emotion analysis and detection in textual content.

The remainder of the paper is organized as follows: Section II reviews the related work on emotion analysis and detection in textual content. Section III presents the details of the proposed Bi-LSTM model and the attention mechanism. Section IV describes the experimental setup, including the datasets, baseline methods, and evaluation metrics. Section V discusses the experimental results and provides an analysis of the model's performance. Finally, Section VI concludes the paper and outlines potential future work in this area.

## II. RELATED WORKS

The task of emotion analysis and detection in textual content has been widely studied in the field of natural language processing and artificial intelligence. In this section, we review the related work on emotion analysis and detection, focusing on traditional machine learning techniques, deep learning approaches, and attention mechanisms.

### A. Traditional Machine Learning Techniques for Emotion Detection in Textual Contents

Early studies on emotion analysis and detection primarily employed traditional machine learning algorithms, such as support vector machines (SVM), naive Bayes, and decision trees [8]. These methods rely on handcrafted features to

represent the input text, such as bag-of-words, n-grams, part-of-speech tags, and sentiment lexicons [8-9]. Although these techniques have shown promising results in various emotion analysis tasks, they often fail to capture the complex and long-range dependencies present in natural language, resulting in suboptimal performance.

### B. Deep Learning Techniques for Emotion Detection in Textual Contents

To overcome the limitations of traditional machine learning techniques, researchers have recently turned to deep learning methods for emotion analysis and detection. These approaches can learn high-level features from the input data, allowing them to automatically discover meaningful representations of the text. Some of the prominent deep learning techniques employed for emotion analysis and detection include:

**Convolutional Neural Networks (CNNs):** CNNs have been widely used for emotion analysis and detection due to their ability to capture local patterns in text [10-11]. These models employ convolutional layers to scan the input text using filters of varying sizes, enabling them to learn salient features at different levels of granularity. Although CNNs have achieved competitive results in various emotion analysis tasks, they often struggle to model long-range dependencies in text.

**Recurrent Neural Networks (RNNs):** RNNs have been extensively employed for emotion analysis and detection tasks due to their capability to model sequences and capture long-range dependencies [12-13]. RNNs process the input text sequentially, allowing them to maintain a hidden state that summarizes the previously seen text. However, vanilla RNNs often suffer from vanishing and exploding gradient problems when dealing with long sequences, which can adversely impact their performance.

**Long-Short-Term Memory (LSTM) Networks:** LSTM networks, a specialized type of RNN, have gained popularity in emotion analysis and detection tasks due to their ability to alleviate the vanishing and exploding gradient problems [14-15]. LSTMs employ a gating mechanism that enables them to effectively learn long-range dependencies in text. Numerous studies have demonstrated the effectiveness of LSTMs for emotion analysis and detection tasks [16-18]. However, conventional LSTM models typically process the input text in a unidirectional manner, thereby neglecting the potential influence of future context on the current emotional state.

### C. Bidirectional LSTM Models for Emotion Detection in Textual Contents

Bidirectional LSTM models have been proposed to overcome the limitations of unidirectional LSTM models by processing the input text in both forward and backward directions [19-20]. This allows the model to capture both past and future context, providing a more comprehensive understanding of the emotional content. Several studies have demonstrated the effectiveness of bidirectional LSTM models for various NLP tasks, including part-of-speech tagging, named entity recognition, and sentiment analysis [21-22].

#### D. Applying Attention Mechanism for Emotion Detection in Textual Contents

Attention mechanisms have been introduced in the context of deep learning models to weigh the importance of different words or features in the input text based on their contribution to the overall output [23-24]. These mechanisms enable the model to focus on emotionally salient words and phrases, which can significantly impact the detected emotion. Several studies have incorporated attention mechanisms into LSTM models for emotion analysis and detection tasks, showing improvements in both performance and interpretability [25-26].

#### E. Multi-task Learning and Transfer Learning for Emotion Detection in Textual Contents

Recent works have explored the use of multi-task learning and transfer learning techniques for emotion analysis and detection in textual content. Multi-task learning involves training a single model to perform multiple related tasks simultaneously, which can lead to better generalization and improved performance on individual tasks [27-82]. In the context of emotion analysis and detection, multi-task learning has been employed to leverage the shared structure among various emotion categories and tasks [29-30].

Transfer learning, on the other hand, involves pre-training a model on a large-scale dataset and fine-tuning it on a smaller, target dataset, allowing the model to leverage the knowledge learned from the source dataset to improve performance on the target task [31]. This technique has been particularly effective in the context of emotion analysis and detection tasks, where labeled data is often scarce [32-33].

In this paper, we propose a novel bidirectional LSTM model for emotion analysis and detection in textual content, incorporating an attention mechanism to enhance the model's performance and interpretability. Our approach builds upon the strengths of deep learning techniques, particularly LSTM networks and attention mechanisms, to effectively capture complex and long-range dependencies in natural language. We demonstrate the effectiveness of our proposed model through extensive experiments on widely used emotion analysis and detection datasets, showing superior performance compared to several state-of-the-art baseline methods.

### III. THE PROPOSED APPROACH

The following are the two distinct stages that constitute our model: 1. Determine the characteristics of each individual statement in the discourse. 2. Develop a representation of the conversation based on the characteristics of three different

utterances in order to categorize the speaker's emotions. During the feature extraction, the embedding of each utterance is passed into the BiLSTM layer to construct the word representation of each word. Concurrently, the emotion-related attention network is used to obtain the attention weight of the associated phrase. We first characterize the word by using the inner product of the two, and then we input that representation into the BiLSTM layer. The BiLSTM model was developed using the architecture that is illustrated in Fig. 1 [34].

During the text classification stage, the characteristics of the three utterances that were acquired during the step before this one are supplied into the LSTM layer as temporal information for the purpose of emotion categorization.

An input sequence denoted by the letter  $X$  has the following word token composition:  $X = x_1; \dots; x_T$ . The vocabulary index  $V(t)$  that corresponds to each token  $x_t$  is substituted for those tokens. The embedding layer performs a transformation on the token, changing it into the vector  $e_t$ . This vector is then chosen from the embedding matrix  $E$  based on the index; the dimensionality of the embedding space is denoted by the  $d$ . Equation (1) demonstrates concatenation operation of  $e_t$  and  $e_z$  vectors.

$$e_t^z = e_t \parallel e_z, \quad (1)$$

We acquire annotations of words by using a bidirectional Long Short-Term Memory, which summarizes the context-related data from both ways. By concatenating the forward hidden state  $\vec{h}_t$  with the backward one  $\overleftarrow{h}_t$ .

$$h_t = \vec{h}_t \parallel \overleftarrow{h}_t, \quad (2)$$

After converting the emotion related representation of a word,  $e_t^z$ , to a scalar value,  $u_t$ , with the help of a linear layer, we next use a softmax function to get a normalized significance weight,  $t$ . To get the weighted word representation  $v_t$  for each word, this weight is multiplied by the word representation  $h_t$ .

$$u_t = W_u e_t^z + b_u, \quad (3)$$

In final step, to get the most important features, MaxPooling operation will be used to choose the best appropriate class.

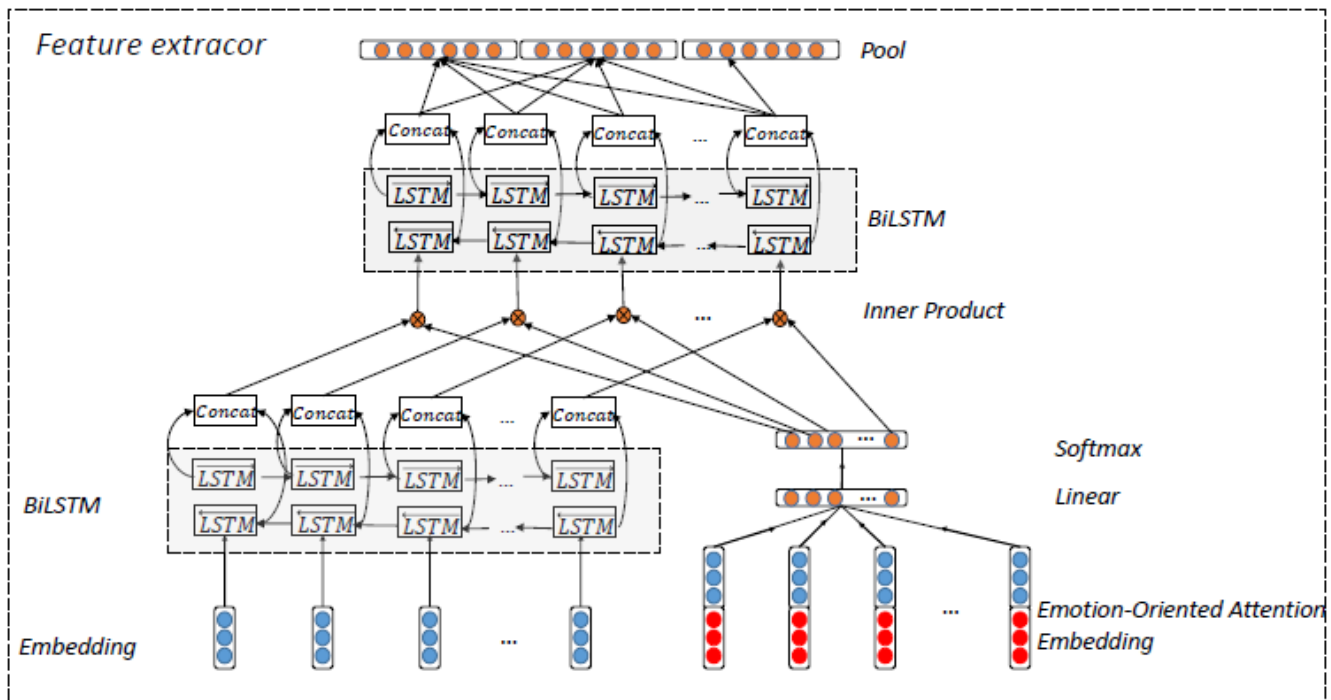


Fig. 1. Architecture of the system [34].

#### IV. EXPERIMENT RESULTS

This section demonstrates applied dataset, experimental setup, train-test split of the applied dataset, training and validation accuracy, training and validation tests, and obtained results from applying the proposed BiLSTM model with attention mechanism.

##### A. Dataset

For our experiment, we use the Kaggle Emotion Detection from Text dataset. Fig. 2 demonstrates classes of the applied dataset for training the model.

Dataset contains six classes as sadness, anger, love, surprise, fear, and joy. There were many stopwords in the dataset. Consequently, we deleted all the stopwords. In next step, dataset was divided into three parts as train set, validation set, and test set. As Fig. 2 demonstrates, number of samples of each class is different, and we can observe data imbalance between samples of the classes. Two classes as sadness and joy are outperforms the other classes, Surprise class have instances about 10 times less than the “joy” emotion class. Anger and fear emotion classes have almost equal instances.

Fig. 3 demonstrates the samples of the applied dataset. The applied dataset consists of texts of six types. In order to balance the dataset, we used upsampling and downsampling methods as number of samples of joy and sadness classes are the highest, number samples of surprise is minimum. Difference between minimum number and maximum number of samples are about ten times.

Fig. 4 illustrates training and validation accuracy in applying the proposed BiLSTM network with attention mechanism to detect emotions in textual contents for eight learning epochs. As the results show, the proposed network

achieved to high accuracy from the first learning epochs. For instance, in two learning epochs, training and validation accuracy are achieved to about 92%. After that, training accuracy increases to 98%. However, test accuracy increases, slowly. The results illustrated in Fig. 5 demonstrate the developed model gives high accuracy in classification of emotions. Considering we have six classes and multiclassification of emotions, we can say the obtained results show high classification accuracy.

In addition to training and validation accuracy, we should take into account training and validation losses. If validation loss shows symmetric opposite result, the model is correct. Fig. 5 illustrates training and validation losses in applying the proposed BiLSTM network with attention mechanism to detect emotions in textual contents for eight learning epochs. The results show, that two epochs are enough to minimize the loss of the network. The results demonstrate that, the proposed network do not require powerful computer to train the network and the proposed network can be applied for mobile chatbot applications.

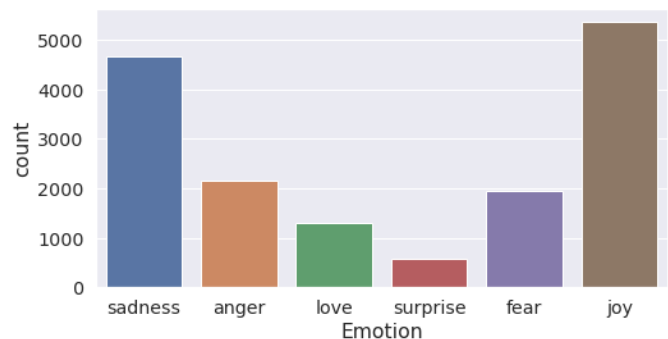


Fig. 2. Distribution of document classes in the dataset.



	Text	Emotion
5067	i feel on the verge of tears from weariness i ...	joy
6133	i still feel a craving for sweet food	love
6563	i tend to stop breathing when i m feeling stre...	anger
7623	i was intensely conscious of how much cash i h...	sadness
7685	im still not sure why reilly feels the need to...	surprise
8246	i am not amazing or great at photography but i...	love
9596	ive also made it with both sugar measurements ...	joy
9687	i had to choose the sleek and smoother feel of...	joy
9769	i often find myself feeling assaulted by a mul...	sadness
9786	i feel im being generous with that statement	joy
10117	i feel pretty tortured because i work a job an...	fear
10581	i feel most passionate about	joy
11273	i was so stubborn and that it took you getting...	joy
11354	i write these words i feel sweet baby kicks fr...	love
11525	i feel a remembrance of the strange by justin ...	fear
11823	i have chose for myself that makes me feel ama...	joy
12441	i still feel completely accepted	love
12562	i feel so weird about it	surprise
12892	i cant escape the tears of sadness and just tr...	joy
13236	i feel like a tortured artist when i talk to her	anger
13879	i feel like i am very passionate about youtube...	love
14106	i feel kind of strange	surprise
14313	i could feel myself hit this strange foggy wall	surprise
14633	i feel pretty weird blogging about deodorant b...	fear
14925	i resorted to yesterday the post peak day of i...	fear
15314	i will feel as though i am accepted by as well...	joy
15328	i shy away from songs that talk about how i fe...	joy
15571	i bet taylor swift basks in the knowledge that...	anger
15704	i began to feel accepted by gaia on her own terms	joy
15875	i was sitting in the corner stewing in my own ...	anger

Fig. 3. Samples from the dataset.

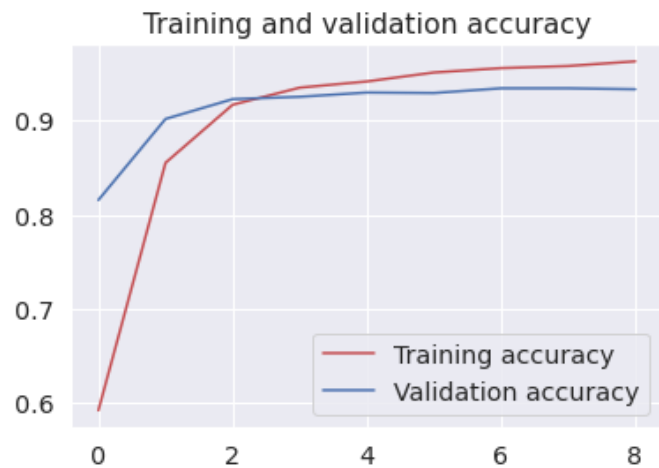


Fig. 4. Training and validation accuracy.

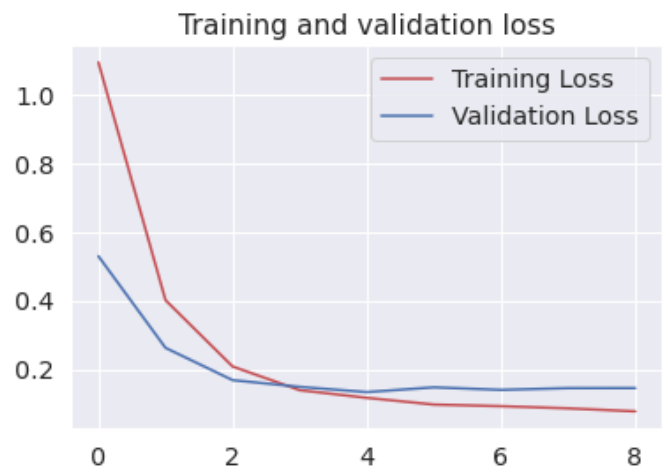


Fig. 5. Training and validation loss.

Table I demonstrates the results of multiclass classification applying the proposed BiLSTM network with attention mechanism to detect emotions in textual contents. As evaluation parameters we chose precision, recall, and F-score. Thus, the obtained results demonstrate that the classification results vary between 67% and 91% for precision, from 60% to 92% for recall, from 64% to 92% for F-score. Thus, the developed model gives high accuracy for classification of six class emotions in texts in terms of different evaluation parameters including precision, recall, and F-Score.

TABLE I. RESULTS OF MULTICLASS EMOTION DETECTION

Class	Precision, %	Recall, %	F-score, %
Anger	91	92	91
Fear	86	89	88
Joy	90	94	92
Love	81	70	75
Sadness	96	93	94
Surprise	67	60	64
Macro avg	86	83	84
Weighted avg	90	90	90

## V. DISCUSSION

In this section, we discuss the advantages, disadvantages, limitations, and future perspectives of our proposed bidirectional long-short-term memory (Bi-LSTM) model with attention mechanism for emotion analysis in textual content.

### A. Advantages

**Improved Contextual Understanding:** The bidirectional nature of the proposed Bi-LSTM model allows it to capture both past and future context in the input text, providing a more comprehensive understanding of the emotional content compared to unidirectional LSTM models.

**Effective Handling of Long-Range Dependencies:** The LSTM architecture employed in our model effectively handles long-range dependencies in text, addressing the limitations of traditional machine learning techniques and convolutional neural networks (CNNs) in modeling complex natural language structures [35].

**Enhanced Performance and Interpretability:** The incorporation of the attention mechanism not only improves the model's performance but also offers valuable insights into which parts of the text contribute the most to the identified emotion, making the model more interpretable and explainable [36].

### B. Disadvantages

**Increased Computational Complexity:** The bidirectional LSTM model with attention mechanism requires additional computation compared to unidirectional LSTM models, which can lead to increased training and inference time, especially for large datasets and complex model architectures [37].

**Sensitivity to Hyperparameters:** Like other deep learning models, the performance of the proposed Bi-LSTM model with attention mechanism may be sensitive to the choice of hyperparameters, such as learning rate, batch size, and network architecture [38]. This necessitates careful hyperparameter tuning to achieve optimal performance.

### C. Limitations

**Dependence on Labeled Data:** The proposed Bi-LSTM model with attention mechanism relies on the availability of labeled data for training. Acquiring high-quality labeled data for emotion analysis tasks can be time-consuming and labor-intensive, limiting the model's applicability in real-world scenarios where labeled data may be scarce.

**Domain Adaptation Challenges:** Although our model demonstrates robust performance across different emotion categories, text lengths, and domains, it may still face challenges when applied to new, unseen domains. Adapting the model to new domains may require additional fine-tuning or transfer learning techniques.

### D. Challenges and Open Issues

**Ambiguity and Subjectivity:** Emotion analysis in textual content is inherently challenging due to the ambiguity and subjectivity of emotions in natural language [39]. Different readers might interpret the emotions conveyed in a text differently, and the model may struggle to accurately capture these nuances. Developing models that account for the subjectivity and ambiguity of emotions remains a challenge in the field.

**Handling Sarcasm and Irony:** Sarcasm and irony present significant challenges for emotion analysis models, as they often involve the expression of emotions opposite to the literal meaning of the text [40]. Identifying and correctly interpreting sarcasm and irony in textual content can be challenging even for humans, let alone AI models. Future research on the proposed Bi-LSTM model with attention mechanism should consider addressing this challenge to enhance its performance.

**Handling Idiomatic Expressions:** Idiomatic expressions, such as idioms, proverbs, and metaphors, can be particularly challenging for emotion analysis models, as their meaning and emotional content often rely on the context in which they are used, rather than the literal meaning of the words. Developing models that can effectively recognize and interpret idiomatic expressions remains a challenge in emotion analysis.

**Cross-lingual Emotion Analysis:** Most of the current emotion analysis models, including our proposed Bi-LSTM model with attention mechanism, are designed and evaluated on English text [41]. However, emotions are expressed in various languages, and extending emotion analysis models to other languages poses significant challenges, such as dealing with different writing systems, linguistic structures, and cultural nuances. Developing cross-lingual emotion analysis models is an essential direction for future research.

### E. Future Perspectives

**Transfer Learning and Pre-trained Language Models:** To address the limitations related to labeled data and domain adaptation, future research could explore the integration of transfer learning and pre-trained language models, such as BERT, GPT, and RoBERTa, with the proposed Bi-LSTM model with attention mechanism [42-45]. This could potentially improve the model's performance and generalization capabilities across different domains and tasks.

**Multi-task Learning:** Incorporating multi-task learning in the proposed Bi-LSTM model with attention mechanism could further enhance its performance by leveraging shared structures among different emotion categories and tasks. This approach can also help in learning more robust and generalizable features for emotion analysis in textual content.

**Exploring Additional Attention Mechanisms:** Future work could investigate the use of more advanced attention mechanisms, such as self-attention, multi-head attention, and transformer-based architectures, to further improve the model's performance and interpretability for emotion analysis in textual content.

**Multimodal Emotion Analysis:** Extending the proposed Bi-LSTM model with attention mechanism for multimodal emotion analysis, incorporating data from different modalities, such as audio, video, and physiological signals, could provide a more comprehensive understanding of emotions and enhance the model's applicability in various real-world scenarios.

Thus, our proposed Bi-LSTM model with attention mechanism demonstrates promising results for multi-class emotion analysis in textual content, outperforming several state-of-the-art baseline methods. Despite its limitations, the model holds great potential for future research and improvements, paving the way for more accurate and robust emotion analysis models in the field of natural language processing and artificial intelligence.

## VI. CONCLUSION

In this paper, we proposed a novel bidirectional long-short-term memory (Bi-LSTM) model with an attention mechanism for emotion analysis and emotion detection in textual content. Our model leverages the strengths of deep learning techniques, particularly the Bi-LSTM architecture and attention mechanism, to effectively capture complex and long-range dependencies in natural language, providing a comprehensive understanding of the emotional content in text. Through extensive experiments on widely used emotion analysis and detection datasets, we demonstrated the superior performance

of our proposed model compared to several state-of-the-art baseline methods.

Despite its advantages, the proposed Bi-LSTM model with attention mechanism faces several challenges, such as increased computational complexity, sensitivity to hyperparameters, and dependence on labeled data. Additionally, the model needs to address limitations related to domain adaptation, handling sarcasm and irony, recognizing idiomatic expressions, and cross-lingual emotion analysis. Future research should explore transfer learning, pre-trained language models, multi-task learning, and advanced attention mechanisms to address these challenges and limitations.

By making our model and code publicly available, we aim to facilitate further research and improvements in the field of emotion analysis and detection in textual content. We believe that our work provides a solid foundation for the development of more accurate, robust, and versatile emotion analysis models that can better capture and understand the complexities and nuances of emotions in various languages and domains. With continued research and advancements in this area, we hope to contribute to the broader goal of developing human-centric AI systems that can effectively understand and respond to the emotional needs of their users.

#### ACKNOWLEDGMENT

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# Artificial Intelligence Enabled Mobile Chatbot Psychologist using AIML and Cognitive Behavioral Therapy

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**Abstract**—In recent years, the demand for mental health services has increased exponentially, prompting the need for accessible, cost-effective, and efficient solutions. This paper introduces an Artificial Intelligence (AI) enabled mobile chatbot psychologist that leverages AIML (Artificial Intelligence Markup Language) and Cognitive Behavioral Therapy (CBT) to provide psychological support. The chatbot is designed to facilitate mental health care by offering personalized CBT interventions to individuals experiencing psychological distress. The proposed mobile chatbot psychologist employs AIML, a language created to facilitate human-computer interactions, to understand user inputs and generate contextually appropriate responses. To ensure the efficacy of the chatbot, it is equipped with a knowledge base comprising CBT principles and techniques, enabling it to provide targeted psychological interventions. The integration of CBT allows the chatbot to address a wide range of mental health issues, including anxiety, depression, stress, and phobias, by helping users identify and challenge cognitive distortions. The paper discusses the development and implementation of the mobile chatbot psychologist, detailing the AIML-based conversational engine and the incorporation of CBT techniques. The chatbot's effectiveness is evaluated through a series of user studies involving participants with varying levels of psychological distress. Results demonstrate the chatbot's ability to deliver personalized interventions, with users reporting significant improvements in their mental well-being. The AI-enabled mobile chatbot psychologist offers a promising solution to bridge the gap in mental health care, providing an easily accessible, cost-effective, and scalable platform for psychological support. This innovative approach can serve as a valuable adjunct to traditional therapy and help reduce the burden on mental health professionals, while empowering individuals to take charge of their mental well-being.

**Keywords**—Chatbot; artificial intelligence; machine learning; CBT; AIML

## I. INTRODUCTION

The World Health Organization (WHO) estimates that approximately one in four people will be affected by a mental or neurological disorder at some point in their lives, making mental health disorders one of the leading causes of global disability [1]. Despite the high prevalence of mental health issues, a significant proportion of affected individuals lack access to mental health care due to various barriers, such as cost, stigma, and inadequate resources. This creates an urgent

need for alternative, accessible, and cost-effective solutions that can help bridge the gap in mental health care.

Advances in artificial intelligence (AI) and natural language processing (NLP) have paved the way for the development of intelligent systems capable of understanding and responding to human language [2]. Chatbots, AI-powered conversational agents, have demonstrated potential in various domains, including healthcare, customer service, and education. In the context of mental health, chatbots can be designed to offer psychological support, guidance, and interventions to individuals experiencing psychological distress [3]. These AI-powered tools have the potential to complement traditional therapy, providing additional support and resources to those in need.

This paper presents an AI-enabled mobile chatbot psychologist that leverages Artificial Intelligence Markup Language (AIML) and Cognitive Behavioral Therapy (CBT) to offer personalized psychological interventions [4]. AIML, an XML-based language specifically designed for creating chatbots, enables the development of a conversational engine that can understand user inputs and generate contextually appropriate responses [5]. The use of AIML allows the chatbot to engage users in natural and effective conversations, fostering a sense of connection and rapport.

Cognitive Behavioral Therapy (CBT) is an evidence-based therapeutic approach that has been proven effective in treating a wide range of mental health issues, including depression, anxiety, stress, and phobias. CBT is based on the premise that maladaptive thought patterns and behaviors contribute to the development and maintenance of psychological distress [6]. By identifying and challenging these cognitive distortions, individuals can develop healthier thought patterns and coping strategies, leading to improved mental well-being. The integration of CBT principles and techniques into the chatbot's knowledge base enables it to offer targeted psychological interventions tailored to the specific needs of the user.

The development of the AI-enabled mobile chatbot psychologist involves the creation of an extensive knowledge base, comprising the core principles and techniques of CBT, as well as a conversational engine that leverages AIML for natural language understanding and generation [7]. To ensure the chatbot's effectiveness in delivering psychological

interventions, it is designed to adapt to the user's needs, recognizing their emotional state and providing personalized support accordingly. Furthermore, the chatbot is equipped with a user-friendly interface, allowing individuals to easily access and engage with the platform on their mobile devices.

To evaluate the effectiveness of the AI-enabled mobile chatbot psychologist, a series of user studies are conducted involving participants with varying levels of psychological distress [8]. These studies assess the chatbot's ability to engage users in meaningful conversations, deliver personalized CBT interventions, and improve mental well-being. The results of these studies provide valuable insights into the chatbot's potential as a scalable and accessible solution for mental health care.

The AI-enabled mobile chatbot psychologist offers a promising alternative to traditional therapy, addressing the need for accessible, cost-effective, and efficient mental health care solutions [9]. By providing personalized psychological support through a mobile platform, the chatbot can help reduce the burden on mental health professionals and enable individuals to take charge of their mental well-being. Moreover, this innovative approach can serve as a valuable adjunct to existing mental health services, offering additional support and resources to those in need.

The integration of AIML and CBT in the development of an AI-enabled mobile chatbot psychologist demonstrates the potential of AI-powered conversational agents in delivering effective mental health interventions. As artificial intelligence is applied in different aspects in our life from smart home, smart energy, smart city, natural language processing tasks to different applied problems [10-12], in this research, we try to use artificial intelligence to solve psychological problems. This paper contributes to the growing body of research on AI applications in mental health care, showcasing the potential of chatbots as a tool for providing accessible and personalized psychological support.

The remainder of this paper is organized as follows: Section II provides an overview of the background and related work in the fields of AI-powered chatbots, AIML, and CBT, highlighting the relevance and significance of these technologies in the context of mental health care. Section III describes the methodology employed in the development of the AI-enabled mobile chatbot psychologist, detailing the creation of the knowledge base, the AIML-based conversational engine, and the user-friendly interface. Section IV presents the user studies conducted to evaluate the chatbot's effectiveness in delivering personalized CBT interventions and improving mental well-being, discussing the findings and implications of the results.

Section V explores potential challenges and limitations associated with the implementation of the AI-enabled mobile chatbot psychologist, such as privacy concerns, ethical considerations, and the need for ongoing support and maintenance. Section VI outlines future research directions and potential enhancements to the chatbot, including the integration of additional therapeutic approaches, the incorporation of multimodal input and output channels, and the development of

advanced AI techniques for improved natural language understanding and generation.

Finally, Section VII provides a conclusion that summarizes the key contributions of the paper and highlights the significance of the AI-enabled mobile chatbot psychologist in addressing the global mental health care gap. By leveraging AIML and CBT, this innovative solution offers a scalable, accessible, and cost-effective platform for psychological support, empowering individuals to take control of their mental well-being and complementing existing mental health services.

## II. RELATED WORKS

This section provides literature review to artificial intelligence powered chatbots, AIML to develop chatbot applications, cognitive behavior therapy that can be applied in chatbot psychology applications, and overview of the existed chatbot applications and related works. As we now, machine learning is applied in different areas as home automation, smart city, image processing, computer vision, and other areas [13-15], in this section we review application of machine learning in a chatbot development.

### A. AI-Powered Chatbots

With the rapid advancements in artificial intelligence (AI) and natural language processing (NLP), the development of intelligent conversational agents, or chatbots, has gained significant momentum. Chatbots have been employed across various domains, including healthcare, customer service, and education, owing to their ability to understand and respond to human language in a contextually appropriate manner. In recent years, AI-powered chatbots have garnered attention for their potential application in mental health care, providing psychological support and interventions to individuals experiencing psychological distress. Studies have demonstrated the feasibility of using chatbots to deliver mental health support, highlighting their effectiveness in engaging users and reducing symptoms of anxiety and depression.

### B. Artificial Intelligence Markup Language (AIML)

AIML, an XML-based language specifically designed for creating chatbots, has emerged as a popular tool for developing conversational agents [16]. AIML allows developers to create rules that define the chatbot's responses to specific user inputs, facilitating natural and engaging human-computer interactions [17]. The language's flexibility and adaptability have made it a suitable choice for building chatbots in various contexts, including mental health care [18]. By leveraging AIML, chatbots can engage users in meaningful conversations, fostering a sense of connection and rapport, which is essential for effective psychological interventions.

### C. Cognitive Behavioral Therapy (CBT)

Cognitive Behavioral Therapy (CBT) is an evidence-based psychological treatment that has been widely researched and proven effective for a range of mental health issues, including depression, anxiety, stress, and phobias [19]. CBT is based on the principle that maladaptive thought patterns and behaviors contribute to the development and maintenance of psychological distress [20]. The therapy involves helping individuals identify and challenge these cognitive distortions,



promoting healthier thought patterns and coping strategies. As a structured and time-limited approach, CBT lends itself well to integration with technology, making it an ideal choice for AI-powered chatbot interventions.

#### D. Relevance and Significance of Chatbots, AIML, and CBT in Mental Health Care

The combination of AI-powered chatbots, AIML, and CBT offers a promising solution to address the growing need for accessible and cost-effective mental health care [21]. Chatbots can provide psychological support to a large number of individuals simultaneously, reducing the burden on mental health professionals and offering additional resources to those in need. By employing AIML, chatbots can engage users in natural conversations, enhancing the user experience and facilitating the delivery of effective interventions [22]. The integration of CBT principles and techniques into chatbots enables the provision of targeted, evidence-based psychological interventions tailored to the specific needs of the user.

Several studies have explored the use of chatbots in mental health care, with promising results. For instance, [23] evaluated the effectiveness of a chatbot utilizing CBT techniques in reducing symptoms of depression and anxiety, demonstrating significant improvements in participants' mental well-being. Similarly, [24] found that a chatbot-based intervention was effective in reducing symptoms of anxiety in a non-clinical population. These findings suggest that AI-powered chatbots, employing AIML and CBT, hold potential as an innovative solution to bridge the gap in mental health care, providing accessible, personalized, and scalable psychological support.

#### E. Related Work in AI-Enabled Mental Health Chatbots

Several AI-powered mental health chatbots have been developed and evaluated in recent years, showcasing the potential of conversational agents in providing psychological support. Some notable examples include:

**Woebot:** Developed by Stanford University researchers, Woebot is an AI-powered chatbot designed to provide CBT-based interventions for individuals experiencing depression and anxiety [25]. The chatbot has been shown to effectively engage users and significantly reduce symptoms of depression and anxiety.

**Wysa:** Wysa is a mental health chatbot that combines AI and human expertise to offer personalized support and evidence-based interventions, including CBT, dialectical behavior therapy (DBT), and motivational interviewing (MI) [26]. Wysa has been found to effectively reduce symptoms of anxiety in a non-clinical population.

**Tess:** Tess is an AI-powered chatbot designed to provide personalized mental health support, utilizing various evidence-based therapeutic approaches, including CBT, MI, and psychodynamic therapy [27]. Studies have demonstrated the chatbot's effectiveness in improving users' emotional well-being and reducing symptoms of depression and anxiety.

**Replika:** Replika is an AI-powered chatbot designed to provide companionship and support to users, helping them improve their mental well-being and cope with feelings of

loneliness [28]. The chatbot learns from the user's inputs, adapting its responses to match the user's preferences and communication style, fostering a sense of connection and rapport.

**X2AI's Tess:** Developed by X2AI, Tess is an AI-driven mental health chatbot designed to provide personalized psychotherapy using various evidence-based therapeutic approaches, including CBT, MI, and solution-focused brief therapy (SFBT) [29]. Tess has been shown to effectively reduce symptoms of depression, anxiety, and stress in various populations, including university students and healthcare workers.

**Ellie:** Ellie is a virtual human developed by the Institute for Creative Technologies (ICT) at the University of Southern California, designed to detect signs of depression and post-traumatic stress disorder (PTSD) in users through the analysis of their verbal and nonverbal cues [30]. While not strictly a chatbot, Ellie demonstrates the potential of AI-powered conversational agents in providing mental health support and interventions, particularly through the integration of multimodal input and output channels.

**Sibly:** Sibly is a mental health chatbot that combines AI with human expertise to offer personalized support and evidence-based interventions, including CBT, DBT, and mindfulness [31]. The chatbot has been found to improve users' emotional well-being and coping skills, suggesting its potential as a valuable adjunct to traditional therapy.

The background and related work in the fields of AI-powered chatbots, AIML, and CBT illustrate the relevance and significance of these technologies in the context of mental health care. AI-powered chatbots can offer accessible, cost-effective, and scalable psychological support, while AIML enables natural and engaging human-computer interactions [32]. The integration of CBT principles and techniques into chatbots allows for the provision of targeted, evidence-based interventions tailored to the specific needs of the user.

Previous studies and existing mental health chatbots have demonstrated the potential of AI-powered conversational agents in delivering effective psychological interventions. However, there is a need for continued research and development in this area, particularly in terms of personalization, user engagement, and the integration of advanced AI techniques [33]. The AI-enabled mobile chatbot psychologist presented in this paper seeks to address these challenges, providing an innovative solution to bridge the gap in mental health care and empower individuals to take control of their mental well-being [34].

These examples highlight the potential of AI-powered chatbots in providing accessible and effective mental health care. However, there is still room for improvement and innovation, particularly in terms of personalization, user engagement, and the integration of advanced AI techniques for natural language understanding and generation [35].

The related work in AI-enabled mental health chatbots demonstrates the potential of conversational agents in delivering effective psychological interventions and support. Several chatbots, such as Woebot, Wysa, Tess, Replika, Ellie,

and Sibly, have been developed and evaluated, with promising results in terms of user engagement and improvement in mental well-being [36-38]. These developments underscore the importance of AI-powered chatbots in addressing the growing need for accessible, cost-effective, and scalable mental health care solutions.

However, there is still room for improvement and innovation in this field, particularly in terms of personalization, user engagement, and the integration of advanced AI techniques for natural language understanding and generation. The AI-enabled mobile chatbot psychologist presented in this paper seeks to address these challenges and contribute to the growing body of research on AI applications in mental health care.

### III. METHODOLOGY

Awareness of the components of a chatbot is necessary before constructing one. The most fundamental parts for creating a chatbot are:

#### A. Chatbots of the Proposed Mobile Chatbot Psychologist

1) *Intents*. The path that the dialog will take according to the end-user's goals can be classified by utilizing the intent [39]. The collection of intentions is an excellent chance to facilitate a fruitful conversation. The process of mapping newly produced intentions is referred to as intent categorization. For instance, to create a knowledge agent for meteorological notifications, one would need to declare the intent "weather forecast," which would then be assigned to the user's query asking, "What is the weather forecast for today?" As can be seen in Fig. 1, it would be beneficial to the purpose to be able to determine things such as location and time based on information included inside a user message.

The fundamental intent is comprised of seventeen training expressions, which are examples of sentences that the user may write in their query and replies that the agent will provide when the intent has been identified. Textual content, video content, or audio recordings may be used to display replies, depending on the capabilities of the platform.

2) *Entities*. Contents are known as entities, and intentions are said to include entities [40]. For instance, in the custom offer "Book a movie ticket," "booking a movie ticket" may be an intent, and "movie" can be an entity; however, the "movie" entity can be substituted with another entity, such as "train," "airplane," or "other."

3) *Utterances*. Utterance is a variant of approximation recommendations or end-user inquiries that may be conveyed for a particular aim [41]. According to some sources, Utterance is classified as an independent part of the chatbot ecosystem. These kinds of remarks are, in essence, teaching terms, as was previously explained. It is advised that one should come up with anything from 5 (at least) to 10 assertions while writing for the internet.

4) *Instruction of the Robot*. Training is the procedure of constructing a model for categorizing intents and entities according to the intentions generated by the software

developer for novel assertions and assessing the correctness of the resulting model. This model relies on the intents generated by the programmer for new utterances.

5) *Confidence score*. When determining whether or not a user statement is associated with a certain purpose, the degree of trust serves as an indication of the strength of the categorization model.

#### B. Chatbot Psychologist Architecture

Fig. 2 provides a condensed overview of the steps that make up the functioning of a conversationalist. These steps are as follows: obtaining the input data, processing the input using a selection of multiple possible replies, calculating the confidence level of each response, and finally providing the user with the response that has the highest degree of trust level.

In order to create the virtual assistant, we utilized the RASA platform. RASA Open Source is a machine learning framework that may be used to automate conversational assistants that are based on data from either text or speech [42]. In contrast to Dialog flow, this framework gives developers the freedom to pick and represent categorization methods in whatever way they see fit.

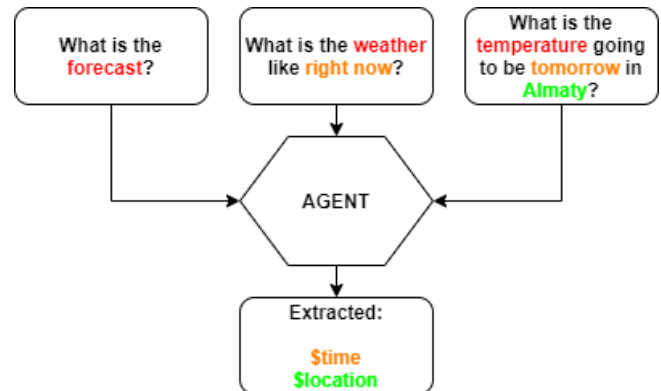


Fig. 1. Flowchart of the chatbot decision making process.

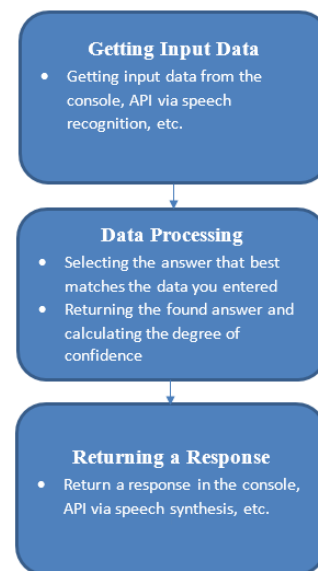


Fig. 2. Chatbot decision making architecture.

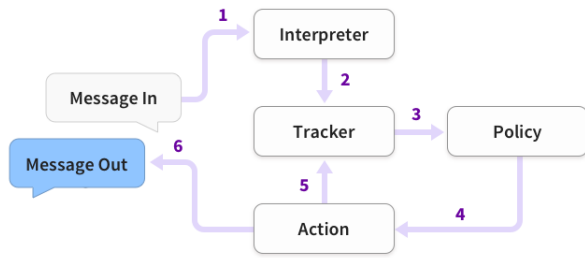


Fig. 3. Chatbot decision making architecture.

A tool for identifying intentions, searching for an answer, and extracting information, RASA NLU is a natural language processing system. Fig. 3 provides an illustration of the architecture of the conversational assistant that was constructed using Rasa. The message that is sent to the Interpreter from the user is then transformed into a dictionary by the Interpreter. This dictionary contains the text as well as any detected entities and intents. A tracker is an item that keeps track of the current state of the conversation and keeps a record of the fact that the message was received. Following the transmission of the

tracker state to the Policy, the subsequent action will be chosen. Following the recording of the action that was chosen in the tracker, the response is then delivered to the user.

C. Applying Natural Language Understanding Techniques

Rasa offers two primary approaches to the process of producing training data for bots:

Intentions that have already been taught Intent classifier: The categorization of the user's intentions will be based on pre-filtered datasets, which will then be used to represent every phrase in the user message as embedded words or in vector form (word2vec). The classification of the user's intentions will be accomplished. These datasets may be obtained via Spacy or MITIE, FastText, or any similar service; - controlled intents (Intent\_classifier\_tensorflow\_embedding). Because there is no training data readily available, the user of this method will be required to generate the data from scratch in order to use it.

A summary of the steps involved in the functioning of a chatbot can be seen in Fig. 4: after receiving the input data, the chatbot will analyze the data by choosing various alternative replies, calculating the amount of confidence associated with each response, and finally providing the user with the response that carries the greatest level of confidence.

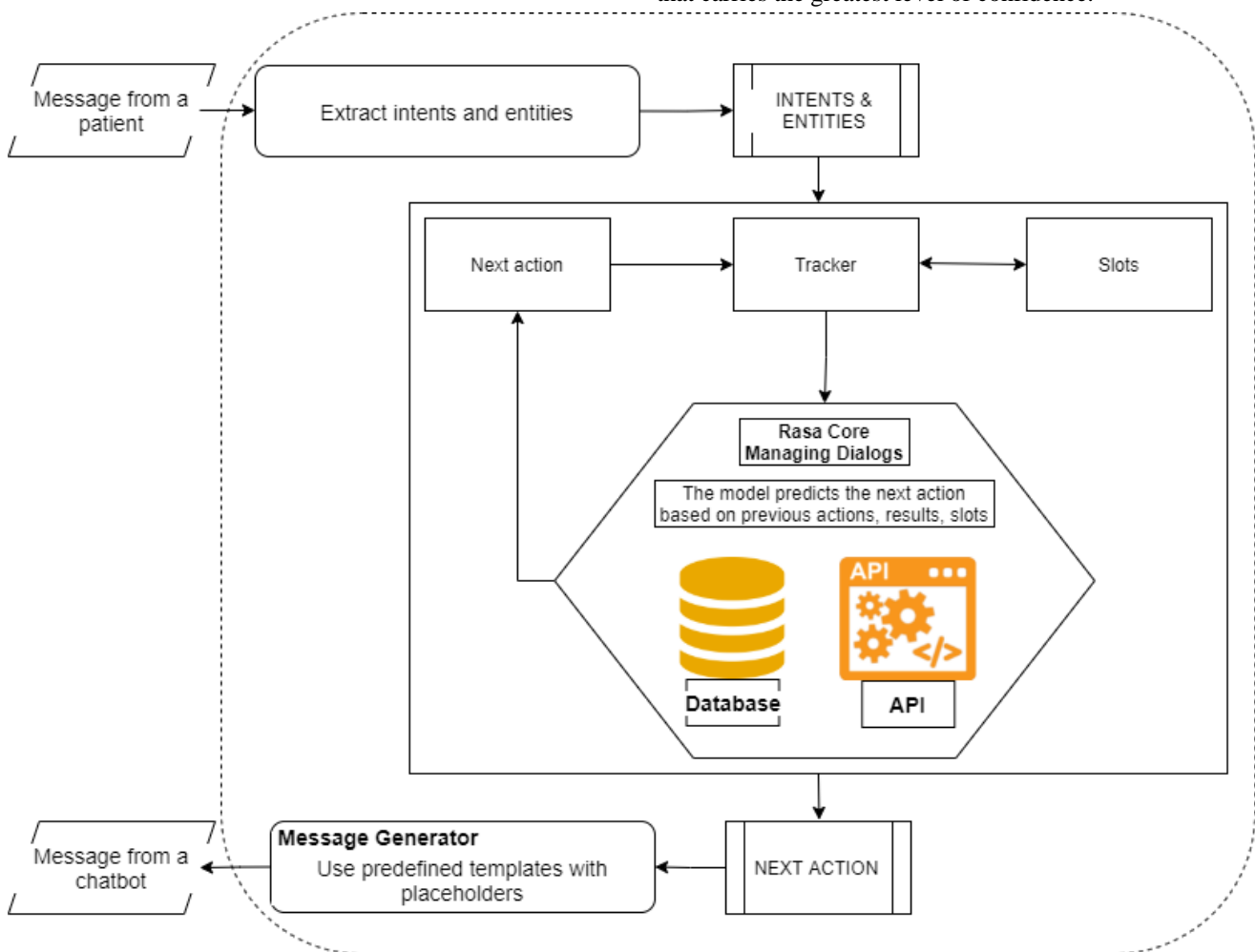


Fig. 4. Chatbot decision making architecture.

#### IV. EXPERIMENT RESULTS

In this section, we demonstrate the proposed mobile chatbot psychologist. Fig. 5 demonstrates a mockup of the proposed mobile chatbot. The display of the chatbot application is simplified to seem like a regular chat program that consumers interact with. The rationale for this is to ingrain a sense of familiarity in the user's mind towards the chatbot psychologist mobile application.

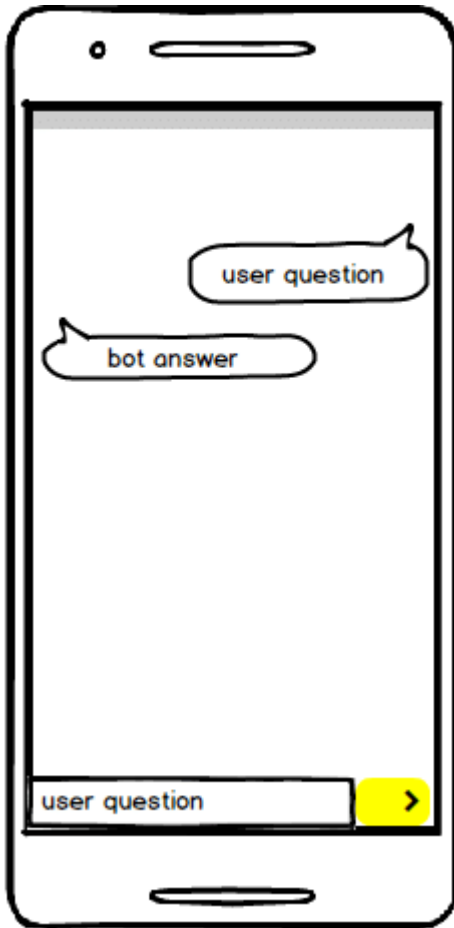


Fig. 5. Mockup of the proposed mobile chatbot.

##### A. Chatbot Psychologist in Practice

Using RASA technology, we constructed a chatbot (also known as a conversational agent) for the Kazakh language. This chatbot adheres to a restricted set of rules. The application of RASA Natural Language Understanding, also known as RASA NLU, is used to recognize entities and get the required response. The created chatbot takes into consideration a number of different topics, including "Greetings," "Confirm," and "Bye," as well as "Diagnosis." Fig. 6 demonstrates Menus of the proposed chatbot. It consists of several menus as take surveys, start chat, read, help, my info, about bot, and reset.

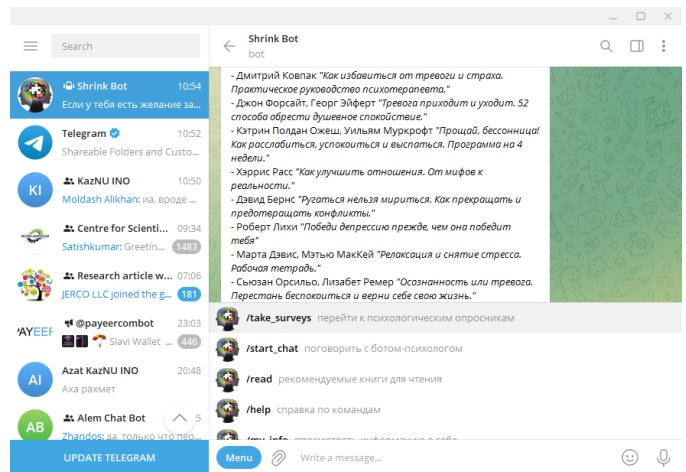


Fig. 6. Menu of the proposed mobile chatbot.

Fig. 7 demonstrates an example of the proposed mobile chatbot when the chatbot suggests different books that would be useful for users. Thus, the users can use the proposed chatbot to improve their knowledge. The users can choose the recommended literature in the chatbot, pass the different psychological tests to understand current psychological conditions, and use cognitive behavior therapy to solve their mental problems.

Fig. 8 shows current progress of a patient. There, we use different questionnaires as GAD-7 anxiety test, BPAQ-24 aggression test, Crafft screening test, Beck hopelessness test, NEO 5 factor inventory test, and open questions. In Fig. 8, we can see that a patient passed two tests as Beck depression test and questionnaire about the level of depression. Depending on the results of the psychology tests, the proposed mobile chatbot psychologist generates decisions and recommendations to the patient.

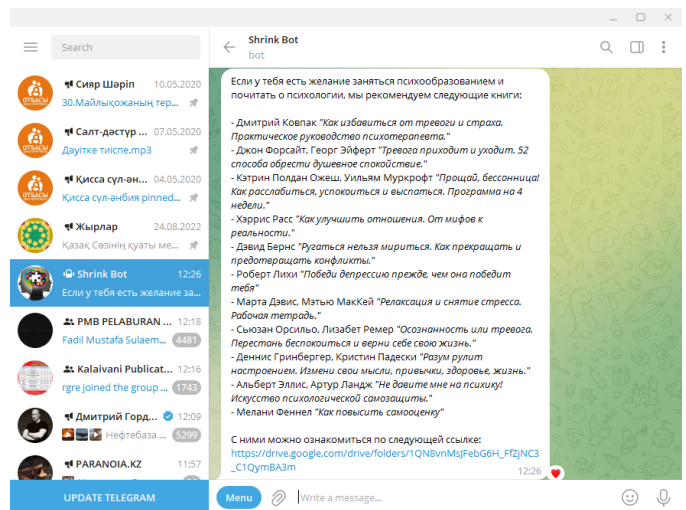


Fig. 7. An example of the proposed mobile chatbot.

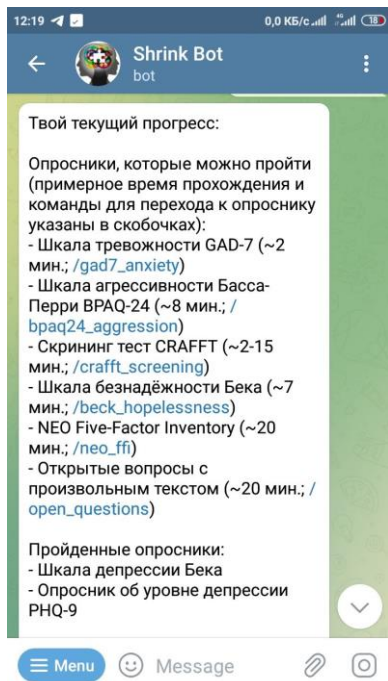


Fig. 8. Current progress of a patient.

## B. Analysis of the Results

According to the findings, the Rasa NLU system has an accuracy of 0.99375 with regard to its intended use. According to the training collection, there is a mistake: the meaning of "how are you?" is incorrectly recognized as "diagnosis," as displayed in Table I. It is quite probable that there is a mistake, since the training outcomes do not include any terms that are comparable. In the phrase "having a nice day," the term "time" is a contemporary machine term that replaces the phrases "day" and "day," and the experiment that was performed on it produced no errors.

We start out by doing an analysis of the RASA NLU procedure. The entity integrity of this particular training package is a score of 0.92, and the accuracy of the entity extract score is equal to one. If there are any grammatical flaws in the text, there is a possibility that errors will occur.

It has been shown that the process of extracting named entities using RASA NLU is very trustworthy since there are no mistakes in the entity extraction during the whole phase which utilizes appropriate training and test evidence.

In the subsequent stage of our investigation, we are going to use NLP strategies to datasets of databases that have been prepared in advance, such as, in order to recognize signals that are associated with depression.

TABLE I. OBTAINED RESULTS

Approach	Confirm	Greetings	Bye	Diagnosis	Total
Confirm	12	0	0	0	12
Greetings	0	5	0	4	9
Bye	0	0	16	0	0
Diagnosis	0	0	0	600	600
Total	12	8	12	600	632

## V. DISCUSSION OF CHALLENGES AND LIMITATIONS

In this section we discuss potential challenges and limitations associated with the implementation of the AI-enabled mobile chatbot psychologist, such as privacy concerns, ethical considerations, and the need for ongoing support and maintenance.

### A. Privacy Concerns

One of the main challenges associated with the implementation of the AI-enabled mobile chatbot psychologist is addressing privacy concerns. Users may be hesitant to share sensitive personal information with an AI-powered system due to potential data breaches, misuse, or unauthorized access [43]. To mitigate these concerns, developers must ensure that the chatbot adheres to strict data privacy and security standards, such as encrypting user data, implementing secure authentication protocols, and maintaining transparency regarding data collection, storage, and usage practices [44]. Additionally, compliance with relevant data protection regulations, such as the General Data Protection Regulation (GDPR), should be prioritized.

### B. Ethical Considerations

Ethical considerations are paramount when developing and deploying AI-enabled mental health chatbots [45]. The chatbot should be designed to respect users' autonomy, providing accurate information and unbiased support without imposing any particular perspective or course of action. Additionally, the chatbot should prioritize user safety, with built-in mechanisms to identify and respond to potential crises or emergency situations, such as active suicidality or severe distress. In such cases, the chatbot should be able to guide users to appropriate professional help or emergency services.

### C. Ensuring Clinical Effectiveness

While the AI-enabled mobile chatbot psychologist aims to provide evidence-based CBT interventions, the effectiveness of these interventions depends on the chatbot's ability to accurately interpret user inputs and deliver appropriate responses [46]. Ensuring clinical effectiveness requires ongoing evaluation and refinement of the chatbot's natural language understanding and generation capabilities. Moreover, it is important to recognize that the chatbot may not be suitable for all users or mental health conditions, and it should not be considered a replacement for professional psychological care.



#### D. Ongoing Support and Maintenance

The AI-enabled mobile chatbot psychologist requires ongoing support and maintenance to ensure its effectiveness and relevance [47]. This includes regular updates to the knowledge base, incorporating the latest research findings and clinical best practices in CBT. Additionally, the chatbot's AIML rules and conversational engine may need to be updated and refined to improve its natural language understanding and generation capabilities [48]. This ongoing maintenance requires dedicated resources, including a multidisciplinary team of mental health professionals, AI experts, and software developers.

#### E. Ongoing Support and Maintenance

While the AI-enabled mobile chatbot psychologist offers a convenient and accessible platform for psychological support, there is a risk that users may become overly reliant on the chatbot, neglecting the importance of face-to-face interactions and professional psychological care [49]. It is crucial to emphasize that the chatbot is intended to complement, rather than replace, traditional mental health services and should be used as an adjunct to professional care as needed.

### VI. DISCUSSION OF FUTURE PERSPECTIVES

#### A. Integration of Additional Therapeutic Approaches

While the current chatbot focuses on CBT principles and techniques, future research could explore the integration of other evidence-based therapeutic approaches, such as dialectical behavior therapy (DBT), acceptance and commitment therapy (ACT), and mindfulness-based cognitive therapy (MBCT) [50-52]. This would allow the chatbot to cater to a broader range of user needs and preferences, potentially enhancing its effectiveness and user engagement.

#### B. Incorporation of Multimodal Input and Output Channels

The chatbot could be further enhanced by incorporating multimodal input and output channels, such as voice recognition, speech synthesis, and emotion recognition through facial expressions or voice tone analysis [53]. This would enable the chatbot to provide more natural and immersive interactions, potentially improving user engagement and therapeutic outcomes.

#### C. Development of Advanced AI Techniques for Improved Natural Language Understanding and Generation

To improve the chatbot's natural language understanding and generation capabilities, future research could explore the integration of advanced AI techniques, such as deep learning algorithms and transformer-based models like OpenAI's GPT series [54]. These techniques could potentially enhance the chatbot's ability to process complex user inputs, generate more contextually appropriate and human-like responses, and adapt to individual users' communication styles and preferences.

#### D. Personalization and User Modeling

Future research could focus on developing more advanced personalization features and user modeling techniques, allowing the chatbot to better understand and adapt to individual users' needs, preferences, and emotional states [55]. This could involve the use of machine learning algorithms to

analyze user inputs, identify patterns in their behavior, and generate tailored interventions based on their unique characteristics.

#### E. Evaluation of Long-Term Outcomes and Real-World Implementation

Further studies should be conducted to evaluate the long-term outcomes of using the AI-enabled mobile chatbot psychologist, as well as its effectiveness in real-world settings [56]. This could involve large-scale, randomized controlled trials with diverse populations, as well as the analysis of user feedback and usage data to identify areas for improvement and potential barriers to adoption.

#### F. Collaboration with Mental Health Professionals and Stakeholders

Future research should prioritize collaboration with mental health professionals, users, and other stakeholders to ensure the chatbot's development is grounded in clinical best practices and addresses the needs of its target audience [57]. This could involve conducting focus groups, user interviews, and expert consultations to gather feedback and insights on the chatbot's design, functionality, and therapeutic content.

Future research directions and potential enhancements to the AI-enabled mobile chatbot psychologist include the integration of additional therapeutic approaches, the incorporation of multimodal input and output channels, the development of advanced AI techniques for improved natural language understanding and generation, personalization and user modeling, evaluation of long-term outcomes and real-world implementation, and collaboration with mental health professionals and stakeholders. These advancements hold the potential to further improve the chatbot's effectiveness, user engagement, and accessibility, ultimately contributing to a more robust and innovative solution for mental health care.

### VII. CONCLUSION

This paper has presented the development and evaluation of an AI-enabled mobile chatbot psychologist that leverages AIML and CBT to provide personalized psychological support and interventions. The key contributions of this work include the creation of an extensive knowledge base of CBT principles and techniques, the development of an AIML-based conversational engine for natural language understanding and generation, and the design of a user-friendly interface for seamless interaction on mobile devices.

The AI-enabled mobile chatbot psychologist addresses the global mental health care gap by offering a scalable, accessible, and cost-effective platform for psychological support. By making evidence-based CBT interventions readily available to users through their mobile devices, this innovative solution empowers individuals to take control of their mental well-being and complements existing mental health services.

Through the integration of advanced AI techniques and a comprehensive knowledge base of CBT principles, the chatbot has the potential to revolutionize mental health care delivery by providing users with immediate access to personalized psychological support, regardless of their geographical location or financial circumstances. This approach not only helps to



reduce the burden on traditional mental health services but also contributes to destigmatizing mental health issues by making support more readily available and approachable.

In conclusion, the AI-enabled mobile chatbot psychologist represents a significant advancement in the field of mental health care, harnessing the power of AI and evidence-based therapeutic approaches to provide accessible, cost-effective, and personalized psychological support. This innovative solution holds great promise in addressing the global mental health care gap and empowering individuals to take control of their mental well-being.

#### ACKNOWLEDGMENT

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# A Multi-branch Feature Fusion Model Based on Convolutional Neural Network for Hyperspectral Remote Sensing Image Classification

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**Abstract**—Hyperspectral image classification constitutes a pivotal research domain in the realm of remote sensing image processing. In the past few years, convolutional neural networks (CNNs) with advanced feature extraction capabilities have demonstrated remarkable performance in hyperspectral image classification. However, the challenges faced by classification methods are compounded by the difficulties of "dimensional disaster" and limited sample distinctiveness in hyperspectral images. Despite existing efforts to extract spectral spatial information, low classification accuracy remains a persistent issue. Therefore, this paper proposes a multi-branch feature fusion model classification method based on convolutional neural networks to fully extract more effective and adequate high-level semantic features. The proposed classification model first undergoes PCA dimensionality reduction, followed by a multi-branch network composed of three-dimensional and two-dimensional convolutions. Convolutional kernels of varying scales are utilized for multi-feature extraction. Among them, the 3D convolution not only adapts to the cube of hyperspectral data but also fully exploits the spectral-spatial information, while the 2D convolution learns deeper spatial information. The experimental results of the proposed model on three datasets demonstrate its superior performance over traditional classification models, enabling it to accomplish the task of hyperspectral image classification more effectively.

**Keywords**—Hyperspectral image classification; convolutional neural network (CNN); multi-branch network; feature fusion

## I. INTRODUCTION

Hyperspectral remote sensing is a cutting-edge technology that utilizes imaging spectrometry to remotely acquire the electromagnetic properties of objects, representing a revolutionary advancement in the area of remote sensing. The key to this technology lies in the utilization of a narrow and continuous spectral channel for remote sensing imaging of objects [1, 2], which can detect the two-dimensional spatial image and the third-dimensional spectral image of the object on earth at the same time and is a cube with the spectral and spatial information, and is also developed based on imaging and spectroscopy. Nowadays, hyperspectral imagery has found extensive application in the field of agriculture [3], military [4], chemistry [5], mineral identification [6], human health [7], and

other fields, playing an indispensable role in the development and progress of human society. The objective of hyperspectral remote sensing image classification is to accurately categorize target ground objects [8], integrate the categories with actual ground object information, and obtain specific category information for the target region [9]. This field of study represents a specialized application of image classification within the realm of remote sensing. However, hyperspectral images are plagued by "dimension disaster" [9], "Hughes phenomenon" [10, 11], the limited quantity of labeled training samples [12], and the inequality of data sample types, which will make hyperspectral images encounter great hardships in the course of extracting features and performing classification.

In the initial exploration of hyperspectral image classification, researchers primarily focused on the spectral information contained within these images, which can effectively capture and reflect the internal mechanisms and chemical composition of ground objects. Specifically, traditional classification methods have harnessed the abundance of bands in hyperspectral images to execute machine learning algorithms for classification purposes with great efficacy, including random forest [13], decision trees [14], support vector machine [15] and K-nearest neighbor [16] algorithms. Relying solely on spectral information, these methods are capable of performing simple classification without the need for feature extraction. Meanwhile, the problem of data redundancy has led subsequent researchers to focus their attention on dimensionality reduction and feature extraction methods. As a preliminary step to classification, the primary techniques of dimensionality reduction can be classified into feature selection and feature extraction [17]. The aim of feature selection is to identify representative spectral information from redundant hyperspectral data while preserving as much original band information as possible [18, 19]. Commercial feature selection methods, including principal component analysis (PCA) [20], independent component analysis (ICA) [21], and linear discriminant analysis (LDA) [22], are commonly used in hyperspectral image processing. PCA method is the most favored linear dimensionality reduction technique. With the continuous advancement and widespread application of deep learning in image processing,

target detection, and speech recognition, it has become a crucial tool for hyperspectral image classification research[23], some typical deep neural network models mainly include stacked autoencoders (SAE) [24], deep belief networks (DBN) [25], and convolutional neural networks (CNN) [26]. Compared to machine learning methods, deep learning models possess a hierarchical structure that enables the extraction of high-level semantic information during feature extraction. This allows for better approximation of the nonlinear structure present in hyperspectral image data and enhances algorithmic effectiveness and robustness [27], thereby facilitating the extraction of complex and high-level features. So far, several deep learning-based approaches have been accomplished within the field of hyperspectral image classification. Just as the application of stacked encoders (SAEs) [28] in hyperspectral image classification. PCA is used to reduce the spectral dimensions of the original data and expanded the data into one-dimensional (1D) vectors as the input of SAE model. Finally, the hyperspectral images were classified by SVM classifier. In 2015, a hyperspectral image classification method based on deep belief network (DBN) was proposed, which also combined PCA method, and used the hierarchical feature extraction and logistic regression classifier to complete the classification of hyperspectral images [29]. As the mentioned two methods expand the spatial neighborhood into a 1D vector, which destroys the correlation of spatial information, they cannot effectively extract the spectral-spatial information to achieve high precision classification of hyperspectral images.

Fortunately, convolutional neural networks, another major branch of deep learning, have demonstrated superior performance in handling hyperspectral data due to their ability to directly address high dimensionality and automatically extract hierarchical image features compared to SAE and DBN [30, 31]. In 2015, the first hyperspectral image classification algorithm based on CNN was introduced. Despite utilizing only the spectral dimension information of the image, its initial application in hyperspectral classification demonstrated superiority over traditional methods such as Support Vector Machine (SVM) [32]. The authors in [33] augmented the number of samples by rotating labelled training data. However, their model's feature extraction process solely relies on spatial domain information while disregarding spectral dimension information. Spectral information is complementary and essential as it indicates that adjacent pixels may belong to the same class [33]. Then, the 1D-CNN+2D-CNN network [34] utilizes a double-branch structure to connect spectral features learned from one-dimensional CNN (1D-CNN) and spatial features learned from two-dimensional CNN (2D-CNN), extracting joint spectral-spatial features for classification. However, this method fails to consider the interdependence between spectral and spatial features. The appearance of three-dimensional convolution just solves the problem of the above model. Using three-dimensional (3D) convolution to work concurrently on information in 3D directions could be more appropriate for the dimensionality of hyperspectral data. A three-dimensional CNN (3D-CNN) model proposed by [35] does not perform any pre-processing on hyperspectral data and uses the full spectral band as input, which retains complete information but actually has high band-to-band correlation and much redundant information. In recent years, an eight-layer

3D-CNN network structure [36] was also proposed for hyperspectral image classification, in which the convolutional layer and the pooling layer were placed alternately.

In this paper, we propose a multi-branch feature fusion model based on CNN for extracting features from hyperspectral images and achieving ground object classification. The present study makes noteworthy contributions in the following aspects:

1) In this paper, a multi-branch feature fusion classification model is proposed for hyperspectral image classification. 3D convolution operations are preferentially used to process special hyperspectral 3D data and extract features from different degrees of spectral and spatial dimensions by utilizing different scales of convolution kernels and number of filters. In addition, 2D convolution was added after 3D convolution to reduce the complexity of the neural network while still efficiently extracting deeper spatial features. Meanwhile, PCA method is used to solve "curse of dimension" of the hyperspectral image.

2) The model framework presented adopts a multi-branch feature fusion structure to integrate features extracted from different branches. By connecting the features extracted from various branches using the Concatenate function, network features can be more comprehensively supplemented, thereby addressing issues of inadequate feature extraction and low precision associated with single branch models, ultimately leading to improved classification performance.

3) The proposed method's effectiveness is demonstrated on three datasets, and the results indicate that it outperforms several other classical methods. The experiments validate that multi-branch feature fusion can significantly enhance classification accuracy. Additionally, various experiments were conducted to determine the model parameters' effects, such as patch size, learning rate, percentage of training samples, and number of branches.

## II. METHODS

The experimental study in this research primarily involves the acquisition of public hyperspectral datasets, preprocessing them, and randomly dividing them into training, validation, and testing sets. During model training, the validation set is utilized for verification to determine whether parameter retuning or training cessation is necessary. Finally, the test set input is used for prediction to obtain results. The specific classification process can be seen in Fig. 1.

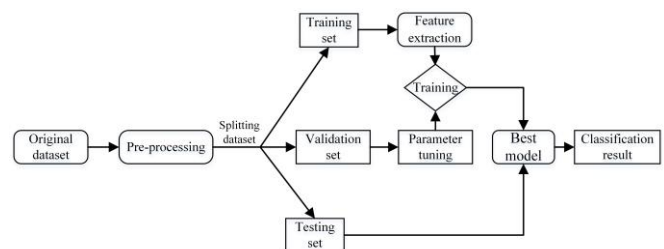


Fig. 1. The hyperspectral image classification flow chart.

### A. Principal Component Analysis (PCA)

Hyperspectral images contain abundant spectral information, but a large number of bands exhibit strong correlation, leading to potential redundancy in the data. Therefore, employing PCA can effectively reduce dimensionality while retaining sufficient information for subsequent feature extraction and classification tasks. This approach not only saves time during model training and testing but also ensures that valuable information is preserved. Meanwhile, as sufficient information is preserved, the discarded band data is essentially superfluous and repetitive, thus exerting negligible influence on the ultimate classification outcomes. For further criteria and a comprehensive overview, refer to [37-39] and relevant literature therein.

To determine the appropriate number of principal components  $k$ , we analyzed the graph depicting the relationship between spectral information and the number of principal components after dimensionality reduction. The aim was to identify a value for  $k$  that would eliminate redundant bands while retaining most of the information in this experiment. Fig. 2 illustrates that even without PCA, the corrected removal of some noise bands does not result in a 100% retention of information across the three downloaded public datasets. After analyzing the outcome plots of these datasets following PCA and ensuring the proposed model's generality, we determined  $k$  to be 30.

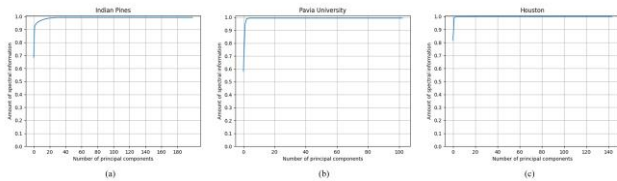


Fig. 2. Relationship between the number of principal components and the amount of retained spectral information.

### B. Convolutional Neural Networks (CNN)

In 1989, LeCun introduced the concept of convolutional neural networks and proposed a multi-layer CNN model for handwritten digit recognition [40]. Since then, CNN, one of the typical feedforward deep neural network architectures, has seen extensive use in numerous computer vision domains. With its inherent advantages in local connectivity and weight sharing, the Convolutional Neural Network (CNN) has proven to be a powerful tool for image classification as well as other related fields. Consisting of an input layer, multiple hidden layers, and an output layer, deep CNN are capable of extracting features at different levels with remarkable efficacy.

As the most crucial operation in CNN, convolution realizes feature extraction of input data by utilizing various convolution kernels to perform sliding pixel extraction on the input image matrix. The nonlinear structure of activation function is then employed to enhance the similarity between image features and real features.

In 2D-CNN [41], both the convolutional kernel and input are in 2D format. When applied to hyperspectral image classification, the network typically takes the neighborhood block surrounding a center pixel as input, with the label of said

center pixel serving as that of the entire block. 2D convolution can effectively utilize neighborhood information, fuse the features of neighborhood samples, and extract spatial information. Its basic principle is to carry out weighted summation of image center pixel and neighborhood pixel according to the weights of convolution kernels and use the output of activation function as the value of center pixel. The output of  $j$ th feature map at  $(x, y)$  of the  $i$ th layer can be expressed as [42]:

$$v_{ij}^{xy} = f \left( b_{ij} + \sum_{k=1}^m \sum_{p=0}^{P-1} \sum_{q=0}^{Q-1} w_{ijk}^{pq} \cdot v_{(i-1)k}^{(x+p)(y+q)} \right) \quad (1)$$

Where in (1),  $f$  is the activation function,  $w$  and  $b$  are the weight and bias of the  $j$ th feature graph in the  $i$ th layer, respectively.

The 3D-CNN [41] is an extension of the 2D-CNN, where convolution is performed along three dimensions of input data simultaneously. This means that convolution is not only carried out in the height and width directions but also in the spectral channel. The output of the  $j$ th feature graph at  $(x, y, z)$  of the  $i$ th layer can be obtained by the formula [42]:

$$v_{ij}^{xyz} = f \left( b_{ij} + \sum_{k=1}^m \sum_{p=0}^{P-1} \sum_{q=0}^{Q-1} \sum_{r=0}^{R-1} w_{ijk}^{pqr} \cdot v_{(i-1)k}^{(x+p)(y+q)(z+r)} \right) \quad (2)$$

Same as (1),  $f$  is the activation function,  $w$  and  $b$  are the weight and bias of the  $j$ th feature graph in the  $i$ th layer, respectively.

In the convolution operation, utilizing an activation function can enhance the nonlinearity of the network. In this study, ReLU activation function[30] is employed for both convolution and full connection layers, while SoftMax classification function is exclusively used for final output classification layer. The formula is presented as follows:

$$f(x) = \max(0, x) \quad (3)$$

The ReLU function is relatively simple compared to other functions, yet it boasts faster operational efficiency and convergence speed. Consequently, it is widely utilized in deep learning models due to its ease of obtaining the required model.

### C. The proposed CNN Classification Model

In this research, a multi-branch feature fusion model based on CNN for extracting more profound and expressive spectral-spatial features of hyperspectral remote sensing images was discussed. To extract both spectral and spatial features from hyperspectral images, 3D convolutional operations are given priority to achieve this goal. This entails the utilization of convolutional kernels with varying scales and numbers to effectively capture features of different degrees, ensuring a comprehensive and efficient feature extraction process. As such, employing a network solely consisting of 3D convolution operations presents challenges in directly computing 3D data, resulting in excessive hyperparameters and prolonged feature extraction time due to its complexity. To augment the model's capacity for extracting spatial information features from data while simultaneously mitigating its complexity, the 3D data



resulting from convolution is transformed into simpler 2D flat data and subsequently subjected to additional 2D convolution operations.

On one hand, the conventional methods for enhancing the classification performance of the entire model involve deepening it, such as augmenting the number of convolutional layers. However, this often results in an increase in training parameters and complexity, as well as higher computational costs. While the classification performance may become better with a deeper network structure, the training difficulty also becomes greater. With consideration of these factors, this paper adopts a multi-branch convolutional neural network structure for the reason of improving the classification performance of the model as much as possible without increasing the overall model complexity and network depth. On the other hand, during the feature extracting procedure, the textural elements such as edge background of the hyperspectral image are mainly extracted by the low-level network, the regions of the image are extracted in the middle-level network, and the overall feature is partially extracted by the upper-level network, consequently, some essential feature contents are lost in the convolution process, which affects the final classification accuracy. In this paper, a multi-branch feature fusion approach is employed, whereby the same hyperspectral data is fed into multiple branches for processing and obtaining multi-scale feature information. Subsequently, the information obtained from each convolutional layer is integrated together. Compared to a single-branch structure, this architecture can capture a more diverse and comprehensive range of information by incorporating low-, middle-, and high-level features, thereby enhancing the overall classification performance of the model. Finally, a Dropout layer is appended after the fully connected layer to forestall overfitting. The specific model framework is illustrated in Fig. 3.

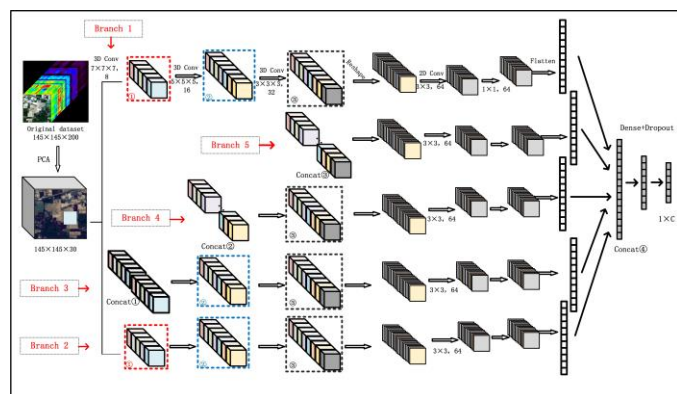


Fig. 3. The proposed network framework.

The proposed network framework is demonstrated using the representative Indian Pines dataset. The first stage of classification involves pre-processing the original hyperspectral dataset, wherein the spectral dimensionality is reduced, and redundant information is eliminated by applying PCA to reduce 200 spectral bands to 30. Afterwards, the reduced-dimensional dataset is fed into small cubes of size  $s \times s \times 30$  and slid from left to right and top to bottom as input for branch 1 and branch 2 of the same design in a convolutional network. These branches utilize three distinct 3D convolutional

layers with kernel sizes of  $7 \times 7 \times 7$ ,  $5 \times 5 \times 5$ , and  $3 \times 3 \times 3$  respectively, along with additional 2D convolutions using kernels of size  $3 \times 3$  and  $1 \times 1$ . As illustrated in Fig. 3, the output of the first convolution layer of the two branches, which is the feature map marked as number ① in Fig. 2, is connected together with the Concatenate function, and it is marked as Concat ①, and it is used as the input of branch 3. The two 3D convolution layers of the third branch are designated as  $5 \times 5 \times 5$  and  $3 \times 3 \times 3$ , respectively. 2D convolution kernel size is  $3 \times 3$  and  $1 \times 1$ , and the fourth branch in the same way.

The three output feature maps marked with number ② in the figure are also connected and marked as Concat ②, which is the input of branch 4, consisting of the second output feature map of branch 1 and branch 2 and the first output feature map of branch 3. The input of branch 5 is Concat ③, which is obtained by connecting the four outputs numbered ③. In this model, all branches finalize with two two-dimensional convolutional layers. Eventually, the one-dimensional vectors obtained by flattening all the branches are connected together again with the fully connected layer and the Dropout layer in turn. The extracted features are multi-classified and compared with the actual ground object map using the Softmax function in the final fully linked layer. The parameters of the complete model framework branches and convolutional layers are shown in Table I.

TABLE I. NETWORK STRUCTURES

Input	Hidden Layer	Kernel Size	Filters
25×25×30,1	Conv3D_branch1_1, Conv3D_branch2_1	7×7×7	8
19×19×24,8 (19×19×24,16)	Conv3D_branch1_2, Conv3D_branch2_2, (Conv3D_branch3_1)	5×5×5	16
15×15×20,16 (15×15×20,48)	Conv3D_branch1_3, Conv3D_branch2_3, Conv3D_branch3_2 (Conv3D_branch4_1)	3×3×3	32
13×13,576 (13×13,2304)	Conv2D_branch1_4 Conv2D_branch2_4, Conv2D_branch3_3 Conv2D_branch4_2 (Conv2D_branch5_1)	3×3	64
11×11,64	Conv2D_branch1_5 Conv2D_branch2_5, Conv2D_branch3_4 Conv2D_branch4_3 Conv2D_branch5_2	1×1	64

### III. EXPERIMENT

The datasets, performance measurements, and experimental setting used in this work are briefly described in this section. It includes the partitioning of three publicly available datasets - Indian Pines, Pavia University, and Houston; as well as an explanation of the three objective evaluation metrics used in our experiments: OA, AA, and Kappa coefficients. Finally, we give a thorough explanation of the experimental setup and variables used in this research.



### A. Datasets

To execute the proposed model, three hyperspectral image datasets were utilized, namely Indian Pines, Pavia University and Houston, which differ in terms of band number, pixel count, feature classes and spatial resolution.

1) *Indian Pines(IP)*: The initial dataset comprises of Indian pine trees, captured by the infrared imaging spectrometer sensor AVIRIS in northwestern Indiana, USA. This image boasts a total of 220 bands, with 20 noise bands being eliminated to enhance its quality. Each individual band has a pixel size of  $145 \times 145$  and spatial resolution of 20 meters. It encompasses an impressive array of 16 feature species. In this paper, each feature class found in the Indian Pines dataset is painstakingly split into a training set, a validation set, and a testing set in the ratios of 1:1:8 in this research.

2) *Pavia University(PU)*: The second dataset captured by the ROSIS sensor over the University of Pavia is a stunning hyperspectral remote sensing image measuring  $512 \times 614$  with an impressive spatial resolution of 1.3 m. The image was imaged continuously in the wavelength range of 0.43-0.86  $\mu\text{m}$ , and after removing noise 12 bands that were severely affected by noise, the remaining 103 bands were used for classification. The dataset contains a total of nine categories of real features for classification, in the experiments of this paper 3% of the samples are selected as the training set and 3% as the validation set and the rest are used for testing.

3) *Houston (HT)*: The Houston dataset is acquired by the ITRES CASI-1500 sensor for ground feature information on the University of Houston campus and adjacent urban areas, and it is provided by the 2013 IEEE GRSS Data Fusion Competition with a spatial resolution of 2.5 meters. It contains  $349 \times 1905$  pixels, and this hyperspectral image consists of 144 spectral bands in the range of 380 nm to 1050 nm and contains 15 feature classes. As with the Indian Pine dataset, each class of features is divided into training set, validation set, and testing sets in the ratio of 1:1:8.

### B. Classification Index

To evaluate the effectiveness of our proposed model accurately and scientifically for classification, subjective perception alone is insufficient. Therefore, this paper employs evaluation indices including Overall Accuracy, Average Accuracy, Kappa coefficient [45].

- Overall Accuracy (OA): refers to the proportion of correctly classified test samples to the total number of test samples, reflecting the precision and effectiveness of classification performance.
- Average Accuracy (AA): refers to the ratio of the sum of classification accuracy of each type of ground object in hyperspectral images to the number of ground object classes.
- Kappa coefficient: It is an evaluation index used to test the consistency. It is used to test the consistency between the actual results and the predicted results in

hyperspectral images. Its value is generally between -1 and 1, and generally greater than 0.

### C. Experimental Environment

To verify the effectiveness of the proposed algorithm, this study was conducted in Python 3.8 environment with code written in TensorFlow framework and experiments on three publicly available datasets, including Indian Pines, Pavia University, and Houston. All experiments were run on NVIDIA RTX A6000 GPU servers.

## IV. EXPERIMENTAL PARAMETERS AND RESULTS

In this section, we first conduct experiments on the model's parameter settings, which involve adjusting parameters such as learning rate and epoch based on validation set results. We also analyse the effects of various settings on experimental outcomes, including training sample ratios across three datasets, input spatial region size for the model, and number of branches in the proposed multi-branch feature fusion model. When all the parameters were set, the results of the method proposed in this paper were analysed and compared with seven other different methods, including SVM[43], 1D-CNN[32], CDCNN[44], 3D-CNN[36], HybridSN[45], M3D-DCNN[46] and DBMA[47]. All the methods run in the same environment and use the same number of training set samples.

### A. Experimental Parameters Setting and Analysis

In this section, the primary objective is to optimize network parameters and determine the optimal configuration for the classification network by comparing experimental results, in order to achieve superior classification results. We ran experiments on three different datasets and picked the best network parameters after comparing them all. This resulted in the most accurate classification results for our network. The following comparative analysis presents learning rate, epochs, spatial size, training set ratio, and number of branches respectively.

1) *Learning rate and epochs*: It is crucial to ascertain the suitable learning rate for the model during training, as it is arguably the most critical hyperparameter to configure. The learning rate represents the magnitude of each parameter update in the network and dynamically adjusts during training with changes in epoch, following a specific update formula:

$$\omega_{i+1} = \omega_i - lr \nabla \quad (4)$$

Where  $\omega_{i+1}$  and  $\omega_i$  are the weight values of the  $i + 1$ st epoch and the  $i$ th epoch, respectively.  $lr$  is the learning rate and  $\nabla$  is the decay exponent.

As depicted in Fig. 4(a), with Adam optimizer and an initial learning rate of 0.001, both training accuracy and validation accuracy gradually improve as the number of epoch increases. The rising trend of both accuracies is consistent with the convergence trend, but there are certain fluctuations during the intermediate process, resulting in less stability. In Fig. 4(b), the relationship between epoch time and loss function is depicted, where an increase in epoch time leads to a gradual decrease and convergence of the loss function; however, it is evident that there exists a significant degree of fluctuation.

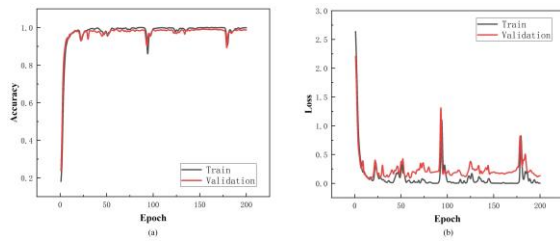


Fig. 4. Learning rate equals to 0.001. (a): Training and validation accuracy curves. (b): Training and validation of loss function curves.

With a reduced learning rate of 0.0005, the results depicted in Fig. 5 demonstrate faster convergence of both training and validation accuracy with smaller fluctuations, as well as quicker convergence of the loss function with less fluctuation compared to a learning rate of 0.001.

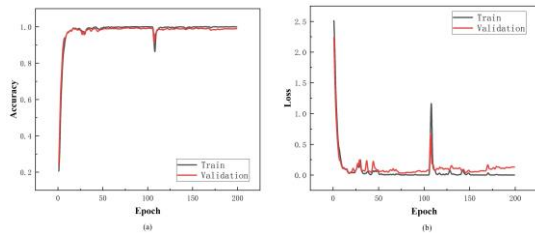


Fig. 5. Learning rate equals to 0.0005. (a): Training and validation accuracy curves. (b): Training and validation of loss function curves.

Furthermore, adjusting the learning rate to 0.0001 results in a clear convergence of the training and validation accuracy curves, with minimal fluctuations and improved overlap as shown in Fig. 6. This indicates a more stable convergence of the loss function. Therefore, following a comprehensive analysis of the relationship between the three learning rates and epochs, we have selected a more effective learning rate of 0.0001 and an epoch of 200 for experimentation in this paper. Based on these findings, we have set the optimizer's learning rate to 0.001 and the epoch to 200.

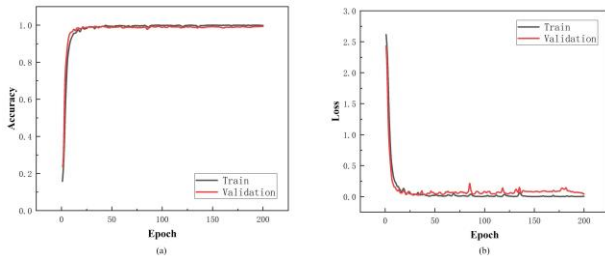


Fig. 6. Learning rate equals to 0.0001. (a): Training and validation accuracy curves. (b): Training and validation of loss function curves.

2) *Spatial size*: The spatial size refers to the dimension of the input sample after segmentation and dimensionality reduction of small cubes. For 3D CNN classification, the input data size is a crucial parameter that affects feature extraction and classification performance. Increasing spatial size captures more information but also introduces redundancy, which may affect final classification results. The experiments were conducted by setting  $15 \times 15$ ,  $17 \times 17$ ,  $19 \times 19$ ,  $21 \times 21$ ,  $23 \times 23$ ,  $25 \times 25$ ,  $27 \times 27$ ,  $29 \times 29$ .

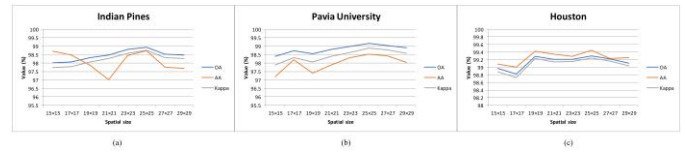


Fig. 7. OA, AA, and Kappa values of three datasets at different spatial sizes. (a): Indian Pines. (b): Pavia University. (c): Houston.

The Fig. 7 shows the results of our experiments on the three datasets. As the space size increases, the OA, AA, and Kappa of the three datasets also increase. After the space size is larger than 25, the classification effect of the three datasets suddenly becomes worse, probably because the selected space is too large leading to more spatial contextual information, which brings redundancy leading to misclassification. And when the *spatial size* =  $25 \times 25$ , the datasets Indian Pines, Pavia University and Houston all reach the highest OA values of 98.92%, 99.16% and 99.30%, respectively. Therefore, combining the experimental results of the three datasets, the optimal parameter *spatial size* =  $25 \times 25$  was chosen in this study.

3) *Training set and ratio*: Deep learning-based classification models are highly reliant on the ratio of training samples. Generally, adding samples leads to improved performance in both training and testing. However, a significant challenge with hyperspectral data is the less labeled training samples. Furthermore, augmenting the size of the training dataset also results in prolonged training durations, which adversely affects model performance. Bearing these factors in mind, we will examine the impact of training set occupancy on classification outcomes. For the two datasets Indian Pines and Houston, training sets were used with 1%, 3%, 5%, 10%, 15%, 20%, 25%, and 30%, respectively; whereas for the larger dataset Pavia University, training sets with 0.1%, 0.5%, 1%, 3%, 5%, 10%, 15%, and 20% were used ratios were performed for the test.

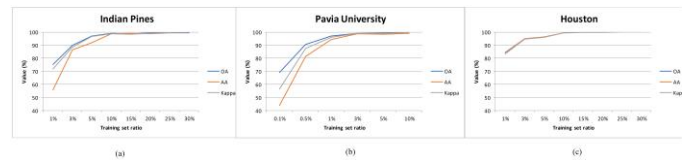


Fig. 8. OA, AA, Kappa values of three datasets with different training set ratio. (a): Indian Pines. (b): Pavia University. (c): Houston.

From the Fig. 8, it is observed that as the training sample gradually increases, the OA, AA, and Kappa predicted by the classification model also improve, and when the training sample reaches 10%, the three evaluation indexes OA, AA, and Kappa of Indian Pines are 98.92%, 98.72%, and 98.76%, respectively, and the classification results of Houston were 99.30%, 99.44%, and 99.24%. In the case of Pavia University, owing to its large sample size, its OA, AA, and Kappa reached 99.16%, 98.53%, and 98.89%, respectively, when 3% was used for the training ratio, and the classification results were already better. In summary, our goal of minimizing the number of training samples and avoiding lengthy training time, was achieved by setting the training sample ratio to 10% for both

Indian Pines and Houston datasets, and 3% for Pavia University.

4) *Number of branches*: To validate the efficacy of branches in the proposed CNN, a series of comparative models have been devised to determine the optimal number of branches by assessing their impact on classification accuracy. The proposed model consists of five branches, Branch 1, Branch 2, Branch 3, Branch 4, and Branch 5 labelled in the network framework. This analysis explores the efficacy of branching in feature extraction and classification by examining the correlation between branch quantity and final classification outcomes.

In Fig. 9, where the meanings of the horizontal axes from 1 to 5, respectively, are:

- 1) (Branch1)
- 2) (Branch1  $\oplus$  Branch2)
- 3) (Branch1  $\oplus$  Branch2  $\oplus$  Branch3)
- 4) (Branch1  $\oplus$  Branch2  $\oplus$  Branch3  $\oplus$  Branch4)
- 5) (Branch1  $\oplus$  Branch2  $\oplus$  Branch3  $\oplus$  Branch4  $\oplus$  Branch5)

where the symbol  $\oplus$  denotes the Concatenate operation.

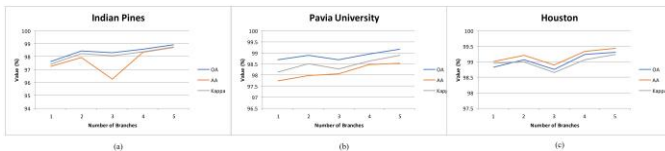


Fig. 9. OA, AA, Kappa values for three datasets with different number of branches. (a): Indian Pines. (b): Pavia University. (c): Houston.

As depicted in Fig. 9, the correlation between the number of branches in feature fusion and the three evaluation metrics (OA, AA, and Kappa) across three public datasets indicates that an increase in extracted features leads to higher OA, AA, and Kappa scores and improved classification performance. In this study, after analysing three sets of data and considering the number of branches and final results, the model ultimately selected five series branches to improve classification accuracy and enhance model robustness.

### B. Results

Table II to Table III and Fig. 10 to Fig. 12 show the results of three different datasets in seven classification methods, including the results of OA, AA and Kappa. In addition, Fig. 13 shows the confusion matrix for the three datasets acquired in this paper.

Table II and Fig. 10 reveal that SVM[43] exhibits the poorest classification results when using a training set of only 10% from the Indian Pine dataset, whereas DBMA[47] and HybridSN[45] demonstrate superior experimental outcomes in terms of classification accuracy compared to other methods. Amongst the seven compared methods, DBMA[47] stands out with its exceptional performance. Compared to DBMA[47], the proposed methods in this paper exhibit significant improvements in OA, AA and Kappa. Specifically, the classification accuracy of all types of ground objects is basically improved, eventually, OA is improved by about

0.88%, AA is improved by about 1.02%, and Kappa is improved by about 1.00%. It is worth mentioning that among the 16 features in Indian Pines, the classification results of five categories of features reached 100% under the classification method proposed in this paper.

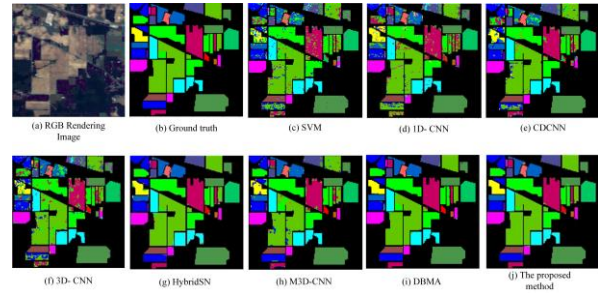


Fig. 10. Classification results of Indian Pines scenes using different methods.

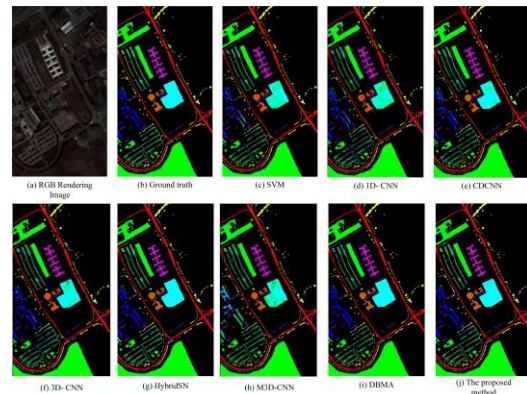


Fig. 11. Classification results of Pavia University scenes using different methods.

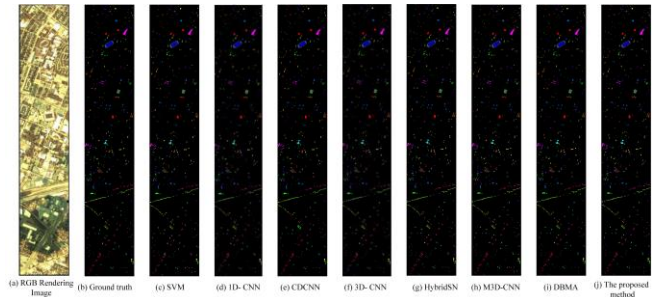


Fig. 12. Classification results of Houston scenes using different methods.

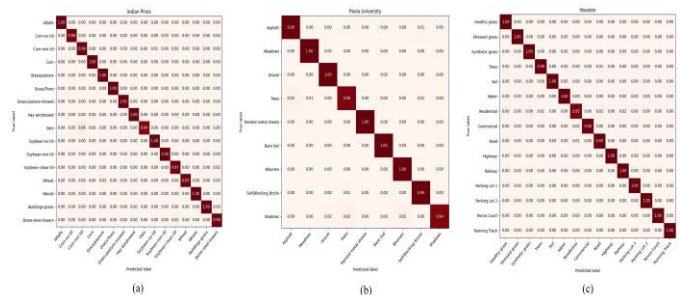


Fig. 13. Confusion matrix of the proposed method for the three datasets. (a): Indian Pines. (b): Pavia University. (c): Houston.

TABLE II. CLASSIFICATION ACCURACY OF INDIAN PINES AND HOUSTON

Classes	Accuracy (%): Indian Pines (IP), Houston (HT)															
	SVM		ID-CNN		CDCNN		3D-CNN		HybridSN		M3D-DCNN		DBMA		Ours	
Dataset	IP	HT	IP	HT	IP	HT	IP	HT	IP	HT	IP	HT	IP	HT	IP	HT
1	66.67	97.69	63.41	97.25	61.90	94.04	65.85	96.00	95.12	96.54	34.15	98.85	100.00	98.68	100.00	99.73
2	71.76	98.14	70.66	98.58	81.28	91.42	81.17	99.38	96.03	100.00	81.40	99.20	99.03	99.40	96.11	99.91
3	74.12	99.52	55.42	99.68	82.62	98.07	64.26	95.37	97.32	100.00	85.54	100.00	99.24	100.00	98.66	99.84
4	70.37	93.21	82.63	97.59	83.80	98.84	58.69	97.23	91.55	98.12	77.00	94.20	95.52	99.50	99.53	99.38
5	90.34	97.67	87.82	97.05	96.82	99.70	83.22	99.82	99.08	100.00	94.94	99.91	94.80	97.28	99.54	100.00
6	89.28	98.29	96.35	98.63	99.31	100.00	93.30	84.25	99.85	97.60	98.63	94.52	99.31	99.26	99.54	100.00
7	85.71	90.36	80.00	82.82	88.89	96.42	60.00	87.99	100.00	96.06	64.00	92.20	90.91	98.91	100.00	95.44
8	87.94	83.84	99.53	83.21	91.81	95.08	95.35	86.61	100.00	92.59	100.00	80.98	99.74	100.00	100.00	98.12
9	55.56	80.48	66.67	84.65	82.35	94.81	38.89	89.62	100.00	95.39	83.33	90.06	100.00	97.41	94.44	99.47
10	75.32	90.22	80.80	82.16	83.08	83.75	80.69	77.08	96.69	99.82	73.60	93.48	98.45	99.70	99.89	100.00
11	78.51	78.42	88.01	77.25	85.71	89.48	82.31	86.78	98.19	100.00	85.48	77.79	97.54	98.90	99.50	100.00
12	75.78	79.55	72.85	69.55	75.41	95.22	68.73	81.35	98.31	96.04	83.52	87.39	97.41	95.68	97.38	99.64
13	89.50	37.20	99.46	32.94	99.40	94.61	95.68	64.22	100.00	94.79	98.92	89.10	100.00	98.94	97.30	100.00
14	92.16	96.88	96.22	96.36	95.81	100.00	93.77	95.58	99.47	100.00	98.68	99.22	98.34	100.00	100.00	100.00
15	70.10	99.66	61.38	99.83	89.00	98.16	69.16	98.32	99.14	100.00	79.25	100.00	94.25	98.34	100.00	100.00
16	98.57		90.48		93.59		100.00		96.43		100.00		98.63		97.62	
<b>OA</b>	<b>80.55</b>	<b>88.75</b>	<b>82.48</b>	<b>87.02</b>	<b>87.47</b>	<b>94.41</b>	<b>81.77</b>	<b>90.03</b>	<b>97.98</b>	<b>97.67</b>	<b>87.05</b>	<b>92.42</b>	<b>98.04</b>	<b>98.66</b>	<b>98.92</b>	<b>99.30</b>
<b>AA</b>	<b>79.79</b>	<b>88.08</b>	<b>80.73</b>	<b>86.50</b>	<b>86.92</b>	<b>95.31</b>	<b>76.94</b>	<b>89.31</b>	<b>97.95</b>	<b>97.80</b>	<b>83.65</b>	<b>93.13</b>	<b>97.70</b>	<b>98.80</b>	<b>98.72</b>	<b>99.44</b>
<b>Kappa</b>	<b>77.72</b>	<b>87.82</b>	<b>79.90</b>	<b>85.95</b>	<b>85.67</b>	<b>93.96</b>	<b>79.19</b>	<b>89.21</b>	<b>97.70</b>	<b>97.48</b>	<b>85.20</b>	<b>91.80</b>	<b>97.76</b>	<b>98.55</b>	<b>98.76</b>	<b>99.24</b>

TABLE III. CLASSIFICATION ACCURACY OF PAVIA UNIVERSITY

Classes	Accuracy (%): Pavia University (PU)							
	SVM	ID-CNN	CDCNN	3D-CNN	HybridSN	M3D-DCNN	DBMA	Ours
Dataset	PU	PU	PU	PU	PU	PU	PU	PU
1	92.06	92.88	92.92	93.11	97.51	94.56	98.12	98.52
2	97.94	96.98	97.75	98.01	99.95	99.31	99.90	99.86
3	72.74	83.06	89.44	91.01	97.69	78.88	90.70	99.51
4	93.78	85.77	97.81	89.70	92.50	94.68	95.94	95.63
5	99.46	99.46	100.00	99.16	99.92	100.00	99.61	100.00
6	83.68	75.34	91.30	88.60	100.00	72.67	100.00	99.94
7	85.04	78.22	94.07	82.64	100.00	82.64	100.00	100.00
8	89.83	82.50	91.26	89.36	97.31	98.40	99.30	99.08
9	100.00	99.67	99.44	90.42	82.05	99.78	99.54	94.23
OA	92.81	90.62	95.26	93.85	98.31	93.54	98.78	99.16
AA	90.50	88.21	94.89	91.34	96.32	91.21	98.12	98.53
Kappa	90.42	87.43	93.72	91.83	97.76	91.32	98.39	98.89

Based on Table III and Fig. 11, it is evident that among the six compared methods for the Pavia University dataset with only 3% training samples, 1D-CNN[32] exhibits the poorest classification performance while DBMA[47] remains superior in terms of classification accuracy. Furthermore, our proposed algorithm has demonstrated significant improvement compared to DBMA. OA, AA, and Kappa reached 99.16%, 98.53%, and 98.89%. Compared with the DBMA[47] algorithm, our method increases by about 0.38%, 0.41% and 0.50% for OA, AA and Kappa, respectively.

Table II and Fig. 12 present the experimental findings for the Houston dataset with a training sample of only 10%. It is evident that Houston's classification performance in 1D-CNN[32] was subpar, while it excelled in DBMA[47]. It is worth mentioning that the results obtained using the proposed

method show that seven of the fifteen classes of objects in the Houston dataset can achieve 100% classification accuracy, and compared with the best method DBMA[47], OA, AA and Kappa respectively increased by about 0.64%, 0.64% and 0.69%. Although the improvement results are modest, the classification metrics have reached 99.30%, 99.44%, and 99.24%.

From the above experimental results, we can see that DBMA [47] shows great superiority among the seven compared methods, which is the result of the development and application of the attention mechanism in recent years. Meanwhile, SVM [43] and 1D-CNN [32] exhibit poor results, confirming that the idea of using only spectral information is not enough, and the 3D convolution operation proposed in this paper is designed to make good use of both spatial and spectral information to improve accuracy. Therefore, it also enlightens

us to research and study the attention mechanism in the field of hyperspectral remote sensing image classification afterwards. And the model still has shortcomings and still needs to be studied and improved in depth. For the characteristics of small training samples of hyperspectral remote sensing data markers, the use of semi-supervised and unsupervised methods for classification in subsequent experiments is also one of the research directions. Moreover, with the development of attention mechanisms, the ability to suppress unimportant information as another improved feature of the model is one of the main points for continued learning in the future.

## V. CONCLUSIONS

A hyperspectral remote sensing image classification method based on multi-branch feature fusion is proposed in this paper to effectively extract spectral-spatial features of hyperspectral images and achieve efficient classification of ground objects. The proposed method, composed of multiple branches, yields more comprehensive and accurate extracted features. The 2D convolution layers are added to reduce the complexity brought by the 3D convolution, which makes the network not only more concise but also more deeply to extract spatial information. The experimental comparison results also demonstrate the preeminence of the proposed model over other methods, surpassing not only traditional classification techniques but also exhibiting significant advancements compared to other deep learning approaches. To sum up, the model approach proposed in this paper yields excellent classification outcomes across most datasets. Not only does it leverage 3D convolutional layers to simultaneously extract spectral-spatial features, but also reduces network complexity through the inclusion of 2D convolutional layers. Moreover, the multi-branch feature fusion structure enhances feature extraction adequacy and improves classification accuracy.

## VI. FUNDING STATEMENT

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# Socio Technical Framework to Improve Work Behavior During Smart City Implementation

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**Abstract**—Every organization uniquely adheres to security culture. Numerous studies have discovered that procrastinating, impulsive, forward-thinking, and risk-taking behaviors vary across organizations, which may help to explain why different organizations' adherence to security policies. This study describes the human aspect of a government organization in contributing to the successful implementation of a smart city by minimizing cybersecurity threats. Improper employee behavior and lack of understanding of cybersecurity will negatively contribute to the successful development of smart cities. The purpose of this research is to develop a framework to determine the factors to improve work behavior in terms of the contribution of social and technical factors. The use of a socio-technical approach to explain how socio-technical integration can contribute to improving work behavior by using mixed methods. The results indicated that several socio-technical factors which include technology, IT infrastructure, work organization, competency, training, and teamwork contribute to improving work behaviors which can be used as a basis for minimizing cybersecurity threats in smart city implementation.

**Keywords**—*Framework; socio technical; cybersecurity; behavior; threat; smart city*

## I. INTRODUCTION

Information and communication technology (ICT) has had an impact that can be felt in all sectors of human development. ICTs provide recent potential for the restoration soundness systems, new methods of citizens' authority, and active inclusion in their community at both charitable and political tiers. The elaboration of ICT has made a huge difference in the world. ICT affects many fields where it becomes a tool that enables the exchange of enormous information. ICTs deliver immensity and profound information to those who did not beforehand have this science and thus the chance for social and economic mobility.

Access to ICTs can have a profound influence on people's sense of empowerment and aptitude to be active participants in their society at both the political and social levels. ICT can intensify the empowerment of civil society by enhancing their proficiency to work as an organized network both within and beyond the frontier [1]. An ICT has altered the lives of society at the operative level. Technology gives people the operative power to commit, notify, create, study, perform, and demolish.

Technology also has its enchantment and attraction. Technology is not only an important means of human headway but also the most glorious human invention. Technological developments are difficult to stem because social entities show

a tendency to dominate and exploit operatively weaker entities [2]. The ICT has succeeded in improving the lives and broadening the horizons of society, but also facilitates the manipulation of society. Stunning sounds emanate from billions of screens and speakers around the world, and they shape people's thoughts and behavior.

Increasingly the means possessed by humans will be able to facilitate progress and human life but do not always lead to this goal. The effects of tool advancements depend to a large extent on the social and political environment that decides how these tools are used, and their operational strength. Society is getting stronger, but this does not mean that people's life has become preferable, wiser, and more beautiful. To make the world and life better, means must be used in a way that decrease misery, nescience, and devastation, for these are the basic dimensions by which human progress must be measured [2].

System improvement in urban areas based on the active use of information technology requires specialists with adequate qualifications, therefore, the methodological development of human resources needs to be considered from a bilateral approach position both in terms of executor and users [3]. Human resource development which is reviewed from two perspectives (executor and user) is necessary for the realization of smart city implementation.

The role of ICT is very substantial hence humans are very dependent on technology and humans cannot live without technology and it is very difficult and almost impossible to work without ICT. In everyday life, there are many cases where most people consciously or unconsciously use ICT purely [4].

Human teamwork in distributed knowledge-sharing groups relies on information and communication technology (ICT) functionality to support achievement. By adapting the level of detail of the information to the situation knowledge must be shared efficiently. In certain situations, information can be exchanged by involving people who work in collaboration [5].

Human development is one of the main factors that capture the core of livelihood in a community. In the current information age, the reach and diffusion of information and communication technology (ICT) that can reach remote countries in the world make it a stimulus to attain the preference for human development targets. The high population growth in urban areas will cause a lot of population problems as well as economic activity. [6].

Human factors contribute significantly to computer security, the human weaknesses that may cause unintentional jeopardize to the company or organization [7]. Cybersecurity is expanding to resolve the range of attack types while the attackers counter with their innovative hacking systems. Cybersecurity uses different approaches to upgrade detection of the threats [8].

Two things are the core elements of organizational culture, namely in the form of basic assumptions and beliefs. Collective norms and values will influence employee behavior. Organizational culture is consequently expressed in the collective values, norms, and knowledge of the organization. Several things are expressions of norms and values, namely artifacts and handbooks, rituals, and anecdotes [9]

Organizational culture can have dissimilar subcultures based on sub-organizations or purposes. Information Security Culture is a subculture concerning common company functions. It should support all activities so that information security becomes a natural aspect of the daily activities of every employee. Information security must become a natural aspect of employees' daily activities so that it can support all activities [9]

Another problem is cyberattacking have succeeded in defeating technical security solutions by utilizing human factor vulnerabilities related to security awareness, and skills and manipulating the human element to inadvertently grant access to important industrial assets. Knowledge and skills capability level contribute to human analytical proficiency to heighten cyber security readiness [10]

Human involvement is necessary to complement a technically based security approach to ensure overall cybersecurity. Human factors and organizational factors contribute to affecting the security of computing systems. The factors that appear on the user side are risk behavior, trust, lack of motivation, and inadequate use of technology while on the management side are inadequate workload and staff knowledge.

Information security violations can be classified in several different ways. The study [11] mentioned that based on several studies performed by other researchers provided thirteen attacks that cover all the computer security risk factors, and eventually defined "nine factors (that) can cover all risks as main factors". These factors are an excess privilege, error, and omission, denial of service, social engineering, unauthorized access, identity thief, phishing, malware, and unauthorized copy.

Information security practice accommodate all sociocultural quantify that support technical security methods, employee recognize that information security is a natural aspect to support daily activities. To utilize this socio-cultural behavior effectively and efficiently, management models and socio technical framework are required. The company must determine that the information security culture must be part of the organizational culture.[12] The contribution of the human factor in the failure to secure and protect systems, services, organizations, and information is tremendous [8]. The interrelationship of human and organizational factors and

computer and information security vulnerabilities is very significant. The factors that contribute to improving work behaviors to reduce cybersecurity threats and how the socio-technical factors contribute to improving work behavior is a discussion that will be explained in the results of study because human factors significantly influence people's interaction with information security hence generating many risks [13].

## II. LITERATURE REVIEW

### A. Smart City

The smart city concept continues to experience rapid development from year to year by following the flow of technological developments and innovations. The latest smart city concept, smart city 4.0, was just launched in 2017 by the innovation acceleration group from the University of Berkeley, California, United States. The Smart City 4.0 concept emerged as an action from the industrial revolution 4.0 by bringing initiatives to develop the skills of young innovators and entrepreneurs in the technology industry. Smart City 4.0 aims to develop skills for the industrial revolution 4.0 and accelerate technology development for young innovators, start-ups, and technology companies to create the best solutions to make cities smarter, safer, and more sustainable. [14].

Further, [15] identified two types of Japanese smart city initiatives: business-led initiatives conducted in conjunction with large-scale urban developments and government-led initiatives that are anchored within the vision statements of municipalities. Several experts have defined smart cities, [16] defined the smart city as a city that should integrate IT infrastructures, and social and economic issues to, more useful, and more flexible responses. Further, [17] mentioned that a smart city should be a city well performing in a forward-looking way with six smart characteristics (also called soft factors: smart economy, smart mobility, smart environment, smart people, smart living, smart governance), built on the smart combination of endowments and activities of self-decisive, independent, and aware citizens.

### B. Cybersecurity

Cyber security is an important issue in the infrastructure of every company and organization. A company or organization based on cybersecurity can achieve high status and countless successes because this success is the result of the company's ability to protect personal and customer data from competitors. Organizations and competitors' customers and individuals are rude. The company or organization must first and foremost provide this security in the best way to build and develop itself [18].

Cybersecurity includes practical steps to protect information, networks, and data from internal or external threats. Cybersecurity professionals protect networks, servers, intranets, and computer systems. Cybersecurity ensures that only authorized individuals have access to that information[19]. According to [19] Information Security is an effort to protect physical and digital data from unauthorized access, disclosure, misuse, unauthorized alteration, and deletion. Operational Security includes the processes and decisions made to control and protect data.

C. Behaviour

Behavior is the way a person or thing acts or reacts. The definition of behavior is based on the opinion of clinical psychologists and psychotherapists [20]. Behavior is an essential means for individuals to externalize information from their (entirely internal) psychological systems to their external surroundings. [21]

D. Socio Technical Concept

A socio-technical system (STS) consists of humans using technology to perform assignment through an operation within a social system (association) toward reaching a specified purpose. Numerous of the issues and losses of management information systems and administration science or operations research projects have been attributed to corporate behavioral concerns [29]. A socio-technical system (STS) consists of the complicated relations between sociable humans and technological systems. [22]

Socio-technical systems are distinguished by a high capacity of social complexity as well as technical intricacy to perform the essential positions of community [23] There was a synergistic combination of people, technology, organizational structures, and processes, including the operating environment in which all of this occurs [15]. The prefix socio is always associated with individuals and community in general, while 'technical' denotes something related to machines or technology. [22] The general structure of the STS and the elements that make up its complex social and technical dimensions are described differently by various researchers.

E. Related Works

Sociotechnical systems include physical and technical artifacts, organizations, scientific components, and legal [24]. Technical subsystems in an organization to solve complex issues [29]. The social subsystem consists of the organizational structure, which encompasses authority structures, reward systems, knowledge, skills, attitudes, values, needs and within the organization, employees can work by utilizing technological artifacts (tools, devices, and techniques) to achieve job satisfaction and economic performance [17]. As shown in Fig. 1, the socio-technical system, describes the interrelated nature of the organizational system, embedded in the external environment consisting of goals, people, buildings, technology, culture, and process [25].

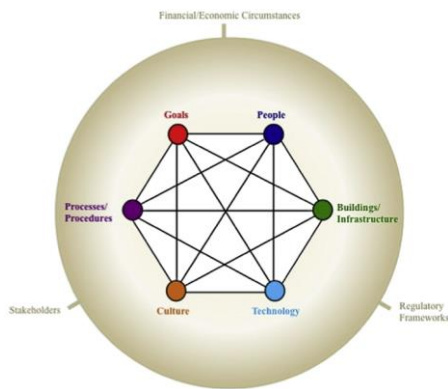


Fig. 1. Socio-technical system, illustrating the interrelated nature of an organizational system, embedded within an external environment from [25].

Refer to Fig. 2. The information technology or information systems when developed require several social sub-system factors (user roles, social interaction) and technical sub-system factors (technical infrastructure, system access) [26].

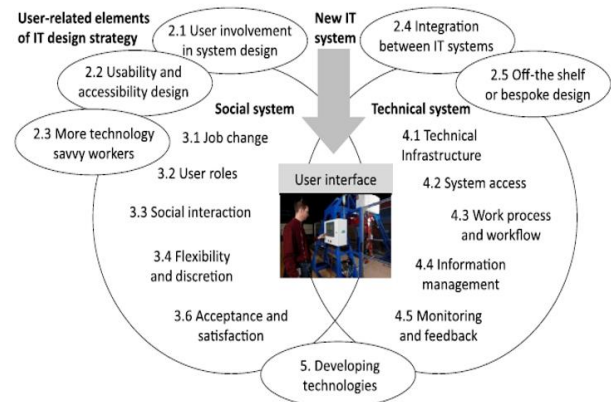


Fig. 2. Elements of the IT introduction and socio-technical system that may affect or be affected by the user-interface from [26].

The supporting elements in establishing a security system that is linked to Socio-technical will depend on the security requirements for the organization to determine the nature of ICT a culture of security to be cultivated. Apart from that, there are other defining requirements policies, and types of countermeasures (security systems) to be implemented. Next comes the security section requirements impose demands on the people who will interact with the system. Other activities such as motivation, training, and education need to be done thoroughly. In security culture issues, culture has effects on attitudes and beliefs, which in turn play a part in individual behaviors actions, and or reactions [30]

Based on Fig. 2, Fig. 3, a generic motif that can be accepted is the necessity and importance of work behavior to minimize cyber security threats. The questions here can rather be:

- 1) What are the factors that contribute to improving work behaviors to reduce cybersecurity threats?
- 2) How can socio-technical factors contribute to improving work behavior

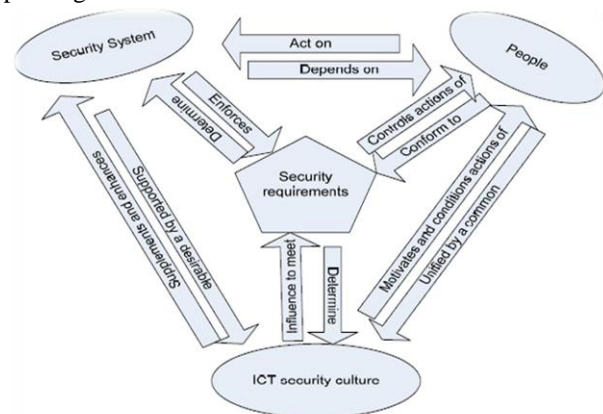


Fig. 3. An organizational framework showing ICT security culture in relation to other ICT security controls from [30].

### III. RESEARCH METHODOLOGY

The research methodology is described in Fig. 4.

1) *Literature review*: Literature reviews are more concentrated on the main studies according to the title of the research and those related to data collection both for interviews and research surveys. The literature review that emerged includes the concept and definition of smart city, definition of cybersecurity, concept of behavior, and socio-technical concept. The components and elements in the socio-technical will be used as a reference for building questions for qualitative studies and become question points in quantitative studies using the Likert scale model.

2) *Initial model*: This stage is the initial model used in this study. Referring to Fig. 1, the initial model adopts all socio-technical components, which consist of structure, technical, people, tasks, and environment. This initial model will then be used as a reference for processing questions for qualitative and point surveys for quantitative studies.

3) *Qualitative model*: The interview process is part of a qualitative study, namely by gathering as much information as possible from appointed and agreed sources. the results of this interview change the initial model by eliminating some of the components, namely by removing the environment hence that there will be four main components, namely structure, technical, people, and tasks.

4) *Quantitative model*: An interview to collect qualitative data will be carried out which is then followed by quantitative data collection by employing a survey questionnaire in the second phase [27]. Numerical data for quantitative research were collected and analyzed using statistical methods [28]. The model from the results of a qualitative study becomes a reference in a quantitative study the survey questionnaire will exclude an environmental component.

5) *Final model*: The final model is based on the quantitative finding. Data collection and data examination are essential when applying structural equation modeling (SEM). Several issues need to be addressed when utilizing a questionnaire survey. These issues include response rates, non-response bias, common method bias, missing data, and data distribution.

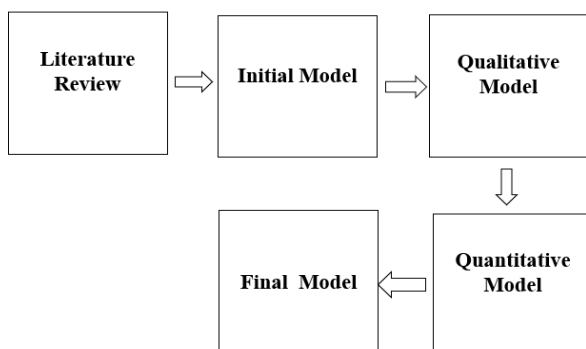


Fig. 4. Research methodology.

### IV. RESULT AND DISCUSSION

Being a part of continual research, this investigation is based on primary data origins gathered in West Java – Indonesia. Using mix-method research, is specifically primary analysis that contains the collection of data (interview and survey data), organizing it in some fashion (a social-technical framework) based on some factors of technological environment, personnel development, and organizational support. Fig. 5 shows the interaction between a social and technical system and the point interviews and questionnaires were made based on socio-technical components [29],[31] to obtain in-depth information about what factors influence improving work behavior. Each question and point questionnaire has been validated by several experts who are competent in their fields. Interviews were conducted thoroughly with several employees in the communication and information department which were conducted randomly and were conducted before the questionnaire process began.

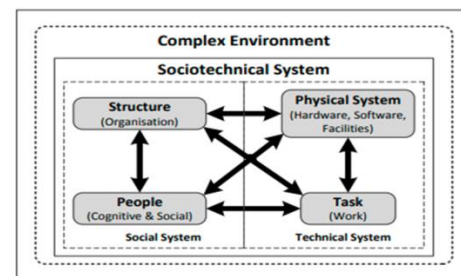


Fig. 5. Socio-technical perspective [29].

The initial model as shown in Fig. 6, propose includes technical, social, and environmental dimensions. Hypotheses that can emerge from the initial model which are displayed sequentially, are IT infrastructure has a positive influence on behavior, technology have a positive influence on behavior, IT infrastructure has a positive influence on competency, technology has a positive influence on work group, work organization has a positive influence on behavior, work organization has a positive influence on competency, competency has a positive influence on behaviors, company procedure have a positive influence on behaviors, IT awareness have a positive influence on behaviors, training have a positive influence on behavior, work group have a positive influence on behavior, environment have a positive influence on behavior, environment have a positive influence on competencies, and behaviors will give contribution and a positive influence for minimizing cyber security threat toward successful smart city implementation.

The interview process involved limited Ministry of Communication and Informatics (Kominfo) staff and employees; the number of interviewees was seven people. The interview process is carried out in stages and at different times according to the agreement. Some of the questions posed to them included:

- What is the impact of the external environment on competence?
- How does the organization provide direction regarding work behavior and culture?

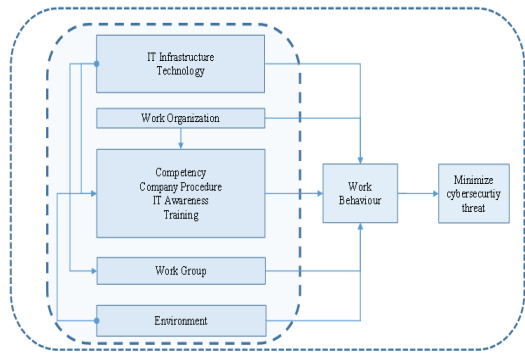


Fig. 6. Initial model.

The answer to the questions above is:

I believe the influence of the external environment on competency is not so significant that I can even say that there is no influence. (Respondent 1)

External factors do have the opportunity to contribute to employee competency but are very small and not significant (Respondent 3)

The qualitative method by using the interview process finally abolishes several hypotheses, as shown in Fig. 7 namely environment has a positive influence on behavior, environment has a positive influence on competencies, IT infrastructure has a positive influence on behaviors, and company procedure has a positive influence on behaviors.

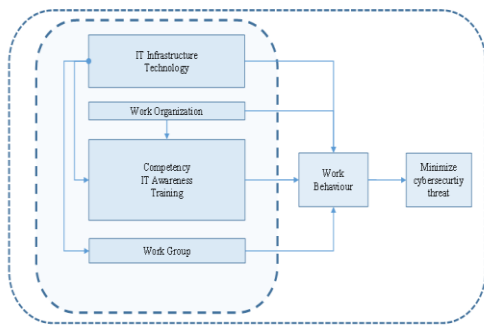


Fig. 7. New model based on qualitative result.

The questionnaires were delivered to employees who work at Kominfo. A total of 110 questionnaires were distributed to the Kominfo office in three districts, and 97 people filled out and returned the questionnaire form within two months. Table I shows the total questionnaire distributed which shows the data collected and which can be used.

TABLE I. DISTRIBUTION OF QUESTIONNAIRE

Office (District)	Distributed	Collected	Unusable	Usable
Karawang	55	43	0	43
Bandung	66	50	0	50
Purwakarta	10	4	0	4
Total	130	97	0	97

An example of a question sheet for a survey questionnaire is listed in Fig. 8.

**INSTRUCTION / ARAHAN:**  
 From Section B to F, please circle a number from 1 to 7 as an indication of the level of your agreement with the statement.  
 Dari Bagian B sampai F, harap lingkari angka dari 1 sampai 7 sebagai indikasi tingkat persetujuan Anda dengan pernyataan tersebut.

Strongly Disagree (1) Disagree (2) Somewhat Disagree (3) Neutral (4) Somewhat Agree (5) Agree (6) Strongly Agree (7)

Sangat Tidak Setuju (1) Tidak Setuju (2) Agak Tidak Setuju (3) Netral (4) Agak Setuju (5) Setuju (6) Sangat Setuju (7)

**SECTION B: COMPETENCY**  
**BAGIAN B : KOMPETENSI**

This section seeks to know your agreement on the level of your knowledge to optimize related to peripheral and application in IT  
 Bagian ini bertujuan untuk mengetahui persetujuan Anda tentang tingkat pengetahuan Anda terkait dengan periferal dan aplikasi di bidang TI

Items	Scales / Scala							
	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	
<i>As Employee in an Organization</i> Sebagai karyawan pada Organisasi ini								
1. Using ICT tools correctly is very important Menggunakan alat TIK dengan benar sangat penting	1	2	3	4	5	6	7	
2. The ability in the field of ICT is getting better with increasing years of work kemampuan di bidang TIK semakin baik seiring bertambahnya masa kerja		1	2	3	4	5	6	7
3. Understanding the office applications that are used in the organization is necessary Memahami aplikasi perkantoran yang digunakan dalam organisasi mutlak diperlukan		1	2	3	4	5	6	7
4. Knowing and understanding work culture is		1	2	3	4	5	6	7

Fig. 8. Form questionnaire.

The data represented in this area defines analysis data such as mean, minimum, maximum, standard deviation, median, and mode. Presentation of data descriptions starts from exogenous variables, namely IT infrastructure (X1), technology (X2), work organization (X3), IT awareness (X5), and training (X6) followed by endogenous variable competency (X4), workgroup (X7), behaviors (X8) and minimize cybersecurity threat (Y), descriptions of each variable are presented successively starting from variables X1, X2, X3, X4, X5, X6 X7, X8 and Y. As shown in Table II to Table X.

TABLE II. LATENT VARIABLE FOR IT INFRASTRUCTURE

	No.	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
X1.1	1.000	5.680	6.000	4.000	7.000	0.844	-0.540	-0.167
X1.2	2.000	5.763	6.000	4.000	7.000	0.822	-0.628	-0.096
X1.3	3.000	5.794	6.000	4.000	7.000	0.811	-0.678	-0.071
X1.4	4.000	5.680	6.000	4.000	7.000	0.781	-0.328	-0.158
X1.5	5.000	5.691	6.000	3.000	7.000	0.854	-0.004	-0.261
X1.6	6.000	5.691	6.000	4.000	7.000	0.829	-0.738	0.088



TABLE III. LATENT VARIABLE FOR QUALITY OF TECHNOLOGY (X2)

	No.	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
X2.1	7.000	5.845	6.000	4.000	7.000	0.889	-0.970	-0.135
X2.2	8.000	5.804	6.000	4.000	7.000	0.893	-0.779	-0.219
X2.3	9.000	5.701	6.000	4.000	7.000	0.875	-0.708	-0.121
X2.4	10.000	5.577	6.000	4.000	7.000	0.906	-0.738	-0.150

TABLE IV. LATENT VARIABLE FOR WORK ORGANIZATION (X3)

	No.	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
X3.1	11.000	6.072	6.000	4.000	7.000	0.900	-0.867	-0.490
X3.2	12.000	5.897	6.000	4.000	7.000	0.902	-0.833	-0.306
X3.3	13.000	6.010	6.000	4.000	7.000	0.891	-0.924	-0.376
X3.4	14.000	5.938	6.000	4.000	7.000	0.883	-0.794	-0.334

TABLE V. LATENT VARIABLE FOR COMPETENCY (X4)

	No.	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
X4.1	15.000	5.753	6.000	4.000	7.000	0.920	-0.727	-0.291
X4.2	16.000	5.763	6.000	4.000	7.000	0.906	-0.812	-0.185
X4.3	17.000	5.784	6.000	4.000	7.000	0.933	-0.855	-0.247
X4.4	18.000	5.742	6.000	4.000	7.000	0.888	-0.631	-0.271
X4.5	19.000	5.804	6.000	4.000	7.000	0.959	-0.796	-0.377
X4.6	20.000	5.784	6.000	4.000	7.000	0.864	-0.482	-0.340
X4.7	21.000	5.742	6.000	4.000	7.000	0.945	-0.739	-0.353

TABLE VI. LATENT VARIABLE FOR IT AWARENES (X5)

	No.	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
X5.1	22.000	5.897	6.000	4.000	7.000	0.879	-0.662	-0.350
X5.2	23.000	5.938	6.000	4.000	7.000	0.859	-0.612	-0.374
X5.3	24.000	6.072	6.000	4.000	7.000	0.911	-0.511	-0.644
X5.4	25.000	5.845	6.000	4.000	7.000	0.889	-0.826	-0.224
X5.5	26.000	5.794	6.000	3.000	7.000	0.952	-0.169	-0.593
X5.6	27.000	5.804	6.000	4.000	7.000	1.012	-0.806	-0.505
X5.7	28.000	5.866	6.000	4.000	7.000	0.926	-0.906	-0.280

TABLE VII. LATENT VARIABLE FOR TRAINING (X6)

	No.	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
X6.1	29.000	5.979	6.000	4.000	7.000	0.773	-0.282	-0.372
X6.2	30.000	5.897	6.000	4.000	7.000	0.831	-0.674	-0.241
X6.3	31.000	5.897	6.000	4.000	7.000	0.793	0.174	-0.568
X6.4	32.000	5.979	6.000	4.000	7.000	0.812	-0.060	-0.548

TABLE VIII. LATENT VARIABLE FOR WORKGROUP (X7)

	No.	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
X7.1	33.000	5.887	6.000	4.000	7.000	0.785	-0.297	-0.315
X7.2	34.000	5.814	6.000	3.000	7.000	0.877	0.340	-0.648
X7.3	35.000	5.845	6.000	4.000	7.000	0.877	-0.441	-0.434

TABLE IX. LATENT VARIABLE FOR BEHAVIOUR (X8)

	No.	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
X8.1	36.000	5.763	6.000	4.000	7.000	0.950	-0.731	-0.384
X8.2	37.000	5.856	6.000	4.000	7.000	0.908	-0.799	-0.295
X8.3	38.000	5.784	6.000	4.000	7.000	0.888	-0.897	-0.095
X8.4	39.000	5.825	6.000	4.000	7.000	0.812	-0.839	-0.016
X8.5	40.000	5.784	6.000	4.000	7.000	0.840	-0.725	-0.098
X8.6	41.000	5.969	6.000	4.000	7.000	0.902	-0.874	-0.366
X8.7	42.000	5.845	6.000	4.000	7.000	0.854	-0.564	-0.301
X8.8	43.000	5.804	6.000	4.000	7.000	0.893	-0.654	-0.307

TABLE X. LATENT VARIABLE FOR MINIMIZE CYBERSECURITY THREAT (Y)

	No.	Mean	Median	Min	Max	Standard Deviation	Excess Kurtosis	Skewness
Y.1	44.000	5.856	6.000	3.000	7.000	0.984	-0.281	-0.626
Y.2	45.000	6.021	6.000	3.000	7.000	0.963	0.080	-0.816
Y.3	46.000	5.969	6.000	4.000	7.000	0.879	-0.704	-0.402
Y.4	47.000	5.979	6.000	3.000	7.000	0.941	0.508	-0.787

The quantitative process provides changes to the qualitative model by removing some of the attributes of the social dimension. The elimination of some attributes on the social dimension was due to the results of the questionnaire which was processed using structural equation modeling. Table XI shows the processing results of the quantitative method using SEM modeling. This hypothesis shows a negative result of IT awareness of work behavior, so the last model shown in Fig. 9 does not include the relationship between IT awareness and work behavior. The descriptive Analysis of Research Variables is shown in the table.

The framework created in this study is a communion of the framework composed by [30] and the research results resulting from the processing of structural equation models (SEM). The quantitative results show that the social dimension presents a great contribution than the technical dimension, this does not mean that social factors are more prominent, the contribution of both dimensions must still be required because both dimensions must continue to exist to be able to contribute to the development of the formation the work behavior. The factors that play a role in improving work behavior according to the research questions are as follows as shown in Fig. 5. The researcher divides the main factors contributing to increased work behavior into three parts, namely, personal development which consists of training and competency, organizational support which consist of teamwork and work organization, and



technological environment which consists of technology and IT infrastructure.

TABLE XI. HYPOTHESIS TESTING

Immediate impact	Path Coefficient	T count	Examination Conclusion
IT Infrastructure to competency (X1→X4)	0.335	3.462	H0 is refused, H1 is accepted. There is a positive direct effect of X1 → X4
Technology to work group (X2→X7)	0.270	2.918	H0 is refused, H1 is accepted. There is a positive direct effect of X2 → X7
Work Organization to competency (X4→X4)	0.283	3.274	H0 is refused, H1 is accepted. There is a positive direct effect of X3 → X4
Technology to behaviors (X2→X8)	0.219	2.860	H0 is refused, H1 is accepted. There is a positive direct effect of X2 → X8
Work Organization to behaviors (X3→X8)	0.160	1.992	H0 is refused, H1 is accepted. There is a direct positive effect of X3 → X8
Competency to behaviors (X4→X8)	0.167	2.135	H0 is refused, H1 is accepted. There is a positive direct effect of X4 → X8
IT Awareness to behaviors (X5→X8)	-0.204	2.502	H0 is refused, H1 is accepted. There is a direct negative effect of X5 → X8
Training to behaviors (X6→X8)	0.184	2.514	H0 is refused, H1 is accepted. There is a positive direct effect of X6 → X8
Work group to behaviors (X7→X8)	0.252	3.607	H0 is refused, H1 is accepted. There is a direct positive effect of X7 → X8
Behaviors to Minimize Cybersecurity Threat (X9→Y)	0.457	5.594	H0 is refused, H1 is accepted. There is a positive direct effect of X9 → Y

T Table = 1.96

Based on Fig. 9, the researcher makes a detailed elucidation by placing personal development as a fundamental basis then followed by organizational support and technological assistance. In most cases, personal development is a process of self-development owned by someone to achieve success in the world of work. In consort with personal development, employees can manage themselves well when working enterprise. The principal objective of this personal development is to dig up the potency that exists within oneself so that it can withstand to encounter all the alteration times that encircle it. Two factors need to be done for the self-development process, which can be through training and competency improvement.

According to [32] competence is the ability to act and think consistently that is owned by someone equipped with skills, basic attitudes, knowledge, and values. Competence is a person's skills and direct and indirect conduct that enable the person to effectively undertake a given assignment or assigned character. Hence, competence is not only about the capability or awareness that an employee has but the compliance to do what is known and can yield advantages.

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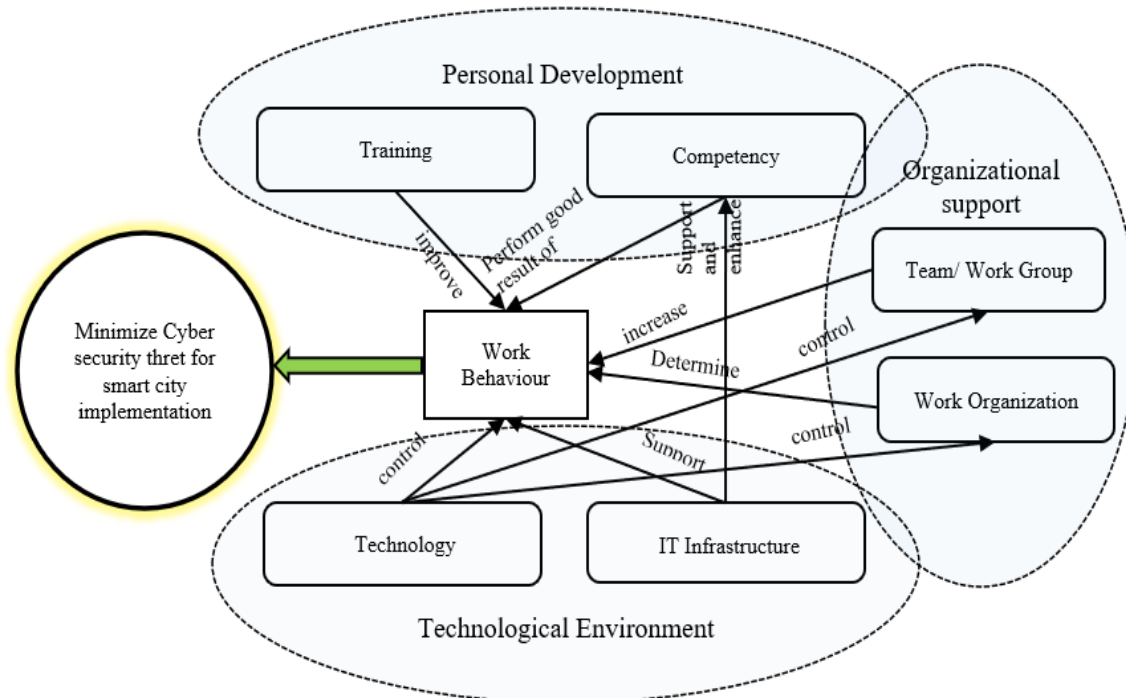


Fig. 9. Final model.

Training is one way to intensify competence [33]. Therefore, competence and training are two interconnected things. To rectify competency through training related to improving work behavior, there are several types of training that employees must obtain. Training is a key tool to increase the firm's organizational learning capability at individual, group, and organizational levels and, through this effect, training may affect performance. Some of the important training for employees, number one is the understanding importance of cybersecurity; cybersecurity is critical because it helps to protect organizations and individuals from cyber-attacks. Cybersecurity awareness is contributed to avert data breaches, identity stealing, and other types of cybercrime. Organizations are compulsory to apply strong cybersecurity measures to protect their data and customers. Behavior in the case of cybersecurity incidents, insider threats occur when an employee's careless behavior or lack of security awareness leads to a security breach.

For example, an employee might use an insecure password or fall for a phishing scam [34]. Malicious insider threats happen in case an employee intentionally causes a security breach.

Another compulsory training is how to defend against cyber-attack; this training will educate the employee to do some action against cybersecurity threats for example Turning on Multifactor Authentication. Implement multifactor authentication on your accounts and make it significantly less likely you'll get hacked [35].

Managing password security and a secure password is further important training for the user [36]. Robust passwords can assist defend against cyberattacks and reduce the hazard of a safety violation. The password generally is long—at least twelve symbols—and include uppercase letters, lowercase notes, digits, and certain symbols [37].

Robust passwords should not have any private data. Workplace protection directs to the measures put in place to save individuals, investments, and data from physical and digital threats. These hazards can reach in different shapes, running from robbery, roughness, and destruction to digital safety risks such as cyberattacks, data violations, and hacking.

Comprehending and protecting sensitive information is the other important training, the information needs to be protected to prevent that data from being misused by third parties for fraud, such as phishing scams and identity theft [38]. Data protection is also essential to help control cybercrimes by ensuring details (specifically banking) and reference report are covered to prevent deception.

The employee should know cyber-attack tactics [39], during a cyber-attack, the attacker gains unauthorized access to a computer system, network, or device for stealing, modifying, or destroying data. The attacker may use a variety of tactics, including malware, social engineering, or exploiting vulnerabilities in software or systems. Further incident response is an organized, strategic approach to detecting and managing cyber-attacks in ways that minimize damage, recovery time, and total costs. Detecting phishing emails, emails with bad grammar, and spelling mistakes, emails with

an unfamiliar greeting or salutation, inconsistencies in email addresses, links and domain names, and suspicious attachments, emails requesting login credentials, payment information, or sensitive data. [40].

Teamwork is part of the actor which is a social dimension. The objective of the entertainers in the organization is to emphasize the position recreated by human beings toward gaining protection. The actors include management and employees, and other stakeholders who execute or influence the way work organizational tasks are carried out and work organization is part of work activities. The purpose of work activities in the organization is to emphasize the purpose and implementation of suitable duties by individuals in extra operation and competency areas, using tools and resources, towards security. The work activities refer to the actual tasks and the way they should be carried out.

Technology and IT infrastructure are part of the technology from the technical dimension. The purpose of technology in the organization is to emphasize the tools and resources used by people in carrying out work activities towards achieving security. The technology includes any useful technical resources that can aid humans in performing their security duties, for example, information, equipment, frameworks, and computers.

In this research, the researcher uses two dimensions on the technical side, namely technology in general refers to Technology as the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment.

While IT infrastructure is part of the technology, more specifically the combined components needed for the operation and management of enterprise IT services and IT environments. The components of IT infrastructure are made up of interdependent elements, and the two core groups of components are hardware and software. The hardware uses software like an operating system to work, and likewise, an operating system manages system resources and hardware. operating systems also make connections between software applications and physical resources using networking components to produce a new framework, as shown in Fig.10., researchers adopted an ICT security framework from [30] as support and contribute to minimize cyber security threat for smart city implementation

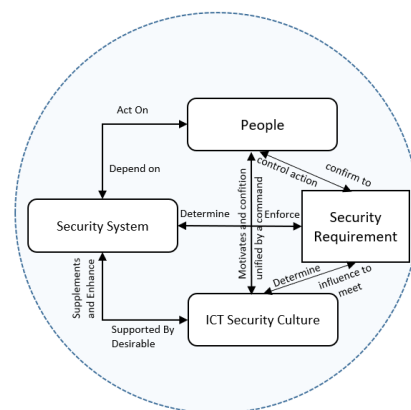


Fig. 10. ICT Security framework [30].

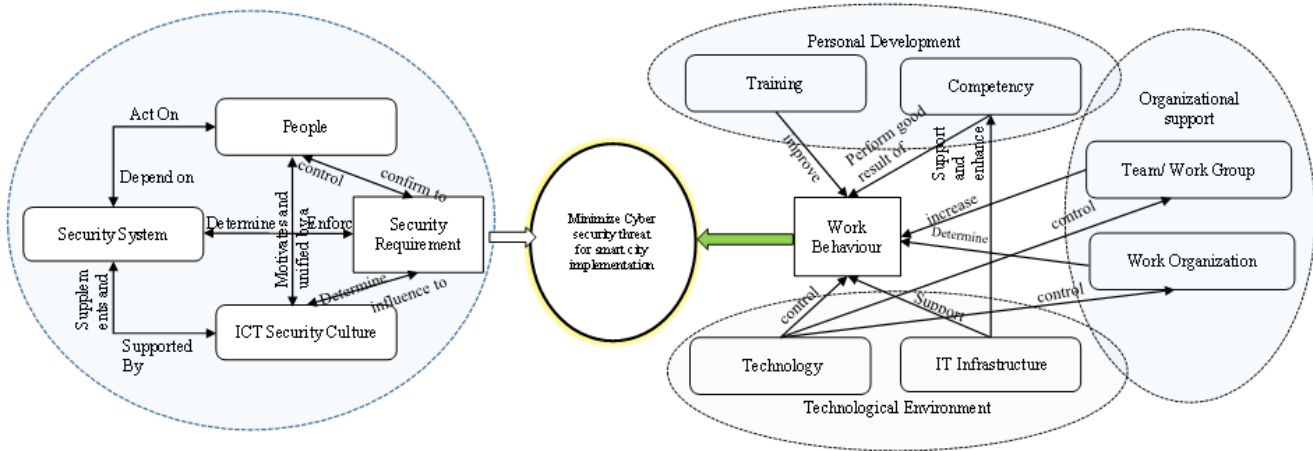


Fig. 11. Socio technical framework to improve work behavior.

Fig. 11 shows the relationship between the socio-technical components and their role in improving work behavior to minimize cyber security threats during smart city implementation. Planned training well and followed by all employees will improve work behavior. Training will contribute to employee competence and perform a good result to the work behavior. In addition, to be able to improve competency, good IT infrastructure support is needed. Organizational contributions make a dominant contribution, consisting of teams and organizational work that improve and determine work behavior. The level of success of the organization is determined by the support provided by the technology environment. The last component that contributes to improving work behavior is support from technology and IT infrastructure, implementation of backup systems, use of operating systems (OS), data communication devices, network security systems, anti-virus, and monitoring systems will have a major impact on work behaviors so that it is expected to be able to contribute to minimizing cyber security attacks in the framework of the successful implementation of smart cities.

## V. CONCLUSION AND FUTURE WORK

The results of the study show that social and technical factors contribute to increased work behavior; this is shown from the results of the quantitative method which produces a summary of hypotheses where there is only one hypothesis that shows negative results so that it cannot be used in the formulation of the framework proposed by the researcher. In this study, three main factors contribute to improving work behavior, namely personal development which consists of training and competency, organizational support which consists of teamwork and work organization, and technological environment which consists of technology and IT infrastructure to be able to contribute to minimizing threats cybersecurity.

In the future, organizations will experience many challenges, so to keep all problems better in the field of cybersecurity, a social-technical framework that is developed which aims to improve work behavior in a positive direction will be stronger when combined with a control framework by adopting a control objective for Information and related

technology (COBIT) and using the program and risk framework by implementing the NIST Cybersecurity Framework.

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# Detecting Malware with Classification Machine Learning Techniques

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**Abstract**—In today's digital landscape, the identification of malicious software has become a crucial undertaking. The ever-growing volume of malware threats renders conventional signature-based methods insufficient in shielding against novel and intricate attacks. Consequently, machine learning strategies have surfaced as a viable means of detecting malware. The following research report focuses on the implementation of classification machine learning methods for detecting malware. The study assesses the effectiveness of several algorithms, including Naïve Bayes, Support Vector Machine (SVM), K-Nearest Neighbor (KNN), Decision Tree, Random Forest, and Logistic Regression, through an examination of a publicly accessible dataset featuring both benign files and malware. Additionally, the influence of diverse feature sets and preprocessing techniques on the classifiers' performance is explored. The outcomes of the investigation exhibit that machine learning methods can capably identify malware, attaining elevated precision levels and decreasing false positive rates. Decision Tree and Random Forest display superior performance compared to other algorithms with 100.00% accuracy. Furthermore, it is observed that feature selection and dimensionality reduction techniques can notably enhance classifier effectiveness while mitigating computational complexity. Overall, this research underscores the potential of machine learning approaches for detecting malware and offers valuable guidance for the development of successful malware detection systems.

**Keywords**—Malware; classification; machine learning; accuracy; false positive rate

## I. INTRODUCTION

In contemporary times, the Internet holds a crucial position in people's lives, functioning as a worldwide network of computers that employ the Internet Protocol for communication and information exchange. Nevertheless, the Internet is affected by multiple hazards, with malware being a prevalent issue [1]. The study [2] defines malware as harmful software, comprising viruses, worms, Trojans, Adware, and Ransomware. Most of the malicious software created in recent times poses a severe threat to an organization's information. Malware can infect any device that is connected to a computer network, causing damage to data, and facilitating theft that can be used for identity theft [3]. The widespread interconnectivity of modern devices has made this type of malware infection very common. Various forms of malicious software exist, such

as computer viruses, worms, Trojan Horses, spyware, rootkits, adware, and botnets.

Computer viruses are widely prevalent and propagate through files, infecting computer systems upon file access. Worms resemble viruses, reproducing rapidly and causing damage without user intervention [4]. Trojan Horses disguise themselves within programs, tricking users into downloading them to seize control and capture sensitive information. Spyware surveils and records user activities, including personal data [5]. Rootkits are purposefully designed to avoid detection, granting unauthorized remote access, and modifying system files. Adware generates intrusive ads while collecting personal information, and botnets disrupt computer networks by infecting multiple devices [6]. Hence, malware is classified as malicious software and presents significant risks that can result in substantial harm if not adequately protected [7].

The research paper makes several significant contributions as follows:

- A comprehensive dataset was obtained from a reputable source, [www.kaggle.com/datasets](http://www.kaggle.com/datasets). The dataset underwent thorough pre-processing to ensure its quality and suitability for analysis.
- Advanced techniques were employed to select the most relevant and informative features from the dataset. This process improved the accuracy of malware detection while reducing data dimensionality.
- The study employed various classification machine learning algorithms, including Naïve Bayes, SVM, KNN, Decision Tree, Random Forest, and Logistic Regression to detect and classify malware. These techniques enabled automated and efficient malware detection, saving valuable time and resources.
- The research aimed to improve the accuracy of malware detection. By leveraging the proposed methodology, the study contributes to reducing false positive rate, thereby enhancing the overall precision of malware identification.

The findings from this research have practical implications for the development of cybersecurity measures. By improving the accuracy of malware detection, organizations can enhance their defenses against cyber threats, ultimately safeguarding digital systems more effectively.

To ensure a well-structured approach to the research, this paper is divided into multiple sections. In Section II, a discussion of related work in the field is provided, with a particular focus on the research objectives of the study. Section III outlines the methodology utilized to complement the research, including details on data pre-processing and feature selection to optimize the performance of the classification machine learning techniques. Meanwhile, in Section IV, the outcomes of the evaluation on the machine learning classification techniques employed are presented, and a summary of the discoveries is provided in Section V.

## II. RELATED WORK

In this section, various investigations carried out by previous scholars on machine learning classification techniques are examined. Table I is provided to assist in this examination, summarizing the evaluated classification techniques in these studies. Classification is a valuable method for organizing objects according to their attributes and designations, and the insights gained from these investigations reveal the efficacy of different machine learning methods for this purpose.

To start, a method proposed by [8] for machine learning-based malware classification will be examined. Their approach involves analyzing packet information stored in a dataset. The team evaluated the accuracy and precision of four machine learning techniques, namely SVM, Decision Tree, Naïve Bayes, and Random Forest. While the researchers found Random Forest to have the highest accuracy of the four methods, they did not report on the false positive rate, a critical metric for assessing the efficacy of malware classification techniques.

A group of researchers [9] have conducted a study on identifying malicious network traffic in a cloud environment. They proposed a machine learning-based framework for intrusion detection, utilizing a dataset containing both normal and malicious traffic. The team extracted, selected, and added relevant features to train the machine learning models to differentiate between incoming traffic as either normal or anomalous. The researchers assessed the models using two methods: cross-validation and split-validation. The results indicated that KNN, Random Forest, and Decision Tree techniques achieved the highest detection accuracy. However, the SVM and Naive Bayes techniques had very low detection accuracy, resulting in a high false positive rate for both methods.

Research conducted in [10] focused on the identification of malware traffic through DNS over HTTPS connections. They employed four machine learning techniques: Random Forest, KNN, Logistic Regression and Naive Bayes, and tested them after selecting features. The results showed that Random Forest outperformed the other three techniques in detecting malware traffic. Consequently, the other three methods exhibited a relatively high false positive rate. Therefore, the study highlights the significance of selecting the appropriate machine learning technique for detecting malware traffic effectively.

Another technique designed by [11] aims to detect malware in a network environment using a visualization method involving 2D images and machine learning techniques. The

researchers evaluated the technique's accuracy for detecting malware using three different datasets. However, the technique did not achieve a high percentage of malware detection. For instance, the 2015 BIG dataset only achieved a 97.20% detection rate, which could indirectly affect the false positive rate.

TABLE I. PAST STUDY CLASSIFICATION TECHNIQUE

Title of Paper	Machine Learning Classification Technique					
	SVM	KNN	Naïve Bayes	Logistic Regression	Decision Tree	Random Forest
Machine learning techniques for malware detection	✓	✗	✓	✗	✓	✓
Apply machine learning techniques to detect malicious network traffic in cloud computing	✓	✓	✓	✗	✓	✓
Detecting malicious DNS over HTTPS traffic using machine learning	✗	✓	✓	✓	✗	✓
Intelligent vision-based malware detection and classification using deep random forest paradigm	✓	✓	✓	✓	✓	✓
Malware detection & classification using machine learning	✗	✗	✗	✗	✓	✓
Malware analysis and detection using machine learning algorithms	✓	✓	✓	✗	✓	✓
Empirical study on Microsoft malware classification	✗	✓	✗	✓	✗	✓

In a recent academic paper by [12], a technique for detecting and categorizing malware was developed. The research process involved five phases, namely dataset creation, data preprocessing, feature selection, training dataset, and malware classification. The study aimed to discover fresh indicators of compromise through the utilization of machine learning methods to detect and classify malware. Nevertheless, the accuracy of the approach using Decision Tree and Random Forest models was found to be less than 99.50%, which implies that there is a high rate of false positives.

Researchers from [13] have proposed a robust and innovative methodology for effectively detecting malware by leveraging advanced machine learning algorithms. They discuss the challenges in analyzing and detecting malware due to its increasing complexity and sophistication. The proposed methodology involves three stages: data preprocessing, feature selection, and classification. The researchers use several machine learning algorithms such as decision tree, random forest, support vector machine, and logistic regression for malware detection. To evaluate the effectiveness of the proposed methodology, the authors used different evaluation metrics such as accuracy, precision, recall, and F1-score.

The research [14] discusses a study conducted on the Microsoft malware dataset to classify malware samples into



different families using four different classification algorithms: KNN, Decision Tree, Random Forest, and SVM. The algorithms' performance is evaluated using various metrics such as accuracy, precision, recall, F1 score, and AUC. The Random Forest algorithm is found to outperform the other algorithms, with an accuracy, precision, recall, F1 score, and AUC of 99.58% and 0.998, respectively. The SVM algorithm also performs well, with an accuracy, precision, recall, F1 score, and AUC of 98.74% and 0.994, respectively. Additionally, the authors analyze the algorithms' performance on different malware families, showing that the Random Forest algorithm performs consistently well across all families. The study concludes that machine learning algorithms are effective in classifying malware and provides insights into the performance of different algorithms on the Microsoft malware dataset.

The research [15] presents an empirical study of detecting malware families and subfamilies using machine learning algorithms. The study evaluates four different algorithms: Logistic Regression, KNN, Decision Tree, and Random Forest to classify malware samples into various families and subfamilies. The study evaluates algorithm performance using various metrics such as accuracy, precision, recall, F1 score, and AUC. Results indicate that the Random Forest algorithm outperforms others, achieving 98.7% accuracy in identifying malware families and 92.8% accuracy in identifying subfamilies. It also performs consistently across different type of malware. The study concludes that machine learning algorithms are effective in detecting malware and provides insights into their performance.

After reviewing previous studies in this field, it is evident that the feature selection present in the datasets utilized should be enhanced. It is crucial to decrease the false positive rate percentage to attain a high level of detection accuracy. This finding underscores the significance of selecting relevant and effective features for use in malware detection and classification techniques. By improving feature selection, the risk of generating false positive rates can be minimized, leading to more reliable and accurate results.

### III. PROPOSED METHODOLOGY

In this section, the stages required to finalize the research were covered. The process consists of a total of five stages, commencing with dataset preparation, and followed by the remaining four phases depicted in Fig. 1.

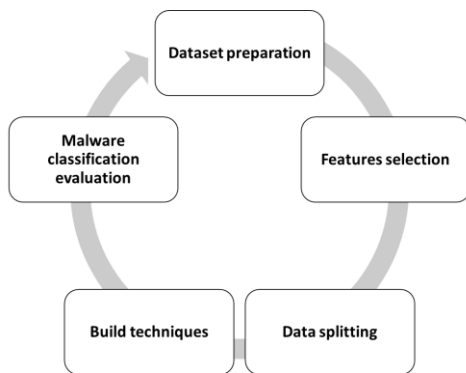


Fig. 1. Methodology of proposed malware detection.

#### A. Dataset Preparation

The initial stage involves preparing a dataset, which is critical as it enables the generation of data appropriate for machine learning techniques. The data will be utilized for classifying malware. Dataset preparation aids in establishing the proper data collection method. The dataset was procured from Kaggle, an open-source platform frequently employed by researchers in machine learning projects. Table II illustrates the 35 features that will be utilized in the study. To ensure high-quality data, data preprocessing will be conducted, and the refined data will be stored in a new file.

TABLE II. SAMPLE OF DATASET

hash	millisecond	classification	state	...	signal_nvcsw
abc.com	415	Benign	0	...	0
42fb5e	420	Malware	4096	...	0
024b27	90	Malware	4096	...	0
xyz.com	773	Benign	0	...	0

During the review process, some shortcomings were identified in the dataset, including redundant data and missing values. The fundamental principle is to ensure high-quality data for the study. To achieve this, two data preprocessing techniques will be undertaken: data cleaning and data reduction. The dataset will be inspected for missing values or empty cells, as illustrated in Fig. 2, in order to address these issues and ensure the data quality. A value of 1 denotes an empty cell in the hash, state, or prio columns, while a value of 0 indicates no missing values.

The secondary approach involves examining duplicated information, as depicted in Fig. 3. Whenever the result is affirmative, a duplicated record exists within the respective row. To illustrate, the application of this technique reveals the presence of replicated data on rows 3, 5, and 8.

```

In [4]: import pandas as pd
df = pd.read_csv('Desktop/malware_dataset.csv')
df.isnull().sum()

Out[4]: hash            1
millisecond            0
classification         0
state                 1
usage_counter         0
prio                  1
static_prio           0
normal_prio           0
policy                0
  
```

Fig. 2. Check for missing values.

```

In [13]: import pandas as pd
df = pd.read_csv('Desktop/malware_dataset.csv')
df.head(10).duplicated()

Out[13]: 0    False
1    False
2    False
3     True
4    False
5     True
6    False
7    False
8     True
9    False
  
```

Fig. 3. Check for duplicate data.

B. Features Selection

The subsequent stage of the research, referred to as feature selection, involves utilizing the correlation matrix to select the appropriate features. This is a crucial method for analyzing the connection between input and target data variables [16]. The correlation matrix enables the determination of whether the variable values are positive, negative, or zero. Out of the 35 features in the dataset, only 24 were selected based on the correlation matrix values that range from -0.39 to 1. Thus, 11 features had to be disregarded since the correlation matrix did not generate any values for them.

C. Data Splitting

Moving to the third phase of the study, data splitting is performed. This phase allows for the division of the dataset into two distinct parts: the training set and the testing set. The training set is critical in determining the suitability of machine learning techniques using data samples from the dataset, whereas the testing set is used to evaluate these techniques [17]. The train and test functions were implemented to segregate the two data categories. The dataset was split, with 80% of the data allocated to the training set and the remaining 20% to the testing set. The uneven allocation of data samples ensures an unbiased performance percentage for malware classification.

D. Build Techniques

Moving on to the fourth phase, which involves building machine learning techniques. This phase is dedicated to developing machine learning techniques using specific functions after providing training and testing sets. As an example, the SVC class was utilized to develop the SVM technique and evaluate its classification accuracy in detecting malware. All the developed techniques were trained and tested based on the selected features presented in the second phase.

E. Malware Classification Evaluation

The final stage of the study involves evaluating the malware classification. The techniques developed were evaluated using the confusion matrix, as illustrated in Table III, to assess their performance.

TABLE III. CONFUSION MATRIX

		Predicted Classification	
		Malware	Benign
Actual Classification	Malware	TP	FN
	Benign	FP	TN

The confusion matrix contains four parameters: true positive (TP), false positive (FP), true negative (TN), and false negative (FN). TP measures the correctly classified malware, while TN measures the correctly classified benign samples. On the other hand, FP measures the benign samples incorrectly classified as malware, and FN measures the malware samples incorrectly classified as benign. To measure accuracy and false positive rate, standard formulas were utilized. The results are presented in percentage form.

$$Accuracy = \frac{TP+TN}{TP+TN+FN+FP} \times 100 \tag{1}$$

$$FPR = \frac{FP}{FP+TN} \times 100 \tag{2}$$

IV. RESULT AND DISCUSSION

In this section, the experimental results for all the techniques involved are presented. The performance of the proposed malware detection method will be examined first, followed by a comparison with the performance of the previous techniques.

A. Performance Comparison in Proposed Malware Detection

Based on Fig. 4, it illustrates the performance of all the techniques tested in the proposed malware detection. The evaluation of each method's performance was done using two crucial metrics: accuracy and false positive rate. The results are presented in percentage format, providing a comprehensive overview of the achieved performance levels.

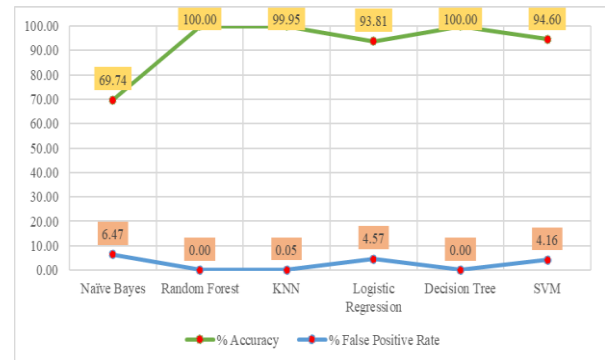


Fig. 4. Comparative analysis of classification techniques in proposed malware detection.

The obtained results demonstrate significant variations in the performance of the different techniques. Naïve Bayes achieved an accuracy of 69.74% with a false positive rate of 6.47%. Random Forest exhibited exceptional performance, attaining a perfect accuracy of 100.00% and a false positive rate of 0.00%. KNN achieved a high accuracy of 99.95%, with a minimal false positive rate of 0.05%. Logistic Regression demonstrated a balanced performance, with an accuracy of 93.81% and a false positive rate of 4.57%. Decision Tree matched Random Forest in terms of accuracy and false positive rate, both achieving perfect scores of 100.00% and 0.00%, respectively. SVM achieved an accuracy of 94.60%, with a false positive rate of 4.16%.

The results indicate that Random Forest and Decision Tree outperformed all other techniques in terms of accuracy and false positive rates, achieving perfect scores. However, it should be noted that achieving 100.00% accuracy may raise concerns of overfitting, especially if the dataset used for evaluation is relatively small or unrepresentative. Naïve Bayes exhibited a lower accuracy compared to other techniques, but it demonstrated a relatively low false positive rate. KNN and SVM also performed well, showcasing high accuracy rates with negligible false positive rates. The performance of all techniques is based on the experimental results presented in Table IV. The Naïve Bayes technique exhibited a correct identification of 3,401 malware packets and 6,921 benign packets. However, it also misclassified 4,478 packets, which indicates a relatively high misclassification rate. This suggests that Naïve Bayes may not be the most accurate approach for this specific task of identifying malware and benign packets.

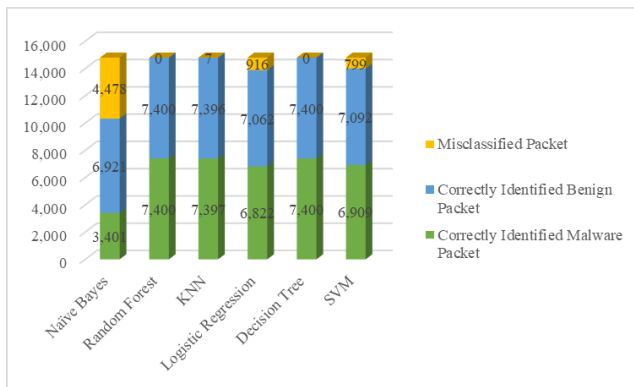


Fig. 5. Classification of the number of packets.

The Random Forest technique demonstrated impressive performance by correctly identifying 7,400 malware packets and 7,400 benign packets. It achieved a perfect classification rate with zero misclassified packets. This indicates that Random Forest is a robust and accurate technique for effectively identifying both malware and benign packets in this context. Meanwhile, KNN achieved high accuracy by correctly identifying 7,397 malware packets and 7,396 benign packets. However, it did misclassify a small number of packets, amounting to only 7 instances. This suggests that KNN may face some difficulty in accurately distinguishing certain types of packets. Following that, the Logistic Regression technique achieved accurate identification by correctly classifying 6,822 malware packets and 7,062 benign packets. However, it had a higher misclassification rate compared to other techniques, misclassifying 916 packets. This indicates that Logistic Regression may struggle with distinguishing between certain types of packets, leading to a relatively higher number of misclassifications (see Fig. 5).

Similar to Random Forest, the Decision Tree technique achieved perfect classification by correctly identifying 7,400 malware packets and 7,400 benign packets. It had zero misclassified packets, showcasing its effectiveness for accurately classifying packets in this task. Moving forward, the SVM technique demonstrated correct identification by accurately classifying 6,909 malware packets and 7,092 benign packets. However, it had a comparatively higher misclassification rate of 799 packets in comparison to certain other techniques. This indicates that SVM may not deliver optimal performance on this dataset, suggesting that it might not be the most suitable choice for accurately identifying malware and benign packets in this specific context.

### B. Performance Comparison between Proposed Malware Detection Technique and Previous Techniques

This section provides a performance comparison between the proposed malware detection method in this study and previous techniques. The comparison evaluates the accuracy achieved by different machine learning algorithms, as presented in Table IV. In the technique proposed by Harsha and Thyagaraja (2021), Random Forest emerged as the top-performing algorithm with an accuracy of 99.27%. This result highlights the suitability of Random Forest for this particular technique. Naïve Bayes also achieved a decent accuracy of 82.12%, suggesting its effectiveness as well. Decision Tree and

SVM demonstrated respectable performances with accuracy of 88.74% and 92.64% respectively.

TABLE IV. PERFORMANCE COMPARISON BETWEEN PROPOSED MALWARE DETECTION TECHNIQUE AND PREVIOUS TECHNIQUES

Technique	Machine Learning Algorithm					
	Naïve Bayes	Random Forest	KNN	Logistic Regression	Decision Tree	SVM
Harsha and Thyagaraja (2021)	82.12	99.27	NA	NA	88.74	92.64
Alshammari and Aldribi (2021)	59.87	100.00	98.94	NA	100.00	80.66
Singh and Roy (2020)	NA	99.99	99.31	96.86	NA	NA
Roseline et al. (2020)	52.14	91.22	85.28	62.59	86.41	89.25
Agarkar and Ghosh (2020)	NA	99.47	NA	NA	99.14	NA
Akhtar and Feng (2022)	89.71	92.01	95.02	NA	99.00	96.41
Chivukula et al. (2021)	NA	97	96.00	89.00	NA	NA
<b>Proposed malware detection</b>	<b>69.74</b>	<b>100.00</b>	<b>99.95</b>	<b>93.81</b>	<b>100.00</b>	<b>94.60</b>

For the technique introduced by Alshammari and Aldribi (2021), Random Forest and Decision Tree showcased perfect accuracy of 100.00%, indicating their strong performance in this context. KNN also performed well with an accuracy of 98.94%. However, SVM achieved a relatively lower accuracy of 80.66% in this scenario. Singh and Roy (2020) technique showed impressive results with Random Forest achieving an accuracy of 99.99% and KNN achieving 99.31%. Logistic Regression also performed well with an accuracy of 96.86%. Unfortunately, the accuracy for Naïve Bayes, Decision Tree, and SVM are not available.

In the study conducted by Roseline et al. (2020), Random Forest achieved a relatively high accuracy of 91.22%. Decision Tree and SVM also demonstrated respectable performances with accuracy of 86.41% and 89.25% respectively. However, Naïve Bayes and Logistic Regression achieved lower accuracy in this particular scenario. Agarkar and Ghosh (2020) technique showcased the effectiveness of Random Forest and Decision Tree, achieving accuracy of 99.47% and 99.14% respectively. Unfortunately, the accuracy for Naïve Bayes, KNN, Logistic Regression, and SVM are not available.

Akhtar and Feng (2022) technique demonstrated the strength of Decision Tree with an accuracy of 99.00%. SVM and KNN also performed well, achieving accuracy of 96.41% and 95.02% respectively. Naïve Bayes achieved a decent accuracy of 89.71% in this scenario. Meanwhile, Chivukula et al. (2021) technique showed strong results with Random Forest achieving an accuracy of 97.00% and KNN achieving 96.00%. Logistic Regression achieved a respectable accuracy of 89.00%. Unfortunately, the accuracy for Naïve Bayes, Decision Tree, and SVM are not available. Finally, in the proposed malware detection technique, Random Forest,

Decision Tree, and SVM achieved perfect accuracy of 100.00%, indicating their effectiveness in this context. KNN achieved a high accuracy of 99.95%, while Logistic Regression achieved a decent accuracy of 93.81%. Naïve Bayes achieved a relatively lower accuracy of 69.74% in this scenario.

Based on above discussion, it appears that Random Forest and Decision Tree consistently performed well across multiple techniques and datasets for malware detection. These algorithms achieved high accuracy rates, often reaching perfect or near-perfect accuracy in the studies mentioned. This suggests that Random Forest and Decision Tree are robust and suitable choices for malware detection tasks. KNN and SVM also showed good performance in some scenarios, achieving high accuracy rates. However, their performance varied across different techniques and datasets. It is important to note that the accuracy of Naïve Bayes, Logistic Regression, and SVM was not available in some studies, so it is difficult to make a comprehensive assessment of their performance.

Overall, the results indicate that the proposed techniques generally achieved high accuracy in detecting malware, highlighting their potential for enhancing cybersecurity measures. However, it is essential to consider that the performance of machine learning algorithms can vary depending on the specific technique, dataset, and evaluation metrics used in each study.

## V. CONCLUSION

A classification technique was developed by the research team to differentiate between malware and benign samples. Several machine learning methods were employed to train a dataset for this purpose. To evaluate the effectiveness of these methods, a comprehensive analysis consisting of five crucial stages was conducted, as outlined in Section III. Based on the analysis, it was found that the Random Forest and Decision Tree consistently performed well across multiple techniques and datasets for malware detection.

Future work in the field of malware detection should focus on several key areas. Firstly, enhancing feature engineering techniques can improve the representation of malware characteristics. This could involve exploring more sophisticated feature extraction methods or incorporating domain-specific features that capture nuanced patterns and behaviors unique to malware. Secondly, further investigation into ensemble methods can be valuable. While Random Forest and Decision Tree algorithms have demonstrated strong performance, exploring advanced ensemble techniques, such as boosting or stacking, may enhance the overall classification accuracy and robustness of malware detection models. Finally, the application of deep learning approaches, such as convolutional neural networks or recurrent neural networks to analyze malware samples and behaviors shows promise. Developing deep learning architectures that effectively capture intricate patterns and detect zero-day or polymorphic malware could significantly improve detection capabilities.

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# Evaluation of the Accidents Risk Caused by Truck Drivers using a Fuzzy Bayesian Approach

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**Abstract**—Road accidents cause hundreds of fatalities and injuries each year; due to their size and operating features, heavy trucks typically experience more severe accidents. Many factors are likely to cause such accidents; however, statistics mainly blame human error. This paper analyses the risk of accidents for heavy vehicles, focusing on driver-related factors contributing to accidents. A model is developed to anticipate the probability of an accident by using Bayesian networks (BNs) and fuzzy logic. Three axioms were verified to validate the developed model, and a sensitivity analysis is performed to identify the factors that have the most significant influence over truck accidents. Subsequently, the result provided by the model was exploited to examine the effects of in-vehicle road safety systems in preventing road accidents via an event tree analysis. The results underlined a strong link between the occurrence of accidents and parameters related to the driver, such as alcohol and substance consumption, his driving style, and his reactivity. Similarly, unfavourable working conditions significantly impact the occurrence of accidents since it contributes to fatigue, one of the leading causes of road accidents. Also, the event tree analysis results have highlighted the importance of equipping trucks with these mechanisms.

**Keywords**—Heavy truck vehicle; road accident prevention; risk management; bayesian-fuzzy network; analysis tree event

## I. INTRODUCTION

The increase in road crashes is currently a significant concern for health and social policies in countries worldwide. Approximately 1.3 million people worldwide die on the roads yearly, while 20 to 50 million suffer serious injuries, most of which require lengthy and costly treatment [1]. Road crashes result in significant economic losses for victims, their families, and the nation. Most countries spend 1% to 3% of their gross domestic product on road crashes [2].

Collisions with heavy trucks are more critical than other traffic accidents [3]. In 2019, there were 510,000 crashes involving large trucks, of which 4,479 (1 per cent) were fatal [4]. Heavy trucks' large size and operational characteristics make the consequences of large truck crashes catastrophic: injuries are severe to disastrous and property losses are massive [5]. Various factors can contribute to an accident, including road, human, environmental, and vehicle-related factors [5]. However, human error accounts for 90% of fatal accidents [6].

This paper focuses on the driver-related parameters that contribute to accident occurrence. A predictive model incorporating the various causal links between the driver-related variables that influence the probability of an accident is

created. Using BNs, the propagation of probabilities on all possible states of each node within the network could be achieved. Also, various scenarios were tested using the configuration of the input nodes in the network. Finally, an event tree analysis was carried out to examine the impact of in-vehicle road safety systems in preventing road accidents.

The model developed will make it possible to estimate a driver's probability of causing an accident in advance, which will help implement preventive measures such as developing targeted awareness programs. These programs will inform high-risk drivers of unsafe behaviors and help them adopt safer driving practices. In addition, financial incentives can encourage drivers to adopt safer behaviors, whether by offering monetary rewards or applying penalties to higher-risk drivers.

The article's body has the following structure: Section II presents the related work. Section III explains the methodology used to build the proposed fuzzy Bayesian model; the results obtained are also discussed in this section. Section IV discusses the likely crisis scenarios relating to a truck accident through the application of event tree analysis. Finally, the conclusion is presented in Section V.

## II. RELATED WORK

Numerous issues about road safety have been investigated in earlier studies. In accident detection, several models based on machine learning and deep learning have been developed to detect road accidents ([7], [8], [9], [10], [11]). Concerning predicting the severity of accidents, neural networks have been used to create models capable of predicting the severity of road accidents [12], [13]. In accident prevention, Kabir et Roy [14] developed an algorithm based on deep learning for real-time collision avoidance. Fan et al. [15] used SVM and deep neural networks to develop an algorithm for identifying and analyzing traffic accident black spots. To predict accidents, neural networks have made it possible to build models capable of predicting the occurrence of road accidents [16], [17]. Sangare et al. [18] combined two approaches: support vector classifier (SVC) and Gaussian mixture model, to give a prediction of traffic accident occurrence.

Regarding BNs, they have been widely used to solve problems related to road safety. Sun et al. [19] used a hybrid method integrating a random parameter logit model and a BN to analyze accidents involving vulnerable road users and motor vehicles in Shenyang, China, focusing on seasonal differences. The study uses three accident datasets: the entire dataset, the "spring and summer" dataset, and the "fall and winter" dataset.



The random parameter logit model was used to identify significant factors and heterogeneity across the three datasets. The critical factors were then used to build a BN to investigate statistical associations between injury severity and descriptive attributes. Kuang et al. [20] proposed a two-level model, consisting of a cost-sensitive BN and a K-nearest neighbour weighted model, to predict the crash duration. Using the collected data, a cost-sensitive BN can qualitatively indicate whether the accident duration is less than or greater than 30 minutes. Then, the KNN regression model will give the precise duration value for each accident class. Karimnezhad et Moradi [21] considered learning the BN structure from the data collected on the accidents recorded on one of the highways in Iran. They could also calculate the probability of being injured by a driver based on some information about his node. They also examined the effect of seat belt use on the number of fatal accidents. Deublein et al. [22] developed a model to predict the number of injury accidents; this model can give the expected number of road users likely to be slightly, severely, or fatally injured. The model also identifies road sections with a high probability of accidents. The methodology combines three statistical methods: Gamma-updating, multivariate Poisson-lognormal regression analysis and BNs.

Despite the diversity of works that have addressed the road safety problem, the probability of a driver causing an accident has not been addressed in any work. Most of the parameters considered in these studies generally relate to road architecture, vehicle characteristics, and weather conditions. No advantageous interest was given to the human factor.

### III. SYSTEM MODEL

The proposed risk assessment model aims to estimate the probability of a driver causing an accident. To achieve this goal, a thorough literature search was conducted and experts were surveyed to discover all the variables that could affect the probability of an accident. These searches allow us to highlight the relationships between these variables and construct the BNs

structure. The conditional probability tables were produced using a Sugeno fuzzy inference system in the following phase. Finally, the probability of an accident was calculated by anticipating a few possible scenarios.

#### A. Construction of the BN

A BN is a graphical model representing probabilistic relationships between variables; it allows knowledge acquisition, representation, and use [23]. The principle of inference in BNs is based on Bayes' probability theory. The joint probability distribution of a set of nodes  $N = \{X_1, X_2, \dots, X_n\}$  can be expressed as follows [24]:

$$P(X_1, X_2, \dots, X_n) = \prod_{i=1}^n P(X_i | \text{Parents}(X_i)) \quad (1)$$

Where  $\text{Parents}(X_i)$  represents the set of parent nodes of  $X_i$

The availability of values on a child node  $X_i$ , allows us to express the posterior probability of the parent node  $X_j$  as follows [25]:

$$P(X_j | X_i) = \frac{P(X_i, X_j)}{P(X_i)} \quad (2)$$

To build our BN, we conducted an extensive literature review. Also, experts were surveyed to collect their opinions on the factors that can cause an accident and the causal relationships between the different parameters. Thus, a BN was set up in three levels represented in Fig. 1:

- The input nodes are described at the first level; they indirectly impact accident risk. As seen in Table I, they fall into five groups.
- The intermediate nodes (colored in yellow in Fig. 1) lead to the final impacts and make up the second level.
- The third level groups the last effects that directly influence the accident occurrence (colored in gray in Fig. 1).

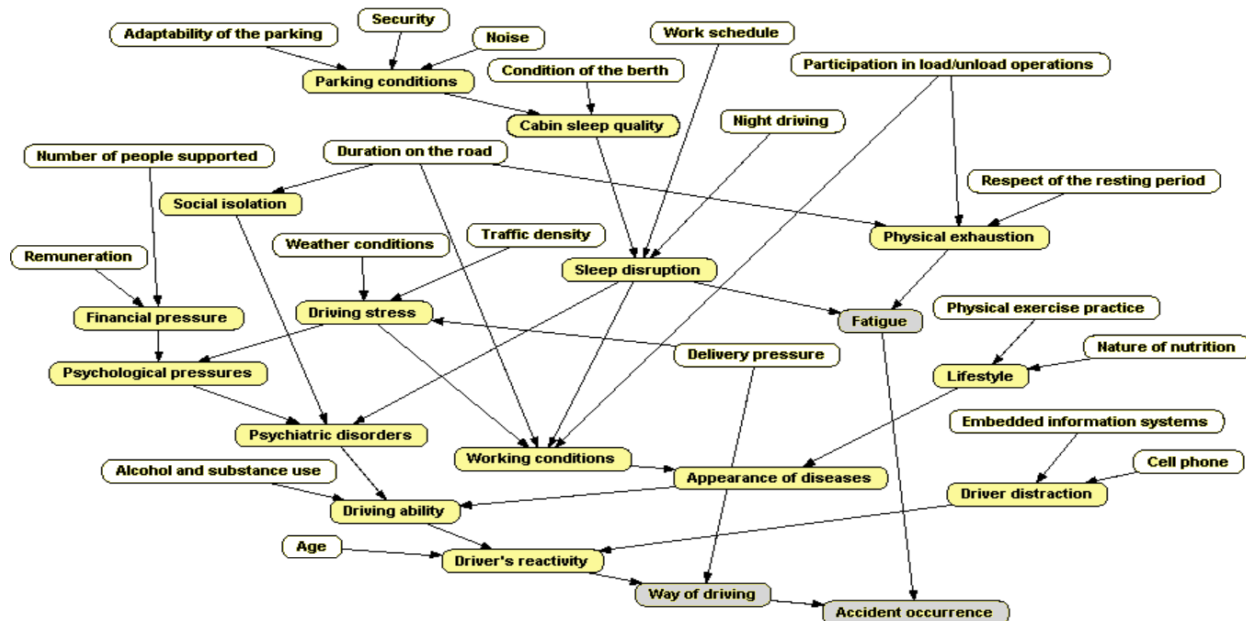


Fig. 1. Driver involvement in an accident model.



TABLE I. THE CAUSAL GRAPH'S INPUT PARAMETERS

Categories of parameters	Parameters	Description
Cabin sleep parameters	Adaptability of the parking	It refers to the ability of this space to meet the needs of drivers and carriers for safety, accessibility, and convenience [26].
	Noise	External noises can significantly affect the quality of sleep in the cabin [27].
	Security	It refers to compliance with parking spaces and safety standards concerning lighting, surveillance, and access control. [28].
	Condition of the berth	Creating a comfortable sleep environment depends on the condition of the berth, which significantly impacts drivers' sleep quality and their ability to rest properly. [27].
Personal driver settings	Physical exercise	Regular exercise improves the physical condition of drivers and helps reduce the risk of developing cardiovascular diseases, which are important risk factors for road accidents involving heavy goods vehicles [29].
	Age	Older drivers drive more safely and responsibly and are less likely to drive under the influence of alcohol compared to middle-aged drivers [30]. However, aging can lead to a decline in vision, memory, and coordination, which increases the risk of road accidents [31].
	Nature of nutrition	Poor nutrition leads to a deterioration in the general health of drivers, which can increase the risk of accidents ([32], [29]).
	Number of people supported	A significant number of people supported by the driver increases the financial pressures on the driver, which may encourage him to work overtime to support his family.
	Alcohol and substance use	Alcohol and substance use can cause reckless behaviour on the road and impair driver faculties [33].
Parameters related to driving conditions	Traffic density	High traffic density can irritate drivers, impairing their concentration and increasing the risk of driving errors and accidents. [34].
	Weather conditions	Weather conditions can disrupt the driver's abilities which can jeopardize their safety [35]
	Delivery pressure	Stress at work harms drivers' mental and psychological health [36]; it significantly reduces driving skills and consequently increases the risk of an accident [37].
	Respect of the resting period	Compliance with the rest range is essential to prevent driver fatigue and the resulting risks [38].
	Duration on the road	Increased time spent on the road increases driver fatigue levels, which may influence the probability of an accident [39].
	Night driving	Night driving can disrupt the sleep of truck drivers, which can have dangerous consequences and increase the risk of traffic accidents [40].
Working conditions parameters	Participation in loading and unloading operations	The duties of truck drivers also include non-driving labor. However, non-driver work is not necessarily remunerated [41]
	Work schedule	Irregular work schedules of truck drivers can increase fatigue and drowsiness at the wheel, which are vital factors in road accidents [42]
	Remuneration	Low pay incentivizes drivers to work overtime, affecting their safety performance [43].
Driver distraction settings	Embedded information systems	Misuse of in-vehicle information systems can distract drivers and thus increase the risk of an accident [44].
	Cell phone	The use of cell phones while driving is one of the critical factors in driver distraction, which can impair concentration and reduce their ability to react quickly to unforeseen events [44].

### B. Generation of Conditional Probabilities

Assigning conditional probabilities to the graph's nodes is necessary to exploit the developed BN. These probabilities can be determined using algorithms that learn from databases or by consulting subject-matter experts. Unfortunately, no database adapted to the identified variables was found in the literature. In addition, the large number of conditional probabilities in this network hindered the use of expert opinions. Then, fuzzy logic was used to generate conditional probability tables.

Fuzzy Bayesian networks result from the fusion between BNs and fuzzy set theory. This method is widely used to solve problems involving uncertain variables or when it is essential to understand and represent the causal dependencies between these variables [45]. This makes fuzzy BNs a particularly appropriate solution to the problem in question. Nevertheless, inference in fuzzy BNs can be costly in terms of computation time and computational resources, particularly for networks of

large size or with a large number of states. This complexity restricts its use for obtaining real-time answers or performing frequent updates.

The implementation of the fuzzy inference system goes through the following steps [46]:

- Fuzzification converts a crisp input value into a fuzzy value via membership functions, determining each fuzzy subset's membership degree [47].
- Inference deduces the result based on fuzzy rules [48].
- The defuzzification transforms the final answer of the fuzzy system into a numerical form [49].

We first define the fuzzy variables and their associated linguistic values to implement this method. Indeed, each variable has been qualitatively represented by natural language expressions illustrated in Table II.

TABLE II. LINGUISTIC VALUES OF NODES

Nodes	Linguistic values
Adaptability of the parking	Low, medium, important
Noise	Low, medium, important
Security	Bad, medium, good
Condition of the berth	Bad, medium, good
Parking conditions	Bad, medium, good
Cabin sleep quality	Bad, medium, good
Night driving	Low, medium, important
Work schedule	Regular, slightly irregular, irregular
Sleep disruption	Low, medium, important
Participation in loading and unloading operations	Low, medium, important
Driver distraction	Low, medium, high
Respect of the resting period	Low, medium, important
Social isolation	Low, medium, high
Time on the road	Small, medium, important
Physical exhaustion	Weak, medium, Strong
Fatigue	Light, medium, important
Delivery pressure	Low, medium, high
Number of people supported	Low, medium, important
Age	Young, medium, old
Traffic density	Low, medium, high
Physical exercise	Low, medium, important
Nature of nutrition	Bad, medium, good
Weather conditions	Normal, medium, extreme
Driving stress	Low, medium, high
Remuneration	Low, medium, important
Embedded information systems	Absent, light use, extreme use
Financial pressure	Low, medium, high
Working conditions	Bad, Medium, good
Appearance of diseases	Low, medium, high
Cell phone	Absent, light use, extreme use
Lifestyle	Bad, Medium, good
Psychological pressure	Low, medium, high
Psychiatric disorders	Low, medium, high
Alcohol and substance use	Low, medium, high
Driver's reactivity	Bad, Medium, good
Driving ability	Bad, Medium, good
Way of driving	Bad, Medium, good
Accident occurrence	Low, medium, high

Concerning the membership functions of all the nodes of the BN, the option was made for those of Gaussian type since the errors in the prediction of the data are minimal when compared to other forms, mainly triangular and trapezoidal forms [50]. The Gaussian membership function has been widely used in previous studies ([52] ; [53] ; [54]). It depends on two parameters: the mean m and the standard deviation k; the equation gives it [51] :

$$\mu_A(x) = e^{-\frac{(x-m)^2}{2k^2}} \quad (3)$$

Then, the fuzzy rule base was built based on the experts' judgments. These fuzzy rules are of the "IF-THEN" type; for example: IF 'Physical exhaustion' is weak and 'Sleep disruption' is medium THEN 'Fatigue' will be light. Here, linguistic values expressed in natural language represent the variable 'Fatigue'. It will accept one of the following values for all other rules: light, medium, or important.

As a result, we created a fuzzy inference mechanism that draws conclusions from input data and fuzzy rules. The Sugeno inference method was used because of its fast processing time and efficient defuzzification system [55]. In the Sugeno method, the inputs are linguistic variables.

The output of Sugeno inference  $z_i$  of an activated rule  $i$  is a linear combination of the input values ( $x_i$  and  $y_i$ ). It is written in the following form [55]:

$$z_i = f(x_i, y_i) = a_i x_i + b_i y_i + c_i \quad (4)$$

The final net output  $Z$  of Sugeno inference is computed by averaging the outputs of the fuzzy rules weighted with their weights in the following form ([56], [57]):

$$Z = \frac{\sum_r w_r * z_r}{\sum_r w_r} \quad (5)$$

With:

$r$ : the index of activated rules

$w_r$ : the implication result (the activation weight) of the rule  $r$

$z_r$ : the output of Sugeno inference of an activated rule  $r$

This fuzzy system incorporated 354 fuzzy rules, allowing us to produce 1062 conditional probabilities to feed the BN.

In what follows, the methodology will be explained by calculating the conditional probabilities of the 'Fatigue' node.

First, the membership functions and the fuzzy rules for the 'fatigue' node and its parent (physical exhaustion and sleep disruption) are defined. Then, the fuzzy system is initialized by input values close to the peak of the Gaussian distribution. Fig. 2 presents the inference of the variable 'Fatigue' knowing that 'Physical exhaustion' is weak and 'Sleep disruption' is medium.

Next, the max operator is applied to all the triggered conclusions of the activated rules. The following is thus had:

$$\text{Fatigue (light)} = \max (0.2, 0.98, 0.008) = 0.98$$

$$\text{Fatigue (medium)} = \max (0.006, 0.008) = 0.008$$

$$\text{Fatigue (important)} = 0.006$$

Thus, the variable 'Fatigue' will take the values 0.98, 0.008, and 0.006 for light, medium, and important, respectively. By computing the ratio between the probability of each state and the total probabilities of all states, the conditional probabilities table of the node 'Fatigue' can thus be obtained as follows.:

$$P(\text{Fatigue} = \text{low} \mid \text{Physical exhaustion} = \text{weak and Sleep disruption} = \text{medium}) = 0.98 / (0.98 + 0.008 + 0.006) = 0.986$$

$P(\text{Fatigue} = \text{medium} \mid \text{Physical exhaustion} = \text{weak and Sleep disruption} = \text{medium}) = 0.008 / (0.98 + 0.008 + 0.006) = 0,008$ .

$P(\text{Fatigue} = \text{high} \mid \text{Physical exhaustion} = \text{weak and Sleep disruption} = \text{medium}) = 0.006 / (0.98 + 0.008 + 0.006) = 0,006$ .

The generalization of this approach for all the nodes of the causal graph allowed us to obtain the conditional probabilities necessary to feed the BN.

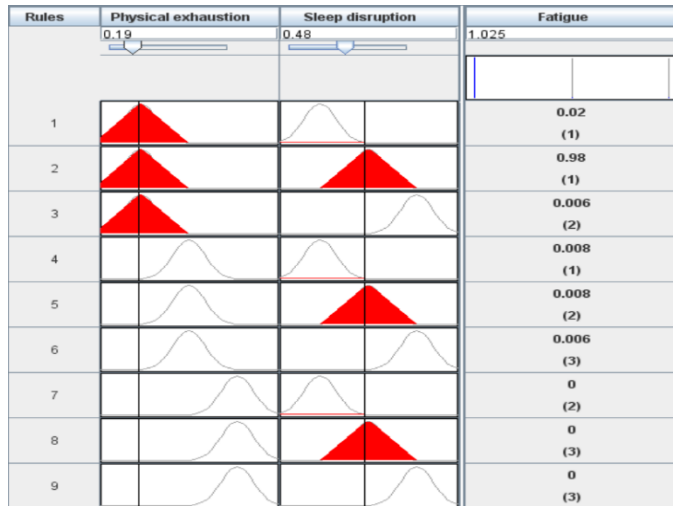


Fig. 2. Result of the inference mechanism.

C. Anticipation of Scenarios

Implementing the BN allowed us to examine the effect of the distribution of states for some nodes on the other nodes of the causal graph. In what follows, the probability of a driver causing an accident will be anticipated through the study of four scenarios listed below:

- Scenario 1 (S1): the parameters related to the driver are favourable and the parameters related to the work environment are favourable.
- Scenario 2 (S2): the parameters related to the driver are favourable and the work environment's parameters are unfavourable.
- Scenario 3 (S3): the driver parameters are unfavourable, and the work environment parameters are favourable.
- Scenario 4 (S4): the driver parameters are unfavourable, and the work environment parameters are unfavourable.

The driver-related parameters concern the driver's parameters and those that contribute to his distraction. On the other hand, the work environment parameters refer to the set of parameters related to the driving and working conditions and those related to sleep in the cab. Table III provides the configuration of the network input parameters according to the studied scenarios. The probabilities associated with the nodes were obtained using the inference of the fuzzy-Bayesian model. Since the network has many nodes (38), the probability of occurrence of some nodes has been presented in Table IV.

TABLE III. THE INPUT PARAMETER VALUES ACCORDING TO THE SCENARIOS STUDIED

	S1	S2	S3	S4
<b>Driver settings</b>				
Embedded information systems	Light use	Light use	Extreme use	Extreme use
Cell phone	Light use	Light use	Extreme use	Extreme use
Physical exercise	Important	Important	Low	Low
Age	Medium	Medium	Old	Old
Nature of nutrition	Good	Good	Bad	Bad
Number of people supported	Low	Low	Important	Important
Alcohol and substance use	Low	Low	High	High
<b>Work environment settings</b>				
Traffic density	Low	High	Low	High
Weather conditions	Normal	Extreme	Normal	Extreme
Delivery pressure	Low	High	Low	High
Respect of the resting period	Important	Low	Important	Low
Time on the road	Small	Important	Small	Important
Night driving	Low	Important	Low	Important
Participation in loading and unloading operations	Low	Important	Low	Important
Work schedule	Regular	Irregular	Regular	Irregular
Remuneration	Important	Low	Important	Low
Adaptability of the parking	Important	Low	Important	Low
Noise	Low	Important	Low	Important
Security	Good	Bad	Good	Bad
Condition of the berth	Good	Bad	Good	Bad

TABLE IV. DISTRIBUTION OF PROBABILITIES FOR BN VARIABLES

Variable	Value	S1	S2	S3	S4
<b>Working conditions</b>	Bad	0,0010	0,9908	0,0010	0,9908
	Average	0,0365	0,0082	0,0365	0,0082
	Good	0,9625	0,0010	0,9625	0,0010
<b>Psychiatric disorders</b>	Low	0,9837	0,0026	0,9712	0,0012
	Medium	0,0083	0,0111	0,0208	0,0115
	High	0,0080	0,9863	0,0080	0,9873
<b>Way of driving</b>	Bad	0,0110	0,9669	0,9799	0,9917
	Average	0,0526	0,0318	0,0121	0,0072
	Good	0,9364	0,0013	0,0080	0,0011
<b>Fatigue</b>	Light	0,9889	0,0011	0,9889	0,0011
	Average	0,0100	0,0086	0,0100	0,0086
	Important	0,0011	0,9903	0,0011	0,9903
<b>Accident occurrence</b>	Low	0,9357	0,0014	0,0083	0,0012
	Average	0,0523	0,0107	0,0391	0,0093
	High	0,0121	0,9879	0,9526	0,9896

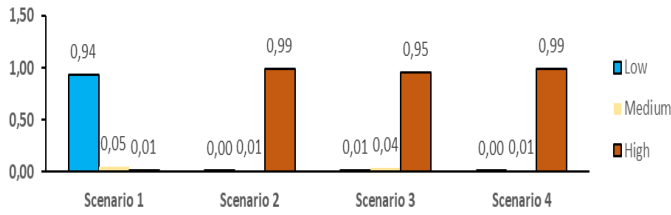


Fig. 3. The probability of occurrence in the different scenarios.

The probability distribution for the occurrence of an accident for each scenario is displayed in Fig. 3.

#### D. Result Discussion

In the first scenario, the probability of fatigue and psychiatric disorders is low, with a probability of 98.89% and 98.37%, respectively. Also, the way of driving and the working conditions are good, with 93.64% and 96.25%, respectively. Therefore, the probability of an accident is low, with a value of 93.57%.

Regarding the second scenario, there is a 99.03% chance that the driver will become fatigued; the working conditions and the way of driving are bad, with 99.08% and 96.69%, respectively. In addition, a high probability of psychiatric disorders with 98.63% is observed, which leads to a high risk of accident occurrence of 98.79%.

For the third scenario, the probability of fatigue is low, with 98.89%. In addition, the working conditions are good at 96.25%, and the probability of psychiatric disorders is low at 97.12%. On the other hand, the way of driving is bad, with a probability of 97.99%. Therefore, the probability of an accident is high at 95.26%.

In the fourth scenario, we have a high probability of fatigue and the appearance of psychiatric disorders, with 99.03% and 98.73%, respectively. Regarding the way of driving, the working conditions are bad with 99.17% and 99.08%, hence a high probability of accident occurrence is with 98.96%.

According to the findings of the inference of the first and third scenarios, the probability of an accident increases if the driver's parameters are unfavorable. Additionally, unpleasant working conditions significantly influence the probability of accidents.

#### E. Sensitivity Analysis

Sensitivity analysis makes it possible to find the most dominant factors in the occurrence of a particular event [58]. This analysis would allow us to make the necessary prevention adjustments and reallocate resources more efficiently.

The results of the sensitivity analysis of the 'Accident occurrence' node are shown in Fig. 4. According to this figure, we can estimate that the preponderant factors in accidents are: alcohol and substance consumption, poor driving, fatigue, and distraction caused mainly by cell phones and embedded information systems. These results highlight the crucial role of the human factor in the occurrence of accidents.

#### F. Model Validation

The validation of the BN guarantees the reliability of the results provided by the model. In order to validate the developed BN, a method based on three axioms was used. This method was proposed by [59] and widely used by several researchers such as: [60], [61] and [62]. The principle of the three axioms is as follows [63]:

- Axiom 1: the increase or decrease in the probability of the parent node must result in a change in the probability of the child node.
- Axiom 2: The occurrence of a change in the probability distributions of the parent node must have a consistent impact on the child node.
- Axiom 3: The total effect of all parent nodes must be greater than either parent's effect.

Validation analyses were conducted on all nodes in the graph to confirm the verification of the three axioms. Tables V and VI show the verification results for axioms 1 and 2 for the 'Lifestyle' node. The impacts of the parent nodes 'Exercise Practice' and 'Nature of Nutrition' on the child node 'Lifestyle' were evaluated by increasing them by 10% and 20%, respectively, and then decreasing them by 5% and 10%. We found that the probability of the 'Lifestyle' node increased from 64.82% to 82.06% when the probability of the 'Exercise' node was increased by 20%. However, the probability of the 'Lifestyle' node increased to 56.20% when the probability of the 'Exercise' node was reduced by 10%. The 'Lifestyle' node replies for the other increments and decrements were consistent, supporting the developed network's stability.

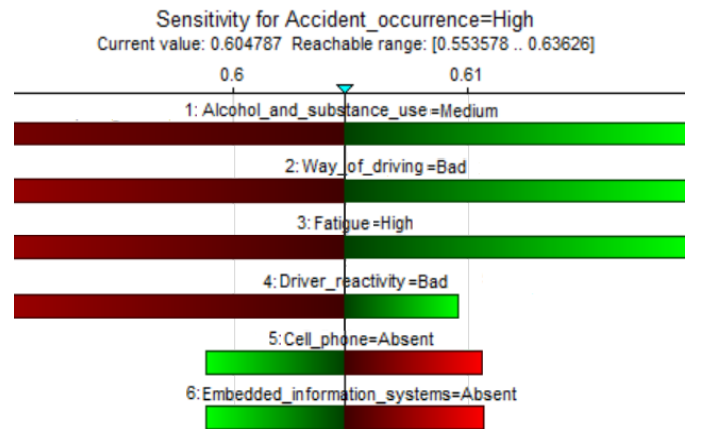


Fig. 4. Sensitivity analysis for accident occurrence.

TABLE V. AXIOM 1 VERIFICATION

	Parent node: Physical exercise		Child node: Lifestyle	
	Value	Probability	Value	Probability
20% increase	Low	95%	Bad	82,06%
10% increase		85%		73,44%
A priori probability		75%		64,82%
5% decrease		70%		60,51%
10% decrease		65%		56,20%

TABLE VI. AXIOM 2 VERIFICATION

	Parent node: Nature of nutrition		Child node: Lifestyle	
20% increase	Bad	97%	Bad	83,32%
10% increase		87%		75,06%
A priori probability		77%		66,80%
5% decrease		72%		62,67%
10% decrease		67%		58,54%

TABLE VII. AXIOM 3 VERIFICATION FOR THE 'LIFESTYLE' NODE

Nature of nutrition		Physical exercise		Lifestyle		Percentage change
Bad	90%	Weak	84%	Bad	77,53%	
	100%		84%		83,33%	7,48%
	90%		100%		92,20%	18,92%
	100%		100%		100%	28,98%

Regarding the verification of axiom 3, from the results presented in Table VII, we can say that the total effect of increasing all parents of the 'Lifestyle' node to 100% resulted in a more significant increase than when only one parent is increased separately, which is well in line with axiom 3.

G. Result Discussion

This article examines the importance of identifying and preventing risk factors in improving road safety. It focuses specifically on driver-related parameters that increase the risk of accidents. Based on bibliographical research and experts' opinions, road accidents cannot be attributed to a single type of cause but to a panoply of parameters linked together by causal relationships that ultimately give rise to a road accident. In order to prevent accidents, this article has developed an approach based on fuzzy BNs so that carriers can take the necessary precautions to avoid catastrophe. Adopting this model will ensure a high level of visibility and improve the efficiency of logistics deliveries. In addition, validating the proposed BN further guarantees the reliability of the results provided by the model. The scenarios studied highlighted the impact of working conditions on the occurrence of accidents. The sensitivity analysis results confirm that the most critical factors in accidents are: alcohol and substance abuse, poor driving style, fatigue, and driver distraction. These results underline the crucial role of the human factor in accident occurrence. This model has also created a synthetic database that can be used by learning models to predict the risks associated with road accidents.

The following section focuses on integrating in-vehicle safety devices to improve road safety. This aspect is explored through analysis of the proposed event tree.

IV. PREDICTIVE MANAGEMENT OF HEAVY VEHICLE ACCIDENTS BY APPLICATION OF EVENT TREE TECHNOLOGY

A. Event Tree Analysis

Event tree analysis uses a tree structure of events to provide potential probabilities of the outcomes of events that contribute to the success or failure of a management. The tree is constructed chronologically by predicting, in the first place, the probability of an initiating event. Then, a sequence of intermediate events occurs to prevent additional risk [64].

In order to develop the scenarios of probable crises related to a truck accident, different road safety devices installed were taken into account, such as:

- Adaptive cruise control: This system uses sensors to monitor the distance between the truck and other vehicles on the road and automatically regulates the speed to maintain a sufficiently safe distance.
- Driver Fatigue Monitoring System: This system uses sensors to monitor eye movements and the driver's head position. If the system detects the driver is tired or distracted, it can warn them to take a break.
- Automatic Emergency Braking System: This system uses sensors to detect objects near the truck and can automatically initiate emergency braking if the driver does not react quickly enough.

Then, the steps prescribed below were followed:

- Initiator event gave rise to the system's critical state; in our case, it is a road accident.
- Intermediate events aim to detect or prevent the initiating event or reduce its consequences as much as possible. The intermediate events that have been chosen are: adaptive cruise control system activated, driver fatigue monitoring system activated and automatic emergency braking system activated
- Identification of consequences specifies the expected outcomes of each series of events.
- Quantization of the tree assigns probabilities for each branch in order to calculate the probability of each sequence in the following form:

$$P(R) = \prod_1^n P(B_i) \tag{6}$$

With B<sub>i</sub>: Set of branches that make up the path to the result R.

Fig. 5 illustrates the event tree developed to study the probability of successful accident prevention based on the safety systems installed.

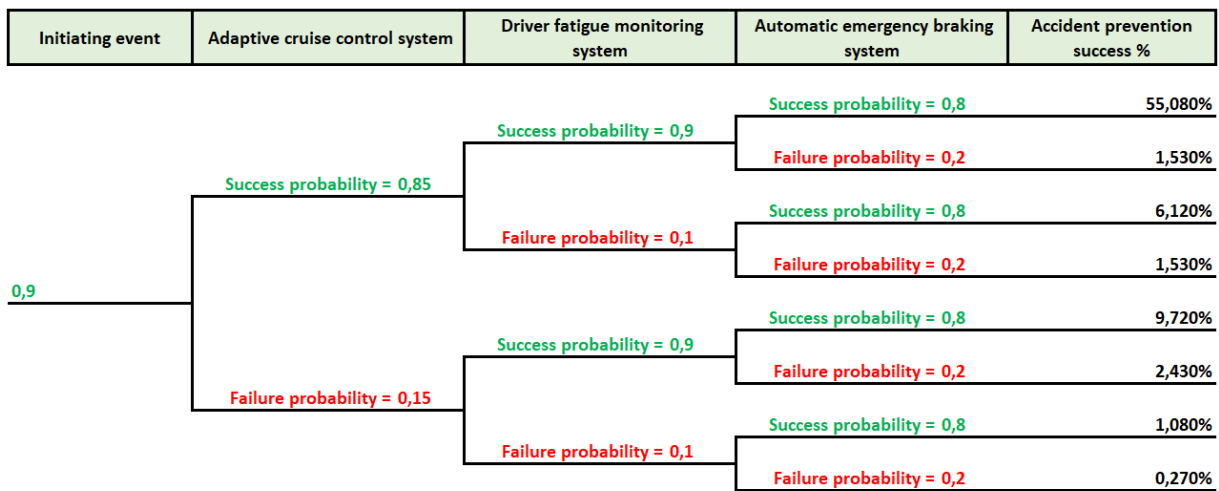


Fig. 5. Event tree showing the probability of success in preventing an accident based on the success rate or failure of the various safety systems installed.

### B. Analysis of Results

The quantification of our event tree allowed us to predict the probability of success of road accident prevention efforts according to the different operating rates of the safety systems installed. We found that the success rate is highest (55.08%) if all installed systems are working correctly and minimal (0.27%) for the opposite case. These results highlight the importance of equipping heavy goods vehicles with systems monitoring driver behavior to improve road safety.

### V. CONCLUSION

Road accidents involving heavy goods vehicles attract particular interest because of their devastating consequences of loss of life and property damage. In this article, the focus was placed on the prediction of heavy vehicle accidents in order to improve road safety and adequately manage this problem. To this end, BNs and fuzzy logic were combined to develop a model capable of scrutinizing the possibility of an accident.

The simulation of several scenarios allowed us to value the impact of the factors identified on the occurrence of accidents. In addition, the results deduced from the application of event trees allowed us to shed light on the importance of road safety mechanisms in preventing road accidents.

The developed system takes advantage of BNs and the strength of the fuzzy set theory, making it a robust and efficient model capable of providing reliable predictions. Similarly, this work may promote the development of new systems operating in research fields other than transport.

The limitations of the model developed lie in the complexity of road accident scenarios; the plurality of factors that can influence the occurrence of accidents makes it inappropriate to take them all into consideration, which could impact the accuracy of the predictions provided by the model.

One of the potential perspectives at work presented is the model's generalization to all occupational risks relating to truck drivers, such as work accidents the appearance aggravation of certain diseases; and we also intend to use deep learning methods in our future work to push back the prediction of the

risks mentioned above and manage the resulting crises appropriately.

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# Software Cost Estimation using Stacked Ensemble Classifier and Feature Selection

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**Abstract**—Predicting the cost of the development effort is essential for successful projects. This helps software project managers to allocate resources, and determine budget or delivery date. This paper evaluates a set of machine learning algorithms and techniques in predicting the development cost of software projects. A feature selection algorithm is utilized to enhance the accuracy of the prediction process. A set of evaluations are presented based on basic classifiers and stacked ensemble classifiers with and without the feature selection approach. The evaluation study uses a dataset from 76 university students' software projects. Results show that using a stacked ensemble classifier and feature selection technique can increase the accuracy of software cost prediction models.

**Keywords**—Software project management; effort estimation; prediction model; machine learning

## I. INTRODUCTION

The process of developing software has evolved into a fundamental function of modern society as a result of the quick development of software in our days. However, a crucial step in the lifecycle of software development is software effort estimation. The goal of a software development task is to deliver the product on time and within budget. The planning process for any software project must therefore include early software cost estimation.

Predicting the amount of work required to create a software system is a part of software effort estimation. It is expressed in terms of the number of working hours or the number of hours needed to construct the software. Software testing, maintenance, requirements engineering, and other software operations are all included in the broad category of software effort estimation.

To produce software projects, various software development lifecycle models call for varying amounts of work at each stage. Software effort estimation is regarded as one of the most significant problems in software engineering. It affects the cost of the project and is a problem that many engineers and project managers encounter. A major issue that could harm software companies is the accuracy of the development effort estimation.

Several scholars as [1] have suggested various models to predict the effort of software development. Several researches have been done to determine the early software effort estimate to determine the significance [2]. Software companies need to

understand the work required to develop projects in addition to how they should proceed about accomplishing this.

In this paper, the software work is estimated based on project attributes using four machine learning techniques. This study's primary objective is to assess software effort estimation models created using machine learning techniques.

Before deciding to use a software component as a reusable asset, software engineers must analyze the software component. Assessing reuse potentials can be aided by predicting successful reuse. Datasets are used to train and test predictive models. Datasets, however, occasionally include attributes that are not useful. The performance of the model may suffer as a result of these characteristics. Therefore, choosing the key attributes improves the performance of the model and yields a more accurate output.

In this paper, an empirical study utilized a dataset to investigate and extract the essential features that lead to a successful reuse experience. Usually, the performance of a prediction model can be improved with an ideal subset of useful features. Feature selection algorithm selects a portion of the original dataset's most useful qualities. This subset can improve the prediction model's effectiveness and efficiency. Additionally, it avoids data overfitting. In this paper, six feature selection algorithms were utilized and evaluated to enhance accuracy. These algorithms are; Classifier Attribute Evaluation, Correlation Attribute Evaluation, InfoGain Subset Evaluation, Wrapper Subset Evaluation, Classifier Subset Evaluation, and CfsSubset Evaluation.

There are many benefits of using feature selection techniques. For instance, it reduces the training time, helps visualize the data, and optimizes the storage requirements. In this paper, the primary purpose of using feature selection techniques is to improve the prediction model's performance by removing the irrelevant attributes [3].

The organization of this paper is as follows; the next section discusses the literature that concerning software effort prediction. The proposed evaluation model is presented in Section III followed by a brief description about the used dataset in the evaluation process. The experimental results are presented in Section V. Finally, Section VI concludes the paper and highlights the future work.

## II. RELATED WORK

Many approaches have been presented in the literature about estimating the development's efforts of software projects. Most of these approaches utilize the machine learning and artificial intelligence techniques to predict the effort.

Rankovic et al. [4] proposed two different architectures of Artificial Neural Networks (ANN) for predicting software effort. They used exponent-scale factors, cost factors, and software size as control variables from COCOMO models. BaniMustafa [5] predicted the effort estimation by applying machine learning techniques and data mining. He applied Naïve Bayes, Logistic Regression and Random Forests. Priya Varshini et al. [6] proposed stacking using random forest for effort estimation. They used ensemble techniques to create and combine multiple models termed base-level classifiers. The works in [7, 8] applied Artificial Neural Network (ANN), Support Vector Machines (SVM), K-star, and Linear Regression to estimate software effort based on project features. Mahdie et al. [9] provided a detailed review about the application of Machine Learning in software project management which includes effort estimation. Another systematic performance evaluation study for software effort estimation accuracy prediction of ML techniques is presented in [2].

A different prediction technique has been presented by Nassif et al. [10]. They proposed an approach called regression fuzzy logic that is based on fuzzy logic models and regression analysis. Also, Fadhil et al, [11] used swarm intelligence techniques from the AI field. They applied two models based on dolphin algorithm and the hybrid dolphin and bat algorithm.

Rai et al. [12] proposed a hybrid model, based on team size using Support Vector Regression (SVR) and constructive cost model (COCOMO) approaches. Van Hai et al. [13] proposed a model called effort estimation using machine learning applied to the clusters (EEAC). The goal of the model is to evaluate the influence of data clustering on software development effort estimation.

## III. PROPOSED SOFTWARE COST PREDICTION MODEL

This work proposes an evaluation framework to evaluate the effectiveness of using basic machine learning and ensemble classifiers, as well as, feature selection algorithms to build a software cost estimation model. Fig. 1 depicts the proposed prediction framework. As shown in Fig. 1, the first prediction model is set with the basic standalone machine learning algorithms, while the second model is built using the stacked ensemble approach. Both models are evaluated using the full dataset and with a set of the selected features. The purpose of introducing feature selection to the proposed prediction models is to extract the most relevant features from the dataset. Since, the redundant and irrelevant features increase the data dimensionality without adding new information to the dataset. This could negatively affect the performance of the prediction models.

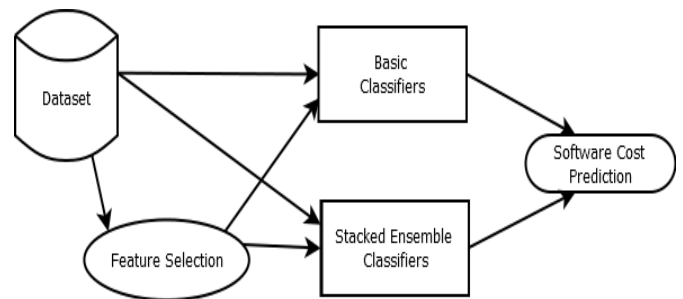


Fig. 1. The proposed software cost prediction framework.

Four machine learning algorithms were applied in the prediction process. These ML algorithms are:

- The Artificial Neural Networks (ANN): ANN system considers unsupervised learning as one of the training algorithms in a command to build an unlabeled data [14]. It consists of an input layer, hidden layers, and an output layer.
- K-Star: K-star is a machine learning algorithm that uses the entropic distance from the information theory to measure the similarities among the data elements and cases. [15].
- Support Vector Machine (SVM): SVM uses Sequential Minimal Optimization (SMO) algorithm, which transfers all nominal attributes and null values into binary ones. Then, the algorithms try to identify a margin that divides the data into different classes [16].
- Random Forest (RF): RF works by building multiple decision trees and then combining their results to make predictions. Each tree is trained on a randomly selected subset of the training data and a randomly selected subset of the features. By doing this, the algorithm can reduce errors and improve accuracy. To make a prediction, the algorithm takes in a set of features and passes them down each of the decision trees in the forest. Then it combines the results of all the trees to arrive at a final prediction [17].

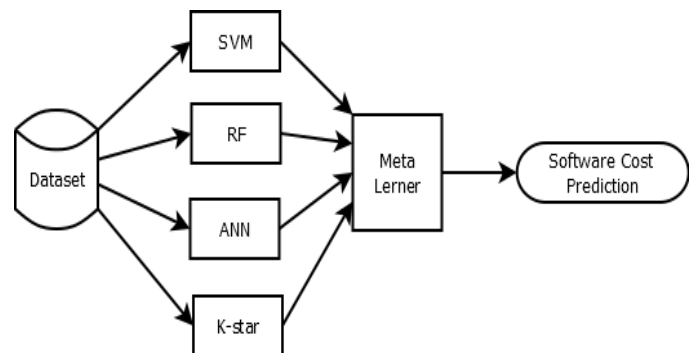


Fig. 2. The proposed ensemble stacked cost prediction classifier.

Ensemble learning is a method that combines more than one learning classifiers. Combining machine learning classifiers is primarily done to reduce risks and errors associated with employing a single classifier [18]. Additionally, ensemble learning enhances prediction

performance by balancing out the shortcomings of a single classifier. Additionally, issues with training the classifier may arise due to the size of the dataset. For instance, using a single classifier on a sizable dataset is impracticable. The dataset should therefore be divided into subgroups, with each subset being used to train a different classifier. Additionally, ensemble learning might be able to alleviate issues brought about by utilizing a tiny dataset [19]. In ensemble learning, different classifiers can be added using Stacking, Bagging, and Voting approaches. In this paper, stacking ensemble approach is used to build different software cost prediction model.

Stacking ensemble classifier is one of the most used approach in ensemble learning to combines multiple classification algorithms. Fig. 2 shows the basic levels of the used stacking ensemble classifiers. The learning process of stacking learning consists of two levels. The first level combines different machine learning classifiers  $C = \{C_i(s, f), i = 1, \dots, l\}$ , which are called base classifiers. Each base classifier utilizes the training set  $f$ . In the second learning level, which is the meta-learning process, a single machine learning classifier  $\mu$  uses the outputs on the base classifiers as an input to generate the ensemble learning final prediction [20]. Therefore:

$$j_{stack}(s) = \mu(s, C) \quad (1)$$

where  $j_{stack}(s)$  is the final stacking prediction of the input  $s$ . As shown in Fig. 2, the used four basic ML classifiers are combined in the first learning level of the proposed ensemble classifier. For the meta learning level, each basic ML classifier is used as based meta-learner classifier to create different stacked ensemble prediction model. The goal is to evaluate all possible combinations of these basic ML classifiers. As a results, the generated ensemble classifiers are:

- ANN-based Stacked classifier
- K-star-based Stacked classifier
- SVM-based Stacked classifier
- RF-based Stacked classifier

All previous basic and ensemble software cost prediction models are evaluated using the full features of software projects, as well as, a set of selected features. In this paper the wrapper method algorithm is used by applying the Classifier Subset Evaluation (CSE) technique [21].

CSE approach is a popular feature selection technique that evaluates the performance of a specific classifier for each subset of features. Fig. 3 shows the basic steps for the used CSE approach. It starts by creating all possible subsets of software features. Then, randomly select a set of features to evaluate it using the target software cost prediction model. This process is repeated until achieving the optimal accuracy for this model. Once the best feature subset is recognized, it is used for the final model training process.

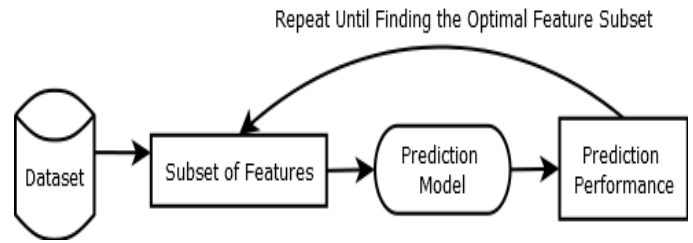


Fig. 3. The used wrapper CSE feature selection approach.

#### IV. USED DATASET

Due to the lack of software expense data, gathering public software effort data is a difficult undertaking. This is owing to the fact that software companies generally keep software cost data private. Usp05-tf, a publicly accessible dataset for empirical software engineering data, is made available online through the promise online repository (<http://tunedit.org/repo/PROMISE/EffortPrediction>), which was used in this study. Data from 76 university students' software projects are included in this dataset. Every project has 13 attributes. A list of these attributes is shown in Table I.

TABLE I. THE 13 ATTRIBUTES OF THE STUDIED PROJECTS

#	Project attributes	Description	Values
1	IntComplex	The complexity of the internal project calculations	1 (lowest) to 5 (highest)
2	DataFile	Total number of accessed data files	Positive integer
3	DataEn	The number of entry data items	Positive integer
4	DataOut	The number of output data items	Positive integer
5	Lang	The used programming language	C++, Java, HTML, etc.
6	UFP	Unadjusted Function Point Count	Positive integer
7	Tools	The used platforms and tools	VJ++, Delphi, Junit, etc
8	ToolExpr	The experience level of the developer team	Range of number of months, e.g. [3, 7]
9	AppExpr	The applications experience level	1 (lowest) to 5 (highest)
10	DBMS	The used database system	SQLServer, Oracle, MySQL, etc.
11	TeamSize	The size of the developer team	Range of min-max number of developers, e.g. [3, 6]
12	AppType	The used system architecture	B/S, C/S, Centered, etc.
13	Effort	The actual effort (in hours) expended on implementation tasks by all participating developers	Positive float

The features listed in Table I are not all numerical. This is crucial to verifying the machine learning approach's capacity for learning. The historical data is utilized as a learning tool to anticipate the work required for future software systems.

## V. EXPERIMENTAL RESULTS

The evaluation criteria and the results of the experiments are discussed in the following two sections.

### A. Evaluation Criteria

In order to assess the performance of the prediction algorithms, five statistical criteria were used. The following is a description of these criteria:

- Statistics Kappa (KS)
- Mean Absolute Error (MAE)
- Root Mean Square (RMSE)
- Error in Relative Absolute (RAE)
- Root Relative Squared Error (RRSE)

Statistics Kappa (KS) is the degree of agreement between the classifier's output and the actual classification is measured by KS. KS values vary from 0 to 1. The closer to 1 KS gets, the better. The following equation is used to compute KS:

$$KS = PA - PC / (1 - PC)$$

where PC is the percentage of agreement by chance and PA is the percentage of actual agreement.

Mean Absolute Error (MAE) calculates how well the actual classification matches the anticipated classification. The value of MAE is calculated using the formula below:

$$MAE = \sum_{n=1}^m |a_n - a'_n|$$

where  $n = 1$  through  $m$ ,  $m$  is the total number of instances,  $a_n$  is the actual reuse output, and  $a'_n$  is the predicated reuse output. The performance of the prediction model is good if the MAE value is low.

Root Mean Square (RMSE) is difference between data that was expected and actual data is measured by the quadratic mean known as RMSE. The accuracy of the model is inversely correlated with the RMSE. High precision is indicated by a low RMSE score. The error value can be calculated using the formula below:

$$RMSE = \sqrt{\frac{1}{m} \sum_{n=1}^m (a_n - a'_n)^2}$$

When  $n$  ranges from 1 to  $m$ ,  $a_n$  represents the observed values, and  $a'_n$  represents the anticipated values.

Error in Relative Absolute (RAE) is calculated by dividing the total absolute error by the total absolute error of the trivial model, RAE normalizes the total absolute error. RAE is obtained by the following equation:

$$RAE = \sum_{n=1}^m |a_n - a'_n| / \sum_{n=1}^m |a_n - a''_n|$$

where  $a_n$  is the predicted value,  $a'_n$  is the target value,  $a''_n$  is the mean of  $a_n$ ,  $m$  is the number of instances, and  $n = 1$  through  $m$ .

Root Relative Squared Error (RRSE) is calculated by dividing the total relative error of the naive model by the square root of the total relative error. Equation used to calculate RRSE is as follows:

$$RRSE = \sqrt{\sum_{n=1}^m (a_n - a'_n)^2 - \sum_{n=1}^m (a_n - a''_n)^2}$$

where  $a_n$  is the predicted value,  $a'_n$  is the target value,  $a''_n$  is the mean of  $a_n$ ,  $m$  is the number of instances, and  $n = \{1, 2, \dots, m\}$ .

### B. Experimental Results

The experiments were conducted using WEKA 3, a machine learning software platform written in Java (<https://www.cs.waikato.ac.nz/ml/weka/>). The ten folds cross-validation training technique was used to evaluate all software cost prediction models. In this technique, the training and testing the prediction models is repeated in iterations. Moreover, the dataset is divided equally into ten subsets called folds. In each iteration, the prediction model uses nine folds for training and one-fold for testing. This process is ended when the classifier tests all the dataset.

Table II shows the selected features of software projects after applying the feature selection approach for each base classifier. Number of the selected feature for K-star, RF, ANN, and SVM are 10, 5, 9, 13 respectively. The smallest number of selected features was produced with the RF classifier while the biggest number happened with SVM classifier.

TABLE II. THE SELECTED FEATURES FOR EACH CLASSIFIER

Classifier	Selected Features
K-star	ID, IntComplex, DataFile, DataEn, DataOut, UFP, Lang, ToolExpr, AppExpr, TeamSize
RF	ID, IntComplex, DataOut, Tools, TeamSize
ANN	ID, IntComplex, UFP, Lang, Tools, ToolExpr, AppExpr, TeamSize, Method
SVM	ID, IntComplex, DataFile, DataEn, DataOut, UFP, Lang, Tools, ToolExpr, AppExpr, TeamSize, DBMS, AppType

Table III presents the selected features of software projects using the feature selection approach for each stacking classifier. As shown in the table, the feature selection approach is more effective in reducing number of selected features needed to learn the stacking classifier than basic classifier. This can be helpful to software project engineers. It can point out a smaller set of key project features which can impact on the project's cost. In this study, number of the selected feature for stacking based K-star, RF, Stacking based ANN, and Stacking based SVM classifiers are 5, 6, 5, 9 respectively.

Fig. 4 shows the MAE values for the four basic classifiers in the used dataset before and after using the feature selection approach. As shown in the figure, the value of MAE is reduced when using the feature selection algorithm. The lowest MAE is obtained when using the RF classifier, were the MAE is



reduced from 2.5025 to 2.3154 after applying the RF on the selected feature instead of using the full features.

TABLE III. THE SELECTED FEATURES FOR EACH STACKING CLASSIFIER

Stacking classifier	Selected Features
Stacking based K-star	DataFile, DataOut, Lang, TeamSize, AppType,
RF	IntComplex, DataEn, DataOut, ToolExpr, TeamSize, Method
Stacking based ANN	IntComplex, DataEn, UFP, Lang, TeamSize
Stacking based SVM	ID, IntComplex, DataFile, DataOut, Lang, ToolExpr, TeamSize, Method, AppType

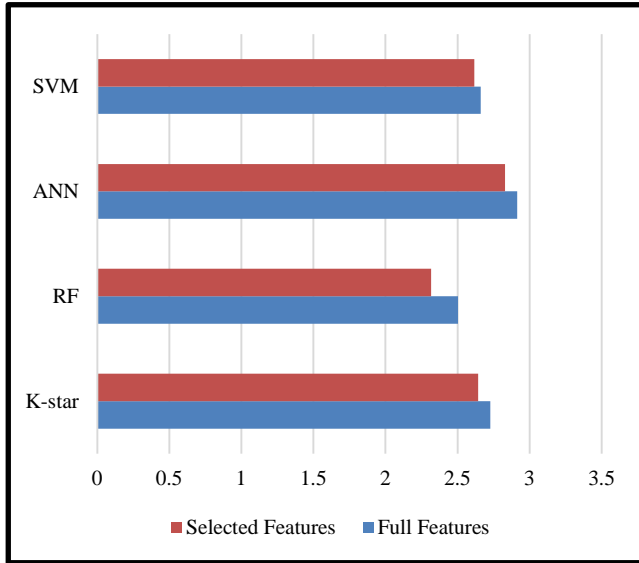


Fig. 4. MAE values before and after using feature selection.

Fig. 5 shows the values of RMSE for the four classifier on the full features and on the selected features. Same as MAE values, the RMSE values were reduced after selecting a subset of the software projects' features. The lowest RMSE value is produced when using RF classifier. For RF classifier the RMSE value was 4.8546 and 4.4979 with and without the feature selection algorithm respectively.

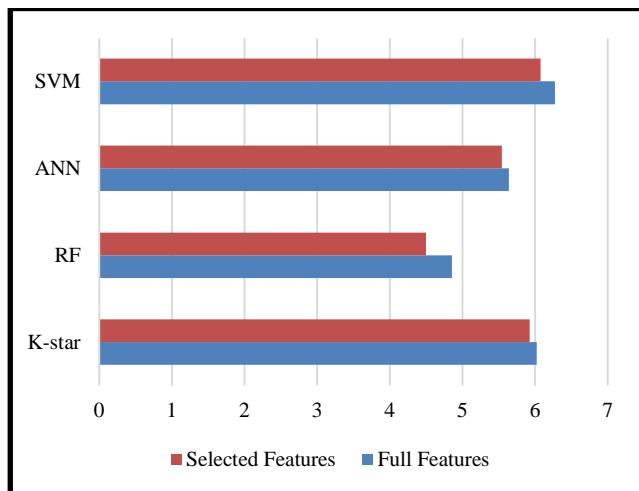


Fig. 5. RMSE values before and after using feature selection.

From pervious results, we can conclude the using the feature selection approach can increase the accuracy of software cost prediction model. Moreover, to evaluate other criteria, Table IV presents the KS, RAE, and RRSE evaluations before and after using feature selection method for the four classifiers. As shown in the table, RF is the best classifier among all others with highest KS and lower RAE and RRSE. However, feature selection approach is able to enhance the performance of all classifiers for all evaluation criteria.

TABLE IV. KS, RAE, AND RRSE EVALUATION RESULTS BEFORE AND AFTER USING FEATURE SELECTION

	KS- Full features	KS- selected features	RAE - Full features	RAE - Selected features	RRSE- Full features	RRSE- Selected features
SVM	0.7504	0.8098	44.3547 %	43.6098 %	64.6744 %	63.5698 %
ANN	0.7981	0.8098	48.8383 %	46.9337 %	64.6744 %	63.5698 %
RF	0.8441	0.8826	41.7323 %	38.6118 %	55.6778 %	51.5873 %
K-star	0.7797	0.7823	45.4795 %	44.0878 %	69.0658 %	67.9704 %

The second part of this experiment is set to evaluate the effectiveness of using stacked classifier on predicting the software cost. Fig. 6 and 7 show the MAE and RMSE evaluation values for the four possible combinations of stacked classifiers over the full features and the selected features. Stacked classifier with SVM is based classifier has the lowest MAE and RMSE with values of 2.4391 and 4.3705 respectively. After applying the feature selection approach, the MAE and RMSE values were reduced to 2.1801 and 4.0779 respectively. On the other hand, the ANN based stacked classifier has the highest MAE and RMSE values with 4.6594 and 8.1786 respectively.

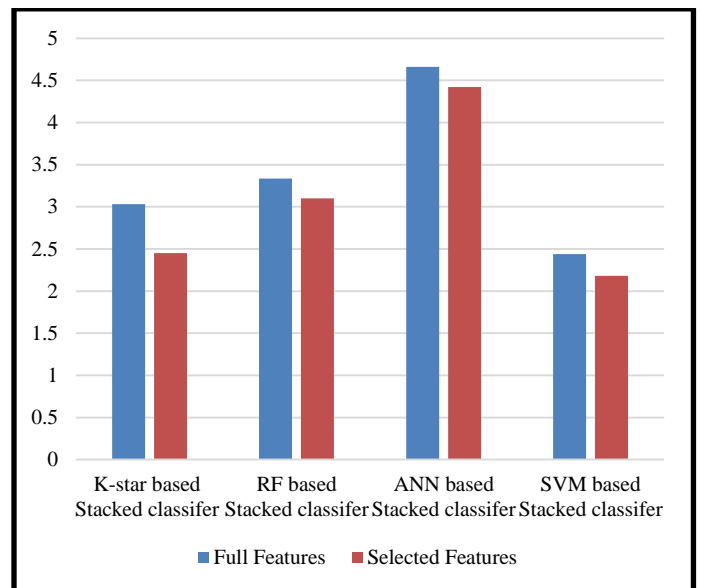


Fig. 6. MAE evaluation of stacked classifiers for full and selected features.

Results in Fig. 6 and 7 show that the using the feature selection approach can increase the accuracy of software cost prediction model based on stacked classifier. Moreover, to evaluate other criteria, Table V presents the KS, RAE, and RRSE evaluations before and after using feature selection method for the four stacked classifiers. As shown in the table, the stacked based RF classifier is the best classifier among all others with highest KS and lower RAE and RRSE. Moreover, feature selection approach is able to enhance the performance of all stacked classifiers for all evaluation criteria.

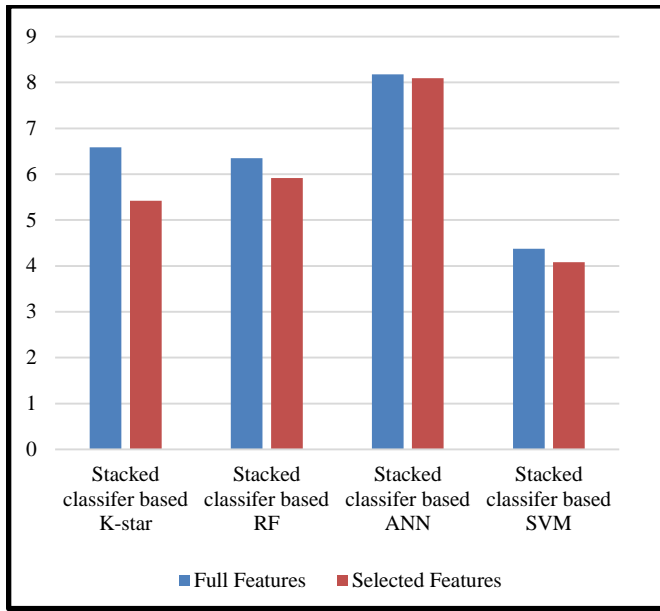


Fig. 7. MAE evaluation of stacked classifiers for full and selected features.

TABLE V. KS, RAE, AND RRSE EVALUATIONS BEFORE AND AFTER USING FEATURE SELECTION

	KS – Full features	KS – selected features	RAE – Full features	RAE – Selected features	RRSE – Full features	RRSE – Selected features
Stacked based SVM	0.7504	0.8098	44.3547 %	43.6098 %	64.6744 %	63.5698 %
Stacked based ANN	0.5168	0.5506	77.7009 %	80.4054 %	64.6744 %	63.5698 %
Stacked based RF	0.8441	0.8826	41.7323 %	38.6118 %	55.6778 %	51.5873 %
Stacked based K-star	0.6635	0.7823	50.559 %	40.8892 %	75.5606 %	62.1436 %

## VI. CONCLUSIONS AND FUTURE WORK

An evaluation model has been presented for effort estimation. The model utilizes a set of machine learning algorithms and techniques to predict the effort. The model was evaluated using basic standalone machine learning algorithms and using the stacked ensemble ML approach. The evaluation is done on full features and a set of selected features that have been previously extracted using feature selection technique. Results showed that a stacked ensemble classifier with feature

selection technique achieved higher accuracy for software cost prediction. Our future work aims to expand the evaluation process by including deep learning techniques. Another issue under investigation is the utilization of more project attributes to enhance the prediction results.

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# An Algorithm Based on Self-balancing Binary Search Tree to Generate Balanced, Intra-homogeneous and Inter-homogeneous Learning Groups

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**Abstract**—This paper presents an algorithm, based on the self-balancing binary search tree, to form learning groups. It aims to generate learning groups that are intra-homogeneous (student performance similarity within the group), inter-homogeneous (group performance similarity between groups), and of balanced size. The algorithm mainly uses the 2-3 tree and the 2-3-4 tree as two implementations of a self-balancing binary search tree to form student blocks with close GPAs (grade point averages) and balanced sizes. Then, groups are formed from those blocks in a greedy manner. The experiment showed the efficiency of the proposed algorithm, compared to traditional forming methods, in balancing the size of the groups and improving their intra- and inter-homogeneity by up to 26%, regardless of the used version of the self-balancing binary search tree (2-3 or 2-3-4). For small samples of students, the use of the 2-3-4 tree was distinguished for improving intra- and inter-homogeneity compared to the 2-3 tree. As for large samples of students, experiments showed that the 2-3 tree was better than the 2-3-4 tree in improving the inter-homogeneity, while the 2-3-4 tree was distinguished in improving the intra-homogeneity.

**Keywords**—Learning group formation; balanced size groups; homogeneous groups; self-balancing binary search trees; greedy algorithm

## I. INTRODUCTION

The formation of learning groups is the first step to the success of the educational process, as it allows, depending on the tasks, students to be grouped into homogeneous or heterogeneous groups to be effective and lead to more effective learning. Heterogeneous groups are more effective on tasks that complete lessons and achieve specific learning outcomes, such as projects, assignments, and e-learning. In such a situation, students collaborate, learn from their peers, and share ideas to achieve common goals or accomplish group tasks that no one individual can complete alone. According to [1] and [3], more group heterogeneity has a negative impact on low-ability students, whereas peer effects were not found for high-ability students. Therefore, for such tasks, it is recommended to build groups with low heterogeneity. According to [19], homogeneous grouping is most useful for some types of learning activities, particularly those involving guided discovery, knowledge development, review of material already learned, or highly structured tasks to build competence, allowing students to progress at the same rate. In some cases, homogeneous groups are imposed due to the conditions and requirements of the courses.

Traditional methods that have been used to group students are basically random grouping, student-formed groups where the student chooses his group, and instructor-assigned groups where the teacher assigns the students into groups. There are many characteristics of the students on which the group formation depends, such as their knowledge level, personality traits, communication skills, etc. These characteristics were classified in [13] into static, such as gender, age, and knowledge level, and dynamic, such as interaction level or emotional status. The multiplicity of these characteristics and the multiplicity of students make the grouping process an NP-hard problem, as confirmed in [16], and so difficult to solve manually. Therefore, automated methods were required to form groups in an efficient manner based on several characteristics.

Most automatic grouping approaches studied in this paper have focused on the formation of heterogeneous groups for cooperative purposes and are of small size, with the number of members ranging between 3 and 5 in most cases. This may be due to their focus on e-learning and collaborative tasks. But, in fact, homogeneous groups are still needed in theoretical lectures and training courses, especially in in-person learning. The issue of forming homogeneous groups of large size was not addressed. Similarly, the balance between groups in terms of size and degree of homogeneity has not been addressed much, except in [2], where the authors examined the effect of group sizes on students in a gamification environment. They found that differing sizes between groups affected students' interest, comparison, and discouragement.

In this paper, an algorithm based on the self-balancing binary search tree is proposed to form learning groups. The goal is to build learning groups that are intra-homogeneous (a high level of similarity between the characteristics of the students within the group), inter-homogeneous (similarity or balance between the degree of homogeneity of the groups), and balanced in size. The idea is that we do not set intra-homogeneity as the sole goal of group formation because this will inevitably lead to groups with varying degrees of homogeneity, especially in the case of a high diversity of students before their distribution, which means groups that are highly homogeneous and others that are highly heterogeneous. In addition, if the focus is only on intra-homogeneity, then the issue of unbalanced sizes between groups is raised, as each student will be added to the group closest to him/her without any restrictions on group size. The connection between the three characteristics, namely intra-homogeneity, inter-homogeneity, and balanced size, is necessary for many uses,

such as lectures where instructors wish to deliver to more than one group with the same plan and progress at the same rate. The self-balancing binary search trees were used at an initial stage to achieve the objectives of group formation, as they contribute to the formation of student blocks (which are tree branches) with close performances and balanced sizes. Then, the groups are formed from these blocks. The proposed algorithm uses GPA (grade point average) as a key feature for grouping students.

Following this part, the paper is organized as follows: The following section discusses the literature review. The methodology used to construct the suggested algorithm, as well as the experimentation and outcomes of applying the proposed algorithm to some student samples, are then provided. The results and recommendations are explored in the concluding parts, which bring the article to a close.

## II. LITERATURE

In the past two decades, the formation of learning groups has been an important educational issue that researchers have addressed for the success of the educational process. This interest has multiplied in the past decade with the development of e-learning platforms, collaborative learning platforms, and collaborative work platforms. This section presents the related works and highlights the three essential aspects: the nature of formed groups (homogeneous vs. heterogeneous), forming methods, and forming characteristics or criteria.

Regarding the nature of groups, heterogeneous grouping is the most widely used grouping type because it can better satisfy diverse learning scenarios, especially in cooperative education, as used by [4], [5], [6], [8], [12], [13], [14], [15], [18], [26], and [28] whereas [19] developed an algorithm to generate homogeneous groups. Some research has focused on intra- and inter-group relationships. In this context, [16], [19], [25], and [27] propose approaches to achieve groups with members that are as similar as possible (inter-homogeneous) but also to enable individual differences among students within such groups (intra-heterogeneous).

There is a consensus that the issue of forming groups cannot be solved manually due to the multiplicity of formation criteria and the multiplicity of students. So, the relationship among these variables and possible grouping alternatives is factorial, making this an NP-hard problem, as confirmed in [16]. In these cases, it becomes necessary to use heuristic search methods to find a satisfactory solution with a considerably lower computational effort. A widely used heuristic method is the genetic algorithm (GA), which is used in [5], [11], [13], [15], [16], [19], [27], and [28]. The study [7] used simulated annealing (SA) to form student groups based on past academic records.

The main characteristics or criteria that were used in the related works to form the groups were knowledge levels, learning styles, communicative skills, leadership skills, gender, age, and self-confidence. Grouping algorithms assign different weights to these characteristics to generate optimized groups. The research [13] classified these characteristics as static and dynamic. Static characteristics are those that do not change or at least do not change during a short period of learning, such as

gender, age, previous levels of knowledge, or learning styles. Dynamic characteristics, which cannot be captured at a fixed point, are constantly changing during students' learning processes, such as levels of interaction or emotional status. According to [13], the main disadvantage of traditional non-automatic grouping methods, which include random grouping (used by [5]), student-formed groups (used by [11]), and instructor-assigned groups (used by [14]), is that they are generally based on static characteristics, and even if dynamic characteristics are used, they are not taken into account enough, which may lead to undesirable collaborative results. On the contrary, automatic grouping methods facilitated the use and good management of dynamic characteristics despite the problems associated with those characteristics, particularly how and when to measure them to form groups. [6], [12], [13], [16], [20], [21], and [25], developed automatic grouping methods that achieve collaborative learning outcomes. The phrase "cold start" was used in [13] to denote the problem of the inaccessibility of students' characteristics, such as personality traits, communication skills, and leadership capacities, at the starting point. Dynamic grouping is a solution to the "cold start" problem, in which groups are initiated and then modified by dynamic swapping. But its running time is expensive, and it takes time for groups to form and stabilize and for students to work on a regular basis. Thus, [6] proposes a dynamic grouping method where groups are initially formed based on students learning styles and knowledge levels, and then an activity-based dynamic group formation technique is proposed to swap students based on their knowledge levels. The authors in [17] propose a method to form dynamic groups for students who did not fit into any group and referred to them as "orphan students". In addition, [10] use dynamic grouping or partial grouping methods to enable students to find the most suitable partners.

The size of groups is less addressed in related works because the interest is in collaborative activities in which the group size ranges from 3 to 5 students. In the study conducted by [2] to investigate the effect of group sizes on students in a gamification environment, they found that varying sizes between groups affected students' interest, comparison, and discouragement but did not affect their perceived effort, perceived choice, perceived competence, tension, or motivation.

In summary, almost all grouping approaches have focused on collaborative tasks that have proliferated rapidly thanks to technological development. But collaborative activities and collaborative learning can be complementary to regular lectures in which the teacher contributes more than the student and in which the number of students is large. For this reason and to facilitate the role of lecturers in achieving the learning outcomes, it is necessary to form learning groups that are homogeneous and balanced in terms of size and homogeneity. We are not aware of any work using a self-balancing binary search tree for forming intra-homogeneous, inter-homogeneous, and size-balanced learning groups.

## III. METHODOLOGY

This section introduces an algorithm to automate the formation of learning groups. This algorithm aims to improve

the homogeneity of students' competence within learning groups for the same course and to achieve a balance between those groups in terms of size and degree of homogeneity. The algorithm relies on two types of self-balancing binary search trees due to its ability to classify and sort data. So, the first stage is to define the homogeneity of the groups and how it should be measured. The second stage introduces self-balancing binary search trees. Next, the steps of the algorithm that generates the learning groups are explained.

### A. Group Homogeneity

The proposed algorithm uses GPA (grade point average) as a key feature for grouping students. That is, students with a homogeneous GPA (closet GPA) are more likely to be in the same group. According to [9], [24], and [22], GPA is positively correlated with subsequent academic performance. The need for other grouping criteria, such as students' personality traits and communication skills, is unnecessary because this work does not address collaborative activities. Thus, the homogeneity of the learning group boils down to the homogeneity of the GPAs of its students. The used terminology and the calculated formula of homogeneity are as follows:

- $\mu(g)$ : The mean of the students' GPAs within a group  $g$
- $S(g)$ : The standard deviation of the students' GPAs within a group  $g$ . It measures the mean distance between each student's GPA and a reference point at the center of the range of GPAs, the  $\mu(g)$ . A small value of  $S$  means that the GPAs are distributed close to the central point,  $\mu$ , and are therefore close to each other, which means that they are homogeneous. Otherwise, they are far from each other and therefore heterogeneous.
- $CV(g)=(S(g)/\mu(g))\times 100$ : The coefficient of variation of the students' GPAs within a group  $g$ . The coefficient of variation measures GPAs' dispersion as a percentage of their mean to see how strong or weak that dispersion is. Hence, it is used as an indicator of both homogeneity and heterogeneity within a group  $g$ . The group  $g$  is considered heterogeneous from  $CV(g)=30\%$  and above because the GPAs of the students in it differ from each other by more than a third of the average. Otherwise, less than 30% ( $CV(g)<30\%$ ), group  $g$  is considered homogeneous. Therefore, the CV is used for measuring the homogeneity of student groups created in different ways, such as traditional methods and the proposed algorithm. Thus, the intra-homogeneity of a group  $g$  is calculated as follows:

$$H_{intra}(g)=(S(g)/\mu(g))\times 100 \quad (1)$$

Consider a set of  $n$  learning groups  $G=\{g_1, \dots, g_n\}$ , and their intra-homogeneity set  $H=\{(S(g_1)/\mu(g_1)), \dots, (S(g_n)/\mu(g_n))\}$  then the inter-homogeneity is calculated as follows:

$$H_{inter}(G)=S(H)/\mu(H) \times 100 \quad (2)$$

### B. Self-Balancing Binary Search Tree: Definition and use for Forming Learning Groups

A tree is a hierarchical data structure consisting of a set of nodes joined together by edges and having one node called the root. One of the most common tree types is the binary search tree (BST), also called an ordered binary tree. It has the property that the key (data) of each inner node is greater than all keys in its left subtree and less than those in its right subtree. One of its main benefits is speeding up data searches since the time complexity of operations on a BST is directly proportional to the tree's height. Fig. 1 provides an example of a BST that records the following list of GPAs for 17 students, where the GPA is measured on a 5-point scale: {1.88, 1.62, 3.3, 2.52, 4.13, 2.78, 3.75, 2.85, 2.56, 4.18, 1.83, 2.3, 4.05, 1, 3.7, 2.55, 3.29}. As it is shown below in Fig. 1, for a GPA search of 2.78, only the nodes with keys 1.88, 3.3, and 2.52 will be accessed.

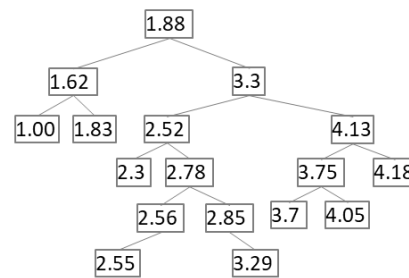


Fig. 1. Example of a BST recording the GPAs of 17 students.

The use of the tree in this work is to build small blocks of students with convergent GPA levels that will be used later to build learning groups with improved homogeneity. Each tree branch (the path from the root to the leaf of the tree) is considered a student block that is represented by their GPAs. The elements of any BST branch are often convergent and homogeneous. For example, in Fig. 1, branches  $B1 = \{1.88, 1.62, 1\}$  and  $B2 = \{1.88, 3.3, 2.52, 2.78, 2.85, \text{ and } 3.29\}$  are two blocks of students represented by their GPAs. The homogeneities of these two branches, calculated according to formula 1, are 30.14% and 19.18%, respectively, which means that these two students' branches are homogeneous. However, the disadvantage of BST is that its branches are not always the same size. For example, the sizes (number of elements) of  $B1$  and  $B2$  are 3 and 6, respectively, which means they are completely different. This can lead to an imbalance in the size of learning groups being built. That is why we are going to use self-balancing BST instead.

A self-balancing BST is a tree that has the property of rearranging its nodes as necessary to ensure that it does not become too tall and thin. It generalizes the BST, allowing nodes to contain more than two children. There are several implementations for balanced binary search trees like AVL trees, 2-3 tree, 2-3-4 tree, and B-trees. For more information about balanced trees, you can review [23]. For the purpose of this work, 2-3 tree and 2-3-4 tree are applied to generate student blocks that will be used to form learning groups. The 2-3 tree allows each node to have one data element and two children, or two data elements and three children. The 2-3-4 tree allows each node to contain one to three data elements and



two, three, or four children. In both trees, if a node contains more than one key, the keys must be in order. Fig. 2(a) and 2(b) redraw the data set of Fig. 1 as the 2-3 tree and the 2-3-4 tree, respectively.

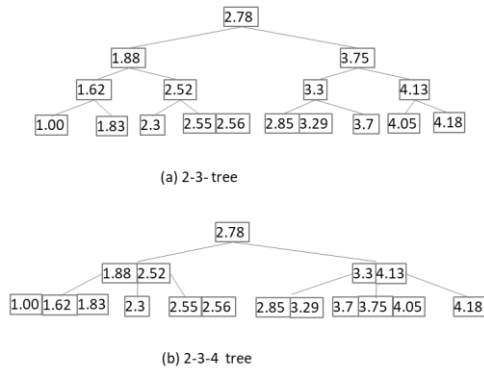


Fig. 2. Examples of self-balancing BST recording the GPAs of 17 students.

As shown in Fig. 2, the two trees are balanced so that all leaves are on the same plane. Using these two trees to form learning groups requires extracting all possible branches by decomposing nodes that are composed of more than one key and then associating each key with its children. The following table shows all possible branches of the 2-3 and 2-3-4 tree shown in Fig. 2.

TABLE I. BRANCHES GENERATED FROM THE 2-3 AND 2-3-4 TREES SHOWN IN FIG. 2.

	2-3 tree	2-3-4 tree
Branches	2.78, 1.88, 1.62, 1.0	2.78, 1.88, 1.0
	2.78, 1.88, 1.62, 1.83	2.78, 1.88, 1.62
	2.78, 1.88, 2.52, 2.3	2.78, 1.88, 1.83
	2.78, 1.88, 2.52, 2.55	2.78, 1.88, 2.3
	2.78, 1.88, 2.52, 2.56	2.78, 2.52, 2.3
	2.78, 3.75, 3.3, 2.85	2.78, 2.52, 2.55
	2.78, 3.75, 3.3, 3.29	2.78, 2.52, 2.56
	2.78, 3.75, 3.3, 3.7	2.78, 3.3, 2.85
	2.78, 3.75, 4.13, 4.05	2.78, 3.3, 3.29
	2.78, 3.75, 4.13, 4.18	2.78, 3.3, 3.7
		2.78, 3.3, 3.75
		2.78, 3.3, 4.05
		2.78, 4.13, 3.7
	2.78, 4.13, 3.75	
	2.78, 4.13, 4.05	
	2.78, 4.13, 4.18	

Table I shows that the branches generated from the 2-3 tree are few in number compared to the 2-3-4 tree but are longer than those produced from the 2-3-4 tree. This difference may play an important role in the formation of learning groups and affect their homogeneity, and this will be examined in the experiment section.

The common feature of the two trees, as shown in Table I, is that the produced branches often have homogeneous elements. However, sometimes the generated branches contain GPAs that are different or far from the majority within the branch, such as the branches {2.78, 1.88, 1.62, 1.83} and {2.78, 4.13, 4.18}, where the GPA 2.78 was far from the rest of the GPAs in the two branches. In this case, the homogeneity of the branch will not be highly affected because most of its

elements are close together. The homogeneity of branches and their balanced sizes in self-balancing BST serve the aims of this work, which is why these kinds of balanced trees were used.

### C. A Greedy Algorithm for Forming Learning Groups

To form learning groups that are intra- and inter-homogeneous and of balanced size, a greedy algorithm was developed using branches of self-balancing BST. This algorithm forms  $n$  learning groups, where  $n$  is predetermined. It processes recursively and, at each iteration, selects the appropriate branch  $br$  to add to the group  $g_i$ , where  $g_i$  is the group with the least size. If the number of groups of least size is greater than one, the lowest order group is selected. This procedure is applied to balance the size of groups.  $br$  is the branch that, when added to  $g_i$ , gives the best homogeneity to  $g_i$ , compared to the rest of the candidate branches for addition. At the end of each iteration, the algorithm reconstructs the candidate branches by removing the elements that are common with  $br$ . The following is the notation used to write the pseudocode for this algorithm:

- $GPAs$ : Students' GPAs that will be divided into groups.
- $TT$ : The used tree kind is either 2-3 or 2-3-4.
- $T$ : The self-balancing BST of kind  $TT$ , which will be constructed to contain GPAs
- $S$ : The generated branches from the  $TT$  tree
- $br$ : a branch in  $S$
- $n$ : The predetermined number of learning groups
- $G$ : The set of learning groups
- $g_i$ : The selected group to add an appropriate branch, where  $1 \leq i \leq n$ .
- $H_{intra}(g_j)$ : intra-homogeneity of the learning group  $g_j$

The pseudocode of the proposed algorithm, denoted for simplicity as the GF-SBT (Group Formation based on Self-Balancing Tree) algorithm, is presented in Fig. 3 below.

```

GF-SBT Algorithm(GPAs, TT, n)
INPUT:
- GPAs: List of students' GPAs
- TT: the type of balanced tree
- n: number of predetermined learning groups
OUTPUT:
- G: the set of created learning groups
BEGIN
1. T ← ConstructTree(GPAs, TT) // Construct the T tree of type TT from the list of GPAs
2. S ← generateBranches(T) // Extract all the branches of T
3. G ← ∅ // Initialize the Learning groups list to be empty
4. For i ← 1 to n do // Initialize all groups to an empty set and add them to G
5.   g_i ← ∅
6.   G ← G ∪ {g_i}
7. End For
8. While (S not empty) do // iterate to fill in the groups of G from S
9.   Find the group g_i ∈ G with the minimum size
10.  br ← first branch in S
11.  bestH ← H_intra(g_i ∪ br) // homogeneity of the GPAs in the set {g_i, U br}
12.  For each: b ∈ S // iterate to find the appropriate branch br to add to g_i
13.    hr ← H_intra(g_i ∪ b)
14.    if (hr < bestH) then
15.      br ← b
16.      bestH ← hr
17.    End if
18.  End For
19.  g_i ← g_i ∪ {br} // add the found appropriate branch br to g_i
20.  For each: b ∈ S // delete from any branch in S the elements in common with br
21.    b ← b - {b ∩ br}
22.  End For
23. Refresh S // Remove from S any branch that has become empty after deleting its elements in common with br
24. End While
25. Return G // return the set of created Learning groups
    
```

Fig. 3. GF-SBT Algorithm for forming learning groups.

#### IV. EXPERIMENTS

##### A. Experiment 1

This experiment investigates the ability of the 2-3 and 2-3-4 tree to help form intra- and inter-homogenous learning groups of balanced sizes. Moreover, it was used to measure the algorithm's ability to improve homogeneity and balance the size of learning groups compared to traditional group formation methods.

For this reason, five different tests were conducted to study the results of forming two learning groups in five different ways for 48 students enrolled in a computer programming course at the University of Tabuk. In the first three tests, traditional methods are used for grouping as follows: the first test keeps the same group formation that the university already made, which is self-formation (the student registered himself and chose the group). The other two tests were performed on random formations. The last two tests apply the algorithm GF-SBT using 2-3 and 2-3-4 tree, respectively. The results of these tests are summarized in Table II below. The mean intra-homogeneity is the average intra-homogeneity of the two groups.

Table II shows the learning group sizes generated by each test, the mean intra-homogeneity of the two groups, as well as the inter-homogeneity. For simplicity, in the rest of this paper, intra-homogeneity is used to denote mean intra-homogeneity.

TABLE II. RESULTS OF THE FIVE TESTS FOR FORMING LEARNING GROUPS FOR A SAMPLE OF 48 STUDENTS

	Self-grouping test	Random test 1	Random test 2	2-3 Tree test	2-3-4 Tree test
First group size	24	23	29	24	24
Second group size	24	25	19	24	24
Mean intra-homogeneity	20.50%	19.34%	21.16%	16.37%	15.63%
Inter-homogeneity	26.15%	50.88%	61.04%	31.95%	27.75%

The results in Table II showed that there was no correlation between the balance of group size and the improvement in homogeneity. For example, the first, fourth, and fifth tests produced groups of balanced size, with 24 students in each group. However, the intra-homogeneity was different between these three tests (20.50% for the first test, 16.37% for the 2-3 tree test, and 15.63% for the 2-3-4 tree test), which means that the contents of the groups differ from one test to another. In addition, the first test groups were balanced in size (24 per group) in contrast to the second test groups, which were not balanced (23 and 25), but the intra-homogeneity for the second test was better than the first.

The above readings of the results, presented in Table II, confirm that balancing group size is not sufficient to improve intra-homogeneity. Therefore, there is a need to use techniques that combine improving numerical balance with homogeneity when creating groups. In this context and based on the above results, the proposed algorithm, with the use of 2-3 and 2-3-4 trees, succeeded in meeting this need to adjust group sizes and improve group homogeneity compared to traditional methods.

Thus, group construction by applying the GF-SBT algorithm is more efficient than traditional formation methods in balancing the number of students between groups and improving intra-homogeneity. The use of 2-3-4 tree was better than 2-3 tree in improving intra-homogeneity (16.37% for 2-3 tree and 15.63% for 2-3-4 tree). Furthermore, the use of the 2-3-4 tree has improved the intra-homogeneity of the self-grouping test by 4.87 percentage points (from 20.50% to 15.63%), the intra-homogeneity of the first random test by 3.71 percentage points (from 19.34% to 15.63%), and the intra-homogeneity of the second random test by 5.53 percentage points (from 21.16% to 15.63%). Therefore, in terms of percentages, the use of the 2-3-4 tree improved the intra-homogeneities resulting from the three traditional tests studied by 23.76% (calculated as  $4.87/20.50$ ) for the first test, 19.18% (calculated as  $3.71/19.34$ ) for the second test, and 26.13% (calculated as  $5.53/21.16$ ) for the third test. The use of the 2-3 trees also improved the intra-homogeneity of the three traditional tests by 20.15% (calculated as  $(20.5-16.37)/20.5$ ), 15.35%, and 22.61%, respectively.

The inter-homogeneity showed that the GF-SBT algorithm was more efficient at narrowing the gap between the two group homogeneities than the randomized tests. In addition, the use of the 2-3-4 tree approach is more effective than the use of the 2-3 tree in adjusting the homogeneity between the two groups, given that the inter-homogeneity was 27.75% for the 2-3-4 tree and 31.95% for the 2-3 tree.

The bottom line from this experiment is that the GF-SBT algorithm, with its two trees, accurately balances learning group sizes and effectively improves intra-homogeneity caused by traditional grouping methods, with rates ranging from 15% to 26%. Also, compared to the random construction of groups, the GF-SBT algorithm is more efficient at balancing group homogeneity. For this small sample of students, the use of the 2-3-4 tree is more appropriate than the use of the 2-3 trees to create learning groups of equal sizes and optimized and balanced homogeneities.

##### B. Experiment 2

This experiment aims to investigate the effect of multiplying the number of students and the number of learning groups on the effectiveness of the GF-SBT algorithm in improving the intra- and inter-homogeneity of learning groups and balancing their size. To achieve this aim, five tests were conducted that used the GF-SBT algorithm with the 2-3 and 2-3-4 tree to construct learning groups for a broad sample of students. The number of groups differs in each test and ranges between 2 and 6. The sample consisted of 96 students who self-enrolled in four educational groups in the communication skills course at Tabuk University, as shown in Table III below.

TABLE III. CHARACTERISTICS OF 4 LEARNING GROUPS FROM A SAMPLE OF 96 STUDENTS

	Group size	Mean intra- homogeneity	Inter-homogeneity
Group 1	24	55.55%	9.05%
Group 2	25		
Group 3	32		
Group 4	15		

Table IV and Table V present the results of the five tests that apply the GF-SBT algorithm, with its two trees, to distribute this sample of students into 2, 3, 4, 5, and 6 learning groups.

TABLE IV. LEARNING GROUP SIZE IN A SAMPLE OF 96 STUDENTS

		Test1: 2 learning groups		Test2: 3 learning groups		Test3: 4 learning groups		Test4: 5 learning groups		Test5: 6 learning groups	
		2-3 Tree	2-3-4 Tree	2-3 Tree	2-3-4 Tree	2-3 Tree	2-3-4 Tree	2-3 Tree	2-3-4 Tree	2-3 Tree	2-3-4 Tree
Group size	Group 1	4 8	48	32	3 2	2 4	24	2 0	20	16	1 7
	Group 2	4 8	48	32	3 2	2 4	24	1 9	19	17	1 6
	Group 3			32	3 2	2 4	24	1 9	19	16	1 6
	Group 4					2 4	24	1 9	19	16	1 6
	Group 5							1 9	19	16	1 5
	Group 6									15	1 6

It is shown in Table IV that the GF-SBT algorithm yields groups of very balanced sizes, with some very slight differences resulting either from the non-divisibility of the total number of students evenly, such as in test 4, where 96 is not divisible by 5, or in cases where the number of groups is high, such as in the fifth test. It is also noted that the number of groups in the third test and in the formation proposed by the university are the same, but the groups produced by the third test are more balanced in size than the ones made by the university.

TABLE V. INTRA- AND INTER-HOMOGENEITIES OF LEARNING GROUPS IN A SAMPLE OF 96 STUDENTS

		Test1: 2 groups		Test2: 3 groups		Test3: 4 groups		Test4: 5 groups		Test5: 6 groups	
		2-3 Tree	2-3-4 Tree	2-3 Tree	2-3-4 Tree	2-3 Tree	2-3-4 Tree	2-3 Tree	2-3-4 Tree	2-3 Tree	2-3-4 Tree
Intra- homo- geneity	%	56.04	55.13	53.39	46.95	54.16	47.18	55.38	53.56	54.56	48.75
Inter- homo- geneity	%	3.25	2.52	10.87	36.86	13.67	32.80	9.22	19.04	18.30	23.26

Table V shows that the homogeneity of the groups is very high compared to the homogeneity of experiment 1. This is because this sample is characterized by the large number of its students and the great diversity of their GPAs. It shows that the difference between the intra-homogeneity of the two uses of trees in most tests was significant and ranged between 5 and 7

percentage points, except for the tests of two groups and five groups. It displayed that the use of the 2-3-4 tree was the best, compared to the 2-3 tree approach, in improving intra-homogeneity in all five tests for this heterogeneous sample. Compared to the self-grouping results presented in Table IV, the algorithm GF-SBT, with the two uses of trees, improves intra-homogeneity. In this respect, the use of the 2-3-4 tree approach yields an improvement of more than 8 percentage points (from 55.55% to 47.18%), which is equivalent to a 15.07% improvement. Thus, the algorithm GF-SBT with the two uses of trees can improve the intra-homogeneity for homogeneous samples, as in experiment 1, and heterogeneous samples, as in this experiment.

The results presented in the Table V did not show any clear correlation between the number of groups and the intra-homogeneity improvement in the two uses of trees. It is shown that intra-homogeneity does not follow the same pattern as the number of groups. For example, for the use of the 2-3 tree, the mean intra-homogeneity in the five-group test (55.38%) was greater than the mean intra-homogeneity for the three, four, and six group tests (53.39%, 54.16%, and 54.56%, respectively), but smaller than the mean intra-homogeneity in the two-group test (56.04%). The same phenomenon is observed with the 2-3-4 tree approach.

In Table V, by measuring the inter-homogeneity, it is shown that the use of the 2-3 tree was more capable compared to the use of the 2-3-4 tree in constructing homogeneity-balanced groups (well inter-homogeneous) in all tests except the two-group test. Fig. 4 below supports this finding and plots the intra-homogeneity of each test. It reveals that the results of the use of the 2-3 tree appear closer to each other than the ones of the use of the 2-3-4 tree, which appear disparate. However, despite their convergence, the levels of homogeneity resulting from the use of the 2-3 tree were mostly high, compared to the results of the use of 2-3-4 tree. This explains the excellence of the 2-3-4 tree in improving the mean intra-homogeneity. In addition, no correlation was observed between the inter-homogeneity and the number of groups.

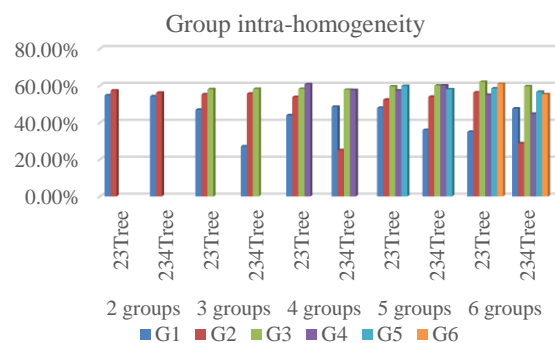


Fig. 4. Groups' intra-homogeneities of the five tests.

All three parameters measured and analyzed here above (group size, intra-homogeneity, and inter-homogeneity) depend on candidate branches (the initial contents of S set in the algorithm GF-SBT) that are used by the GF-SBT algorithm in the group formation process. Table VI below presents the

features of the candidate branches of the two trees used by the GF-SBT algorithm for this sample.

TABLE VI. FEATURES OF THE CANDIDATE BRANCHES GENERATED FROM THE 2-3 AND 2-3-4 TREES

	2-3 Tree	2-3-4 Tree
Branch size	6	5
Total Number of candidate branches	71	100
Standard deviation of homogeneities of candidate branches	8.17	9.05

It is evident in Table VI that the candidate branches of the 2-3-4 tree are shorter with dispersed homogeneities, i.e. its standard deviation is bigger than that of the 2-3 tree, and more numerous than those of the 2-3 tree. This is why using the 2-3-4 tree produces better intra-homogeneity than using a 2-3 tree and poorer inter-homogeneity between groups, as shown in Table V.

## V. DISCUSSION

Based on the results of the experiments presented in the previous section, the GF-SBT algorithm proved effective in forming learning groups of balanced size and improving their intra-homogeneity. In this regard, it exceeded the traditional methods (self-grouping and random grouping methods) that have been adopted in building learning groups. Similarly, these results agree with what is presented in [16], [19], [25], and [27], which propose to improve both the internal and external relationships of the groups. In spite of the similarities in the obtained results, the methods used for measuring the effectiveness of algorithms were different. For instance, [16], [19], [25], and [27] measure the effect of the grouping algorithm on the students' abilities, while this work measures intra- and inter-homogeneity of groups. The measure of students' ability was allowed for the former because they intended a small group made up of five students for collaborative work, whereas the latter was designed to deal with any size of group that may be greater than twenty students.

The results of using the two self-balancing BSTs, 2-3 and 2-3-4, with a small sample are nearly identical in terms of group size, intra-homogeneity, and inter-homogeneity. Thus, small samples are recommended to be used with any of both trees, with bit priority for 2-3-4 tree.

In the case of large samples, the algorithm produces different results for both trees because of the differences in structure of their candidate branches. The candidate branches of the 2-3-4 tree are more numerous than those of a 2-3 tree and are characterized by various homogeneities and short sizes. They allow the algorithm to create learning groups that are often better intra-homogeneous than the 2-3 tree groups but are less inter-homogeneous. Thus, the use of the 2-3-4 tree is preferable if priority is given to intra-homogeneity more than inter-homogeneity of learning groups. On the contrary, the 2-3 tree produces fewer candidate branches with less various homogeneity and a larger size. That is why the algorithm generates learning groups that are often less intra-homogeneous than 2-3-4 tree groups, but good inter-homogeneously. So, 2-3 tree use is beneficial if the priority of

group formation is given to inter-homogeneity. The summary of this paragraph is that the formation of groups through short student blocks improves the intra-homogeneity of learning groups at the expense of their inter-homogeneity, and the opposite occurs through large student blocks.

It has not been proven through experiments that the grouping process adopted by the GF-SBT algorithm is affected by the number of groups to be built. Therefore, the use of the algorithm is effective and recommended regardless of the number of groups to be formed.

The limitation of this work is that, with large samples, neither the use of the 2-3 tree nor the use of the 2-3-4 tree succeeded in integrating improvements in both intra- and inter-homogeneity of the generated learning groups. This limitation will be studied in future work.

## VI. CONCLUSION

In this paper, an algorithm based on self-balancing binary search trees has been implemented and experimented with to form intra-homogeneous (student performance similarity within the group) and inter-homogeneous (group performance similarity between groups) learning groups with a balanced size. The self-balancing binary search trees were used at an initial stage to achieve the objectives of group formation, as they contribute to the formation of student blocks (which are tree branches) with close GPAs and balanced sizes. Then, the groups are formed from these blocks. The algorithm uses two versions of self-balancing binary search trees (the 2-3 tree and the 2-3-4 tree), where the difference between them lies in the number and length of branches they produce.

The experiments have shown, with samples from different numbers of students, the efficiency of the proposed algorithm in balancing the size of the groups, balancing the homogeneity between them (inter-homogeneity), and improving their internal homogeneity (intra-homogeneity) compared to the traditional forming methods by up to 26%, whatever the kind of self-balancing binary search tree (2-3 or 2-3-4).

With small samples of students, using the 2-3-4 tree was more effective than the 2-3 tree for improving intra- and inter-homogeneity. However, with large samples, using the 2-3-4 tree was more effective than the 2-3 tree in improving intra-homogeneity but less effective for balancing homogeneity between groups. In this case, the choice between using 2-3 or 2-3-4 trees depends on the instructor's preference, whether intra-homogeneity or inter-homogeneity. The inability of the algorithm to combine intra- and inter-homogeneity optimization for large samples of students using both kinds of self-balancing binary search trees is a limitation that will be worked on in the future.

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# Multi-Features Audio Extraction for Speech Emotion Recognition Based on Deep Learning

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**Abstract**—The increasing need for human interaction with computers makes the interaction process more advanced, one of which is by utilizing voice recognition. Developing a voice command system also needs to consider the user's emotional state because the users indirectly treat computers like humans in general. By knowing the type of a person's emotions, the computer can adjust the type of feedback that will be given so that the human-computer interaction (HCI) process will run more humanely. Based on the results of previous research, increasing the accuracy of recognizing the types of human emotions is still a challenge for researchers. This is because not all types of emotions can be expressed equally, especially differences in language and cultural accents. In this study, it is proposed to recognize speech-based emotion types using multi-feature extraction and deep learning. The dataset used is taken from the RAVDESS database. The dataset was then extracted using MFCC, Chroma, Mel-Spectrogram, Contrast, and Tonnetz. Furthermore, in this study, PCA (Principal Component Analysis) and Min-Max Normalization techniques will be applied to determine the impact resulting from the application of these techniques. The data obtained from the pre-processing stage is then used by the Deep Neural Network (DNN) model to identify the types of emotions such as calm, happy, sad, angry, neutral, fearful, surprised, and disgusted. The model testing process uses the confusion matrix technique to determine the performance of the proposed method. The test results for the DNN model obtained the accuracy value of 93.61%, a sensitivity of 73.80%, and a specificity of 96.34%. The use of multi-features in the proposed method can improve the performance of the model's accuracy in determining the type of emotion based on the RAVDESS dataset. In addition, using the PCA method also provides an increase in pattern correlation between features so that the classifier model can show performance improvements, especially accuracy, specificity, and sensitivity.

**Keywords**—Deep learning; multi-features extraction; RAVDESS; speech emotion recognition

## I. INTRODUCTION

Speech is a form of information transfer commonly used in everyday life [1]. In everyday conversation, speech can provide a lot of information, not only words but also the emotions speakers convey. Knowing the level or type of emotion the other person is talking to is very important in building conversations in social life [2]. By understanding a person's emotional type, treatment and attitude towards that person will be adjusted to the current emotional state [3].

With the development of information technology and the increasing need for Human-Computer Interaction (HCI), the interaction process has become more advanced. One form of simple but effective advanced interaction is through speech

[4][5]. The development of a voice command system needs to consider the user's emotional state, because when interacting with a computer, users tend to treat computers like humans in general [6][7]. Therefore, developing a sophisticated HCI system requires the availability of a speech database that represents emotions as a basis for developing an artificial intelligence system capable of imitating human emotions.

Speech Emotion Recognition (SER) is a field of research that focuses on recognizing types of human emotions which can then be processed further in the form of feedback to users. Several studies have carried out research related to SER, one of which was put forward by Chowdary and Hemanth [8], who utilized the Mel Frequency Cepstral Coefficients (MFCC) and Convolutional Neural Network (CNN) extraction methods to identify types of emotions using the RAVDESS database. This research produced 92%, 95%, and 69% accuracy, specificity, and sensitivity values, respectively. Another study conducted by Kumala and Zahra [9] proposed a study using a cross-corpus technique to identify the types of emotions in Indonesian conversation. This study's results indicate that using a combination of two SER databases and feature extraction of MFCC and Teager Energy can provide an accuracy of 85.42%. Based on the achievement of the performance parameters of several studies above, it can be said that increasing the accuracy of recognition of types of human emotions is still a challenge for researchers. This happens because not all types of emotions can be expressed equally [10].

From the research above, it can be seen that the results of speech-based emotion recognition depend heavily on the database used, the number of balanced classes, the feature extraction process, and the machine learning method used [11]. The use of multiple features is one aspect of improving the performance of the classifier model in identifying types of human emotions, as stated in the research proposed by Iqbal et al [12], where this research utilizes the features of frequency, Pitch, Amplitude, and Formant which are combined with ANN models based on Bayesian Regularized (BRANN) to recognize the type of emotion using the Berlin Database of Emotional Speech (Berlin EmoDB) dataset. The evaluation results of this study obtained an accuracy value of 95%. These results indicate that the use of several features in recognizing the types of human emotions can have an impact, especially in increasing the value of performance parameters in the classifier model.

Therefore, this study proposes using multi-feature extraction and deep learning methods by utilizing the Deep Neural Network (DNN) architecture to recognize types of emotions based on speech. Deep learning is used because of its



ability to process large data and provide high-accuracy values [13]. Furthermore, the multi-features used in this study consist of Mel Frequency Cepstral Coefficients (MFCC), Chroma, Mel-Spectrogram, Tonnetz, and Contrast. These five features are related to the high and low frequency of speech associated with emotional expression [14]. In addition, PCA (Principal Component Analysis) and Min-Max Normalization techniques will be applied to determine the impact resulting from the application of these techniques. The evaluation results were then analyzed using the Confusion Matrix table to determine the accuracy, specificity, and sensitivity values.

This speech emotion recognition research contributes to:

- 1) Determine the features that affect the recognition of eight (8) classes of human speech emotions
- 2) Determine the optimal number of features for feature selection using PCA and feature normalization using MinMax
- 3) Improve performance parameters of accuracy, sensitivity and specificity.

The following section will explain related research, especially research on SER. Then, Section III will explain the methodology used in this study. Then in the next section, we will present the results of our experiment along with an analysis of these results, and Section V is this study's conclusion.

## II. RELATED RESEARCH

SER, or Speech Emotion Recognition, is a method of recognizing types of emotions through speech by utilizing several data processing techniques and machine learning. Based on the results of a literature study conducted by Singh and Goel [11], it shows that SER is a research area that has high interest, especially in real-world applications. From the results of this study, it was found that the development of SER has several factors that influence the results and performance of SER, namely the availability of datasets used in model development, the feature extraction process that is relevant to the type of emotion, and the type of classifier used in model training.

Several studies have carried out the development of models related to SER, one of which was suggested by research conducted by Chowdary and Hemanth [8]. This study proposes the development of SER by utilizing the RAVDESS and Convolutional Neural Network (CNN). The research phase starts from the MFCC feature extraction stage from the RAVDESS dataset. Then the feature extraction results were validated into 1642 data as training data and 810 data as test data. The training data is used as a reference for training the Conv1D-based CNN model. Next, the model is evaluated using test data. The evaluation results showed a model accuracy of 92%, sensitivity of 69%, and specificity of 95%.

Furthermore, Iqbal et al. [12] proposed speech emotion recognition based on Artificial Neural Networks (ANN). The Berlin Database of Emotional Speech (Berlin EmoDB) was used in this study as a speech-based emotion recognition dataset collection. Several feature extractions are used, including frequency, pitch, amplitude, and formant. While the

classifier model used is ANN based on Bayesian Regularized (BRANN). The model evaluation results obtained an accuracy performance of 95%. In addition, several studies also utilize multi-feature techniques such as MFCC [15], Cross Zero Rate, Root Mean Square (RMS) [16], Chroma, Mel-Spectrogram, Contrast, and Tonnetz [17][14]. The use of multiple features is one aspect of increasing the performance of the classifier model in identifying types of emotions [11].

The use of a different approach was also proposed by Kumala and Zahra [9]. In this study, it is proposed to use the Cross-Corpus technique to recognize speech emotions in Indonesian. This study utilizes several database sources, namely the Berlin Database of Emotional Speech (Berlin EmoDB), Ryerson Audio-Visual Database of Emotional Speech and Song (RAVDESS), and Surrey Audio-Visual Expressed Emotion (SAVEE) so that there are three corpora, consisting of one corpus in German, and two corpora in English. The feature extraction process in this study uses the MFCC and Teager Energy methods. Using the Support Vector Machine (SVM) classifier, this study increased accuracy performance by 4.16% on MFCC and 2.09% on the Teager-MFCC combination. In addition, the three corpora used are in good agreement with Indonesian in terms of emotion recognition.

Using the multi-acoustic feature on the SER is one of the efforts to improve the performance of human emotion recognition. This study will use features such as MFCC, Chroma, Contrast, Mel-Spectrogram, and Tonnetz as emotion recognition features. Then Principal Component Analysis (PCA) and Min-Max Normalization techniques are implemented to see the impact of these processes on the performance of emotion recognition. Deep Neural Network (DNN) is used in this study as a classifier because of its ability to process large data and provide high accuracy values [13]. The model that has been trained is then evaluated using the confusion matrix to determine the performance of the model, especially in terms of accuracy, specificity and sensitivity values.

## III. METHODOLOGY

This study proposes to identify emotions based on RAVDESS voice data using multi-feature extraction and Deep Neural Network (DNN). An overview of this research can be seen in Fig. 1.

In Fig. 1 it can be seen that the RAVDESS dataset will extract its audio features using several types of audio extraction methods such as Mel Frequency Cepstral Coefficients (MFCC), Chroma, Mel-Spectrogram, Tonnetz, and Contrast. Then, PCA (Principal Component Analysis) and Min-Max Normalization techniques are applied to the extracted features to determine the impact of transformation and data reduction on the resulting model.

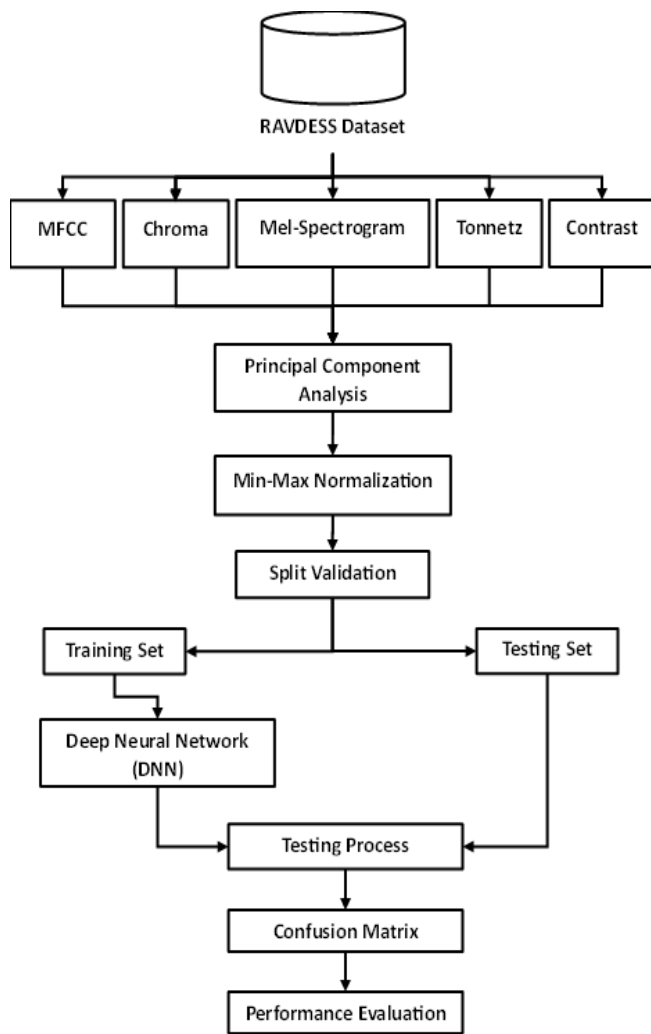


Fig. 1. Concept of proposed study.

After experiencing the pre-processing stage, the dataset can be grouped into training and testing sets using split validation. The Deep Neural Network (DNN) will use the training set as the model training reference data. After the training results model is obtained, the next step is to test using the testing set as the test data. From the testing process, the results of the emotion type prediction will be obtained by the trained DNN model, where these results will be transformed into a Confusion Matrix table as a reference table for determining the performance parameters of the proposed model. The parameters used to determine the performance of the proposed model are accuracy, specificity, and sensitivity.

#### A. Dataset

In this study, the Ryerson Audio-Visual Database of Emotional Speech and Song, or the RAVDESS dataset, was used [18]. The data set is a multi-modal database consisting of separate sound and video recordings showing certain types of emotions. The database is gender balanced, consisting of 24 professional actors, vocalizing lexically-matched statements in a neutral North American accent. Each actor recites a sentence or song in North American English lasting 3 to 4 seconds in a standardized recording scenario.

In this study, the focus will be on datasets in audio format. RAVDESS contains 2452 audio data divided into 1440 audio data for speech and 1012 audio data for songs. The data is also divided into 8 (eight) types of emotions: calm, happy, sad, angry, neutral, fearful, surprise, and disgust.

#### B. Feature Extraction

1) Mel Frequency Cepstral Coefficients (MFCC) is a feature extraction type commonly used in audio files [19]. MFCC is generally suggested to be used as an identifier for monosyllables in audio without identifying the speaker [20]. The MFCC feature extraction process [8] in audio begins with the Pre-emphasis stage, namely amplifying the audio signal at high frequencies. Followed by the framing and windowing stages, where framing stage aims to divide the length of the audio into several time intervals between 20 ms to 30 ms while the windowing technique is used to limit the occurrence of disturbances at the beginning and end of the audio, the next stage is the implementation of the Fast Fourier Transform, Mel Filter Bank, and Discrete Cosine Transform as a process of transforming the windowing results into MFCC. MFCC (Mel-Frequency Cepstral Coefficients) is a feature used in speech emotion recognition which has the advantage of representing the acoustic properties of the human voice. The MFCC uses the mel scale, which is similar to the human auditory perception of frequency. MFCC features are generated by taking the logarithm of the power spectrum and converting it to cepstrum, thereby helping to reduce feature dimensionality and processing complexity. MFCC can represent temporal information in speech signals through short-duration frame splitting techniques to capture variations in speech signals associated with temporal emotional changes.

2) Chroma is a feature extraction focusing on music-oriented audio tones [21]. This feature can provide a distribution of tonal variations in audio in the form of a simple feature. The Chroma feature's result is a chromagram built based on 12 (twelve) tone levels [22]. The use of chroma is expected to recognize the high and low pitch of the actor's speech in audio, where the tone of the speech can indicate a certain type of emotion.

3) Mel-Spectrogram is an audio feature extraction that was built to overcome the problem of limited human hearing ability in distinguishing high-frequency values [22]. The use of the Mel-Spectrogram in this study is to extract information on differences in frequency values, particularly in identifying the types of emotions expressed by actors.

4) Tonnetz is a feature extraction derived from Chroma that also focuses on audio harmony and tone classes [23].

5) Contrast is a feature extraction in audio that is useful for estimating the average sound energy based on each sub-band's peak and valley spectral values [24].

#### C. Principal Component Analysis (PCA)

PCA or Principal Component Analysis, is a statistical method that is widely used, especially in data processing such as dimension reduction, data compression, and feature

extraction [25]. PCA is conceptually able to identify new variables based on the main components, where these values are linearly the result of the combination of the original features used [26]. Simply put, PCA will project a new feature or variable whose representation is the same as the original feature where the number of components can be adjusted. In this study, PCA will be tested as dimension reduction to reduce the number of extracted features and increase the representation of feature values.

#### D. Min-Max Normalization

Normalization is the process of equalizing values among features with significant differences in value so that the weights and the effects on each feature are the same when used as a reference for classifier model training [27]. In this study, the Min-Max Normalization method will be applied where the value of each feature will be distributed over a range of values between 0 and 1. The application of this method will provide an overview of the impact of using normalization in the formation of classifier models. This method works by first determining the maximum ( $x_{max}$ ) and minimum ( $x_{min}$ ) values of each variable or feature. Then each original data ( $x_{old}$ ) is operated with the previously obtained value to produce a new value ( $x_{new}$ ) using the following equation [8]:

$$x_{new} = \frac{x_{old} - x_{min}}{x_{max} - x_{min}} \quad (1)$$

#### E. Deep Neural Network (DNN)

Deep Neural Network or DNN is one of the Deep Learning (DL) methods built on the basis of Neural Networks. DNN is the improved version of the conventional Neural Network method by adding some depth such as additional hidden layers at the input and output layers [28]. This method is generally used to predict or classify data according to class. In this study, the DNN structure used consisted of 1 (one) dense layer as input and 1 (one) dense layer as output with each activation, namely 'ReLU' and 'Softmax'. Then there are 3 (three) hidden solid layers. A detailed description of the proposed DNN structure in this study can be seen in Table I:

TABLE I. PROPOSED DNN STRUCTURE

Component	Layer Architecture	Activation Function
Input Layer	Dense Layer	RELU
1 <sup>st</sup> Hidden Layer	Dense Layer	RELU
Dropout	DROPOUT	-
2 <sup>nd</sup> Hidden Layer	Dense Layer	RELU
Dropout	DROPOUT	-
3 <sup>rd</sup> Hidden Layer	Dense Layer	RELU
Dropout	DROPOUT	-
Output Layer	Dense Layer	SOFTMAX

#### F. Performance Evaluation

The DNN model testing process results will be converted into a Confusion Matrix table as a reference for calculating model performance parameters. The performance parameters used are accuracy, specificity, and sensitivity. Determining the performance parameter values of the proposed model can use the following equation [8]:

$$Accuracy = \frac{TN+TP}{FP+FN+TN+TP} \quad (2)$$

$$Sensitivity = \frac{TP}{TP+FN} \quad (3)$$

$$Specificity = \frac{TN}{TN+FP} \quad (4)$$

In the equation above, TP (True Positive) is the number of test data correctly predicted as a positive class, TN (True Negative) is the amount of test data correctly predicted as a negative class while FP (False Positive) is the amount of test data with a negative class which is predicted as the positive class and FN (False Negative) is the number of test data with the positive class which is predicted to be the negative class. These four values can be generated from the Confusion Matrix table.

#### IV. EXPERIMENT RESULT AND DISCUSSION

Following are the steps in implementing the use of the RAVDESS dataset for speech emotion recognition:

- 1) Dataset exploration and understanding: understand the structure, metadata, and emotional information provided and examine the number of sound recordings, actors involved.
- 2) Feature extraction: uses the combined extraction technique and determines the feature extraction parameters.
- 3) Feature Selection: using the PCA technique
- 4) Data Normalization: using the MinMax Technique
- 5) Dataset division: divide the RAVDESS dataset into training, validation, and testing subsets.
- 6) Model training and evaluation: train a speech emotion recognition model using training subsets and validation splits.
- 7) Testing and final validation: using a subset of testing to test the model that has been trained and calculating the confusion of testing metrics to get accuracy, sensitivity, specificity.
- 8) Analysis of results and evaluation: analyze the results of speech emotion recognition obtained from the model, including performance in each emotion category.

In this study, the experimental phase was carried out using RAVDESS audio dataset which consisted of 1440 spoken audio data and 1012 emotional song data in \*.wav format. Furthermore, the data were extracted using several feature extraction techniques, consisting of MFCC, Mel-Spectrogram, Chroma, Contrast, and Tonnetz. From the extraction results that have been carried out, a total of 193 features were obtained consisting of 40 MFCC features, and 12 Chroma features, whereas Mel-Spectrogram, Contrast, and Tonnetz produced a total of 128 features, 7 features, and 6 features, respectively.

Furthermore, the features obtained are processed using the PCA technique with the total components used are the multiple of 10% of the total features. These results are then normalized using the Min-Max Normalization method to limit the data range that is too large, so that the same range of data for each feature can be achieved.

In the next stage, the normalization results using Min-Max Normalization were validated using separate validation with a ratio of 33% for 810 data as a test set and the remaining 1642

data as a training set. Next, the initialization of the sequential model is carried out by utilizing dense layers to form a Deep Neural Network (DNN) model.

The Deep Neural Network (DNN) model used consists of 5 (five) dense layers. Then the parameter specifications for each layer used consist of the first to fourth dense layers using the 'ReLU' activation function, while the fifth (last) dense layer uses the 'Softmax' activation function which acts as an inference in determining emotion classes. The proposed DNN model uses the 'Adam' optimizer parameter or the adaptive estimates of lower-order moments [29]. Then, the value of 0.1 is used for the dropout rate parameter, which means that the ratio of possible elimination nodes in the DNN is 10% at each embedded dropout step. The model of this sequential DNN uses dropout and parameters, which can be seen in Fig. 2.

```

Model: "sequential"
-----
Layer (type)                Output Shape                Param #
-----
dense (Dense)                (None, 193)                 37442
dense_1 (Dense)              (None, 772)                 149768
dropout (Dropout)            (None, 772)                 0
dense_2 (Dense)              (None, 579)                 447567
dropout_1 (Dropout)          (None, 579)                 0
dense_3 (Dense)              (None, 386)                 223880
dropout_2 (Dropout)          (None, 386)                 0
dense_4 (Dense)              (None, 8)                   3096
-----
Total params: 861,753
Trainable params: 861,753
Non-trainable params: 0
-----
None
    
```

Fig. 2. Specification of deep neural network (DNN) using 100% of features.

DNN model training using 1642 data distributed into 8 (eight) classes, namely calm, happy, sad, angry, neutral, afraid, surprised, and fed up has been carried out. The training process is repeated for 200 epochs. The model produced in the training process was tested using test data with 810 data. The experimental scheme in this study was carried out using several combinations of data pre-processing methods, especially PCA and Min-Max Normalization. The variations of the experimental schemes used consist of experiments with original features, experiments with applying the normalization method, experiments with applying the PCA technique, and experiments with a combination of PCA and Normalization techniques. In experiments that apply the PCA technique, the number of components used is 100% to 10% of the total features used, where the decrease in the number of components used is 10% for each test. Then, the experimental results for each scheme are transformed into a confusion matrix and evaluated using the performance parameters as shown in Table II.

Table II shows the test results for each experimental variation of the proposed method. The initial scheme that uses all original features can produce a Sensitivity of 69.53%,

Specificity of 95.93%, and Accuracy of 92.93%. This table also shows that the use of the Min-Max Normalization and PCA methods can have an impact on the performance value of the classifier model.

TABLE II. THE RESULT OF VARIATION EXPERIMENTAL OF THE PROPOSED METHOD

	Sensitivity (%)	Specificity (%)	Accuracy (%)
Original Features	69,53	95,93	92,93
Normalization	67,71	95,55	92,28
PCA	<b>73,80</b>	<b>96,34</b>	<b>93,61</b>
PCA + Normalization	73,00	96,33	93,61

The use of the Min-Max Normalization method in this study impacts decreasing performance values, although the decrease is not too significant. This can happen because Min-Max Normalization only projects the original feature values to be valued from 0 to 1, so there is a potential for important values to be omitted, which results in bias during pattern analysis in the model-building process.

The application of the PCA method can impact increasing the performance value of schemes with original features. In fact, applying the PCA method provided the best overall experimental performance with an accuracy value of 93.61%, a Sensitivity of 73.80%, and a Specificity of 96.34%. These results were obtained using 100% components or 193 components of PCA. The achievement of this value can occur because at the PCA stage, there is a Data Scaling process, which is similar to the transformation of feature values in the Normalization method. Furthermore, a statistical calculation process is carried out to form component values close to the original feature values, so that the distribution of feature values becomes the same and PCA can also increase the correlation of each component.

Then in the experiment that combined PCA and Min-Max Normalization, the highest results were obtained with sensitivity of 73%, specificity of 96.33% and accuracy of 93.61%. These results have similarities with the results achieved by experiments using PCA only. This can be indicated that the addition of normalization techniques to combined experiments between PCA and Normalization tends to have an impact in the form of decreasing the achievement of model performance values.

Furthermore, Table III displays the result of the PCA technique where a trial iteration is carried out with a 10% reduction in the number of components. It shows a change in the model performance value. As shown in Table III, the drastic reduction of each performance parameter starts from 50% of the components used or half of the total number of features.

This can happen because changes in the number of features or components affect the pattern analysis results from the classifier. The lower the number of PCA components used, the lower the model's accuracy, sensitivity and specificity performance. In the graphic, it can be seen in Fig. 3, 4, and 5.

TABLE III. THE IMPACT OF THE REDUCTION OF PCA FEATURES ON MODEL PERFORMANCE

Component Percentage (%)	Number of Features	PCA			PCA + Normalization		
		Sensitivity (%)	Specificity (%)	Accuracy (%)	Sensitivity (%)	Specificity (%)	Accuracy (%)
100%	193	<b>73.80</b>	<b>96.34</b>	<b>93.61</b>	73.00	96.33	93.61
90%	174	73.24	96.24	93.49	72.07	96.12	93.27
80%	155	72.44	96.10	93.21	73.12	96.24	93.46
70%	136	70.64	96.04	93.15	72.34	96.19	93.40
60%	116	71.32	95.98	93.02	70.45	95.91	92.90
50%	97	69.36	95.75	92.59	67.52	95.58	92.31
40%	78	67.24	95.47	92.16	67.71	95.51	92.22
30%	58	66.34	95.30	91.85	61.62	94.69	90.77
20%	39	58.21	94.30	90.09	58.08	94.20	89.97
10%	20	52.42	93.50	88.67	49.39	92.97	87.72

Fig. 3, 4, and 5 respectively explain the decrease in Accuracy (Fig. 3), Sensitivity (Fig. 4) and Specificity (Fig. 5) performance when using PCA or combined PCA + Normalization at each stage of the performance test with a feature reduction of 10% for each stage.

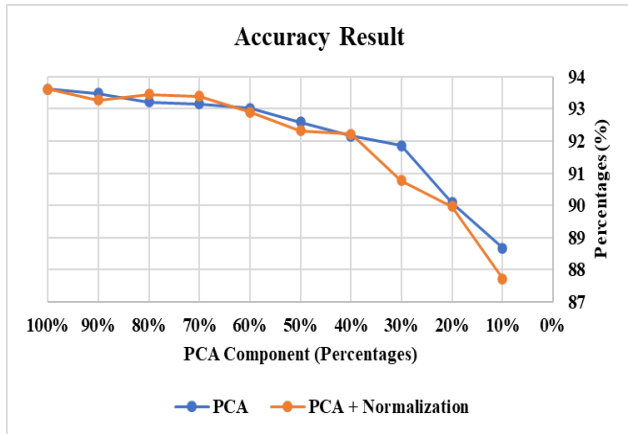


Fig. 3. Accuracy performance.

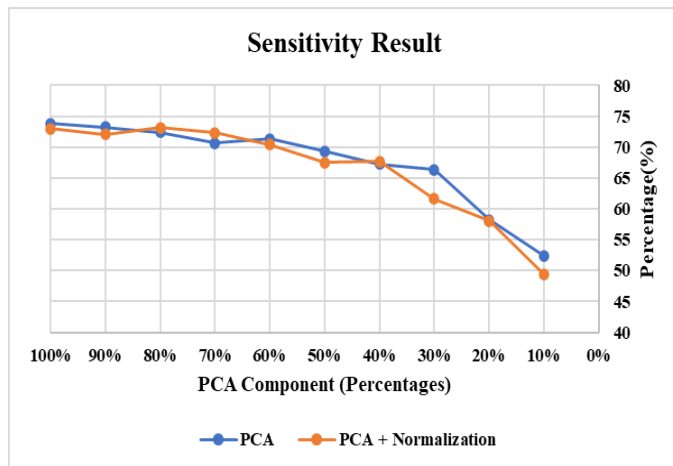


Fig. 4. Sensitivity performance.

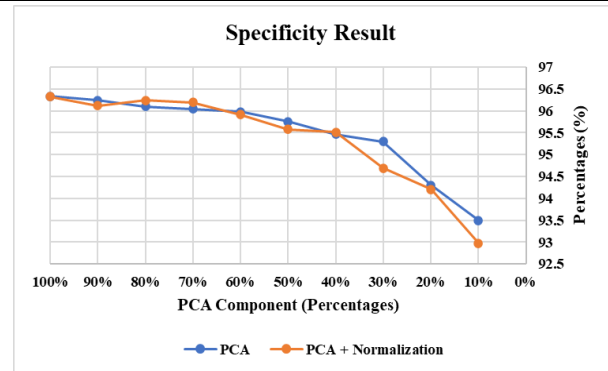


Fig. 5. Specificity performance.

Overall, it was found that high-performance results were obtained with experiments implementing PCA only. Table IV shows a detailed description of the achievement of performance parameter values for each type of emotion in the experiment.

In Table IV, it can be seen that several types of emotions have an accuracy value above 94%, including happy, sad, fearful, and surprised. While the types of disgust and anger emotions obtained an accuracy value of 93.70% and 92.96%, respectively, followed by neutral and calm emotions with an accuracy value of 91.60%. The accuracy value is an indicator that shows how the model performs in predicting a data class correctly. The evaluation results show several differences in the accuracy value in each class. This can occur due to differences in the amount of data distribution according to each class [30].

Furthermore, the specificity parameter is a parameter that indicates the classifier's ability to predict a negative class among all data with a negative class. From the results of the specificity test, the proposed model is capable of producing performance above 95% with an average performance of 96.34%, so it can be said that the proposed model is capable of producing high specificity values.

TABLE IV. THE PERFORMANCE RESULT OF EACH EMOTION CLASS

Class	TP	TN	FP	FN	Sensitivity	Specificity	Accuracy
Neutral	89	653	26	42	67.94%	96.17%	91.60%
Calm	91	651	34	34	72.80%	95.04%	91.60%
Happy	48	718	24	20	70.59%	96.77%	94.57%
Sad	45	722	29	14	76.27%	96.14%	94.69%
Angry	88	665	27	30	74.58%	96.10%	92.96%
Fearful	110	657	21	22	83.33%	96.90%	94.69%
Disgust	92	667	27	24	79.31%	96.11%	93.70%
Surprised	40	730	19	21	65.57%	97.46%	95.06%
<b>Average</b>					<b>73.80%</b>	<b>96.34%</b>	<b>93.61%</b>

Then the sensitivity value is a parameter that shows the model's ability to predict the positive class correctly among all data that is in the positive category. The test results show that the sensitivity value for the type of fearful emotion has a value above 83%, indicating that the proposed model can identify test data with the type of fearful emotion well. Meanwhile, other types of emotions such as neutral, calm, happy, sad, angry, and surprised, can produce a sensitivity value of less or a little bit more than 70%, with an average value for all emotion classes of 73.80%. These results indicate that the RAVDESS dataset has a fairly high level of bias between classes. This can occur because the expression of several types of emotions tends to differ between actors [10].

TABLE V. THE PERFORMANCE RESULT OF EACH EMOTION CLASS

No.	Work	Dataset	Feature	Classifier	Accuracy Result
1	Chowdary and Hemanth [8]	RAVDESS	Mel Frequency Cepstral Coefficients (MFCC)	CNN	92%
2	Jothimani and Premalatha [16]	RAVDESS, CREMA, SAVEE, and TESS	Mel Frequency Cepstral Coefficients (MFCC), Zero Crossing Rate (ZCR), and Root Mean Square (RMS)	CNN+LSTM	92.60%
3	Alnuaim et al [31]	RAVDESS	Mel Frequency Cepstral Coefficients (MFCC), Short-time Fourier transform and Mel Spectrogram	MLP classifier	81%
4	Patnaik [32]	RAVDESS and TESS	Complex Mel Frequency Cepstral Coefficients (c-MFCC)	deep sequential LSTM model	91.60%
5	Proposed Method	RAVDESS	Mel Frequency Cepstral Coefficients (MFCC), Chroma, Mel Spectrogram, Contrast, Tonnetz	Principal Component Analysis (PCA) Deep Neural Network (DNN)	93.61%

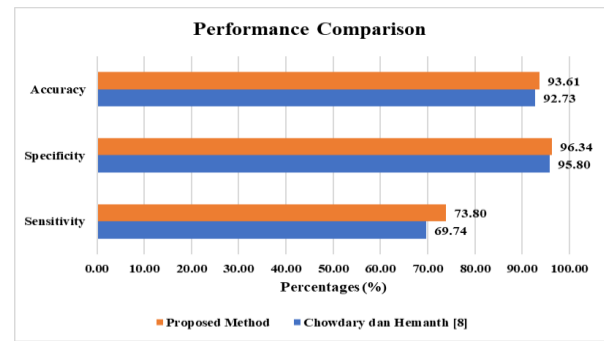


Fig. 6. Comparison of performance results with previous study.

Overall, the performance evaluation results of the proposed DNN model were able to produce the average values of accuracy, sensitivity and specificity of 93.61%, 73.80% and 96.34%, respectively, it can be seen in Fig. 6. These results were able to outperform the results of previous studies put forward by Chowdary and Hemanth [8], where this study also used RAVDESS dataset with MFCC feature extraction and CNN classifier. Comparison of performance results can be seen in Table V.

Based on Table V, the table compares the accuracy value of the proposed method with several previous studies. The comparison of the accuracy values used is the result using the RAVDESS dataset only. From Fig. 7, it can be seen that the proposed method is able to outperform the performance of previous studies. The use of multi-features in the proposed method can improve the performance of the model's accuracy in determining the type of emotion based on the RAVDESS dataset. In addition, the use of the PCA method also provides an increase in pattern correlation between features so that the classifier model can show performance improvements, especially accuracy, specificity, and sensitivity values.



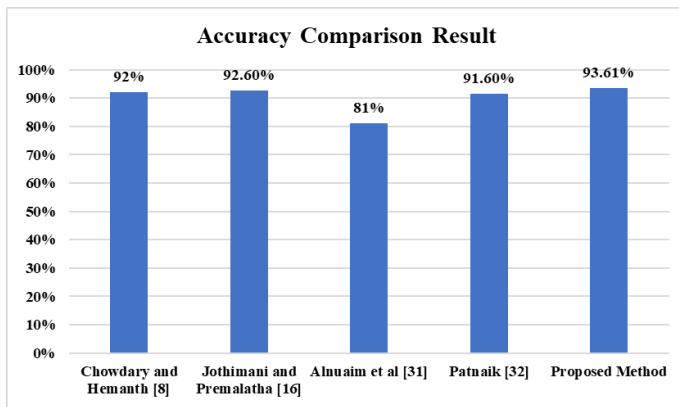


Fig. 7. Accuracy comparison between proposed method with previous studies.

## V. CONCLUSION

Speech Emotion Recognition (SER) based on multi-feature extraction and Deep Neural Network (DNN) has been carried out. A total of 2452 audio data in .wav format taken from the RAVDESS database were used in this study. The data is extracted to produce several features, including Mel Frequency Cepstral Coefficients (MFCC), Chroma, Mel-Spectrogram, Contrast, and Tonnetz. From the extraction process, 193 main features were obtained. This study examines the impact of applying Principal Component Analysis (PCA) and Min-Max Normalization to the performance of the classifier model used. The DNN model is used in this study to determine emotions such as calm, happy, sad, angry, neutral, fearful, surprised, and disgusted. The test results for the DNN model with 200 epochs were able to obtain the accuracy of 93.61%, sensitivity of 73.80%, and specificity of 96.34%. The use of multiple features in the proposed method can improve the model's accuracy in determining the type of emotion based on the RAVDESS dataset. In addition, using the PCA method also provides an increase in pattern correlation among features so that the classifier model can show performance improvements, especially accuracy, specificity, and sensitivity. Moreover, the scheme that uses the PCA technique in which experimental iterations are carried out by reducing the number of components by 10% shows a change in the value of the model's performance, especially when the model uses features less than 50% of all components. The lower the number of PCA components used, the lower the performance of the model. The implementation of multiple features in this study can open opportunities for using other features related to certain types of emotions. Furthermore, the use of other dataset and classifiers can also provide a new approach in the development of this research in the future.

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# Hierarchical Convolutional Neural Networks using CCP-3 Block Architecture for Apparel Image Classification

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**Abstract**—In fashion applications, deep learning has been applied automatically to recognize and classify the apparel images under the massive visual data, emerged on social networks. To classify the apparel correctly and quickly is challenging due to a variety of apparel features and complexity of the classification. Recently, the hierarchical convolutional neural networks (H-CNN) with the VGGNet architecture was proposed to classify the fashion-MNIST datasets. However, the VGGNet (many layers) required many filters (in the convolution layer) and many neurons (in the fully connected layer), leading to computational complexity and long training-time. Therefore, this paper proposes to classify the apparel images by the H-CNN in cooperated with the new shallow-layer CCP-3-Block architecture, where each building block consists of two convolutional layers (CC) and one pooling layer (P). In the CCP-3-Block, the number of layers can be reduced (in the network), the number of filters (in the convolution layer), and the number of neurons (in the fully connected layer), while adding a new connection between the convolution layer and the pooling layer plus a batch-normalization technique before passing the activation so that networks can learn independently and train quickly. Moreover, dropout techniques were utilized in the feature mapping and fully connected to reduce overfitting, and the optimizer adaptive moment estimation was utilized to solve the decaying of gradients, which can improve the network-performance. The experimental results showed that the improved H-CNN model with our CCP-3-Block outperformed the recent H-CNN model with the VGGNet in terms of decreased loss, increased accuracy, and faster training.

**Keywords**—Convolutional neural networks (CNN), hierarchical CNN (H-CNN), CCP-3 block (two convolutional layers (CC) and one pooling layer (P) per block), apparel image classification, fashion applications

## I. INTRODUCTION

In the Big-data era, social media platforms generate a tremendous volume of image data. There have been initiatives to utilize the valuable image data in a variety of industries, including the business and medical sectors. Due to a vast amount of accessible image data for training and the state-of-the-art technology that provides superior processing capability via the GPU, the unstructured visual data can now be implemented in statistical and data mining applications. Under the GPU technology, it is really simple and fast to analyze the image data. In a previous study, the image data were analyzed using traditional machine learning and image processing

techniques [1]. However, typical machine learning and image processing approaches are still limited in their processing capabilities when working with large image data. To overcome the processing restrictions associated with big picture data analysis, deep learning techniques such as Deep Neural Networks (DNN) are applied in the form of Convolutional Neural Networks (CNN) [2]. Currently, a deep learning model, when applied to the image data, provides a CNN architecture that performs well in classifying the image data.

Because apparel products in fashion applications are diverse and difficult to describe, the automatic CNN is frequently used to classify the apparel image data. A fashion-classification system uses a hierarchical structure that can be divided from the coarse to fine hierarchies. Each item in the fine hierarchy can be defined as a higher-level item, such as a t-shirt pullover and a shirt. These three different types of shirts are classified separately but can be combined in the same coarse layered Tops category because of their similarity. However, the classification of features for each hierarchy of items lacks the specific classification criteria and instead is classified based on similar features [3, 4]. As a result, the better categorizing the apparel products by using the CNN architecture is challenging. Applying the efficient CNN method of image classification, which has the advantage of assisting in filtering, categorizing, and product inspection, helps the apparel industry reduce the cost and time, while improving business efficiency [3, 5]. While CNN approaches are popular to the categorization of apparel image data, their tradeoff results (in terms of accuracy and speed) have been questioned. Therefore, many attempts have been made to develop more efficient strategies for optimizing the CNN models for the apparel classification. To improve the classification accuracy [6], a hierarchical classification strategy was used to classify the apparel image.

Recently, the fashion images were classified by using a hierarchical classification system [7]. In a hierarchical structure of fashion types, the Hierarchical Convolutional Neural Networks (H-CNN) was proposed and focused on the VGGNet architecture. The H-CNN was applied to the "Fashion-MNIST" dataset, an improved public image dataset for direct analysis. It is a 28 x 28 grayscale image of 10 classes comprised of 60,000 training photos and 10,000 test images, separated into 3 levels of coarseness: coarse 1, coarse 2, and fine. However, the existing H-CNN and the VGGNet were computed sequentially in deep architectures, where the VGGNet (many layers)

required many filters (in the convolution layer) and many neurons (in the fully connected layer), leading to computational complexity and long training-time. On the other hand, the H-CNN has not yet been implemented to improve the performance in shallow architectures.

Therefore, this study proposes to use the H-CNN in conjunction with our new CCP-3 block architecture, a minimalistic size founded on the concept of a shallow architecture (instead of a deep architecture) to achieve the better performance for not only the accuracy but also the computing time. Based on the popular models from the LeNet and AlexNet designs, the new CCP-3 block was introduced by reducing the number of layers in the network, the number of filters in the convolution layer, and the number of neurons in the fully connected layer, along with a new connection between the convolution layer and the pooling layer. In addition, a batch normalization technique was employed before passing the activation function so that networks can learn independently and train quickly. Moreover, dropout techniques were utilized in the feature map and fully connected to reduce overfitting, and the optimizer adaptive moment estimation was utilized to solve the decaying of gradients. In this study, the hypothesis is that “the integration of selected appropriate architectures in the H-CNN can improve the network performance”. In the performance evaluation, The CCP-3 Block architecture has been implemented in the H-CNN model to observe the improvement of the classification accuracy for the apparel image data and observe the speedup of the training time (on the GPU machine) in an experiment. Performance results showed that the CCP-3 Block architecture in the H-CNN model decreases training time significantly and improves the classification accuracy for apparel picture data over the recent VGGNet architecture in the existing H-CNN.

In summary, the main contributions of this study are as follows:

- This study proposes a novel CCP-3 Block architecture to optimize the H-CNN model for the efficient classification of the apparel images.
- This study compares the performance of the H-CNN models based on the existing VGGNet architecture and new CCP- 3Block architecture.

The remainder sections of this paper are organized as follows. Section II summarizes the CNN architectures and the related works. Section III presents the proposed CCP-3 Block architecture. Section IV illustrates the experiment on the fashion-MINIST dataset. Section V presents the experimental results and Section VI discusses the conclusion of this study and the future study.

## II. RELATED WORKS

In this section, an overview of the convolutional neural networks (CNN), the modern CNN architectures, and the optimization techniques of CNN are reviewed and a related work, called the hierarchical CNN (H-CNN) using VGG16 and VGG19 architectures, was presented to classify the apparel images.

### A. Convolutional Neural Network (CNN)

A convolutional neural network (CNN) is a neural network model of the human-vision emulation that perceives a space as sub-sectors and integrates the sub-sectors together to identify “what is visible”. Human perceptions of sub-areas are shaped by sub-area features, such as lines and color contrasts. Humans recognize that “the focused area is defined by a straight line or a contrasting color” because they combine both of the interested area and the surrounding area concurrently [8, 9]. The construction of CNN is divided into two main components [10-12]: 1. the first one is the feature extraction layer (for extracting features) and 2. the subsequent section is the classification layer (to educate and classify), which will ensure that the connection layer is fully connected. In the feature extraction layer, there are three sub-layers: Convolution Layer, ReLU (Rectified Linear Units) Layer, and Pooling Layer. In the classification layer, there is only one fully connected layer, which resembles a node in the neural network. Each of those layers has the particular and different functions.

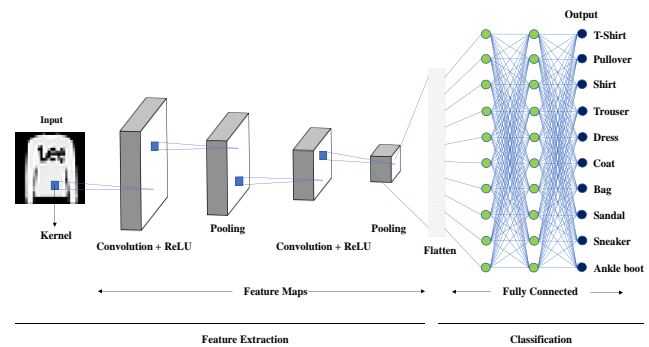


Fig. 1. Structure of CNN.

Fig. 1 describes the standard structure of the CNN, which consists of the following layers:

1) *Input layer*: Read the input data of the image and pass it to the neural network.

2) *Convolutional layer*: Create a sliding window (filter or kernel) that scans the input image to make a feature map. Initially, it scans the image to extract image elements such as borders, colors, and shapes, where the working principle starts with the convolution of the existing input image with the kernel and shifting it to the position of the next kernel. By scrolling the kernel position, the scroll distance can be adjusted. Repeat the same process, until all points of the input image are concerned. The convolution using the formula given below.

$$S_{ij} = (I * k)_{ij} \quad (1)$$

$$(I * k)_{ij} = \sum_{a=0}^{m-1} \sum_{b=0}^{n-1} I_{i+a,j+b} k_{a,b} \quad (2)$$

$S$  refers to the result of convolution at any position.  $I$  refers to image input.  $k$  refers to kernel.  $i, j$  refers to any position.  $m, n$  refers to the number of rows and columns.

3) *Rectified linear unit (ReLU)*: Perform a nonlinear activation function. The function given below

$$f(x) = \max(0, x) \quad (3)$$

4) *Pooling layer*: After the Convolutional layer(s) in the structure of a CNN, a Pooling layer is inserted. It calculates the maximum or average of the input and reduces the output of the Convolutional layers by sliding the filter with a specific shape and stride size.

5) *Fully connected layer*: Configure the output and display in the form of a multiclass logistic classifier.

6) *Output Layer*: Display the results of the classification. However, CNNs can have different layer elements in different architectures because each CNN consists of a layer convolutional for creating feature maps and pooling for the dimensionality of feature maps. By stacking these layers [7], we can formulate various CNN architectures.

### B. Architectures of Convolutional Neural Networks

1) *LeNet architecture*: The study to optimize the CNN model with a very well-structured architecture is another possibility to increase the performance of the CNN model. LeCun et al., [13] developed LeNet-5 in 1998, a network based on the CNN concept. In the convolutional layer, there are seven classification levels for numbers. Numerous banks employ it to identify the handwritten digits on digital checks using a 32x32 pixel image. Increasing the processing capability of higher resolution images requires a larger neural network layer and many layers. The LeNet-5 architecture is composed of two convolutional layers, two pooling layers, and three fully connected layers.

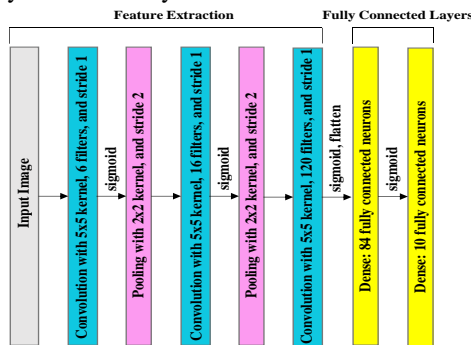


Fig. 2. Architecture of LeNet-5.

Fig. 2 describes the structure of LeNet-5 architecture. There are three convolution layers within the architecture, with two pooling and two fully connected. In each of the three convolution layers, the kernel size is 5x5 and the number of strides is 1. The distinction lies in the number of filters, with the first layer, second, and third having 6, 16, and 120 filters, accordingly. In the pooling layer, the kernel size is 2x2 and the number of strides is 2, which is identical to both layers. In a fully connected layer, the number of neurons in the first is 84, whereas the number of neurons in the second is dependent on the number of outputs. Sigmoid will be used as the activation function.

2) *AlexNet architecture*: AlexNet is a neural network, developed in 2012 by Krizhevsky et al., [14] which was intended to classify 1.2 million high-resolution images with

dimensions of 224x224x3, with images classified into 22,000 different classes. AlexNet achieves a top-5 test error rate of 16.4% in the ImageNet LSVRC-2012 contest. The AlexNet architecture is composed of 5 convolutional layers, 3 pooling layers, and 3 fully connected layers. In addition, it uses Rectified Linear Unit (ReLU) for the nonlinearity function, which is faster than Hyperbolic Tangent (tanh) function.

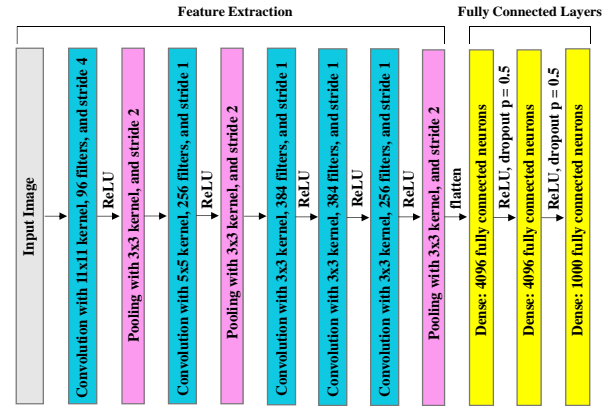


Fig. 3. Architecture of AlexNet.

Fig. 3 describes the structure of AlexNet architecture. There are five convolution layers in the architecture, with three pooling and three fully connected. The kernel sizes for the first and second convolution layers are 11x11 and 5x5, while the kernel sizes for the third, fourth, and fifth layers are all 3x3. In five convolution layers, there are 96, 256, 384, 384, and 256 filters, respectively, with the first layer the number of strides is 1, and in the remaining four layers, the strides are 4. In the pooling layer, the kernel size is 3x3 and the number of strides is 3, which is identical to all layers. In a fully connected layer, the number of neurons in the first and second is 4096, and the third is dependent on the number of outputs. However, in this architecture, the dropout rate is 0.5 and the activation function is used as ReLU.

3) *VGGNet architecture*: VGGNet was invented by the Visual Geometry Group as an architecture standard of deep convolutional neural network (deep CNN) with multiple layers. The most popular depth of the VGGNet architecture is VGG16 and VGG19 because the VGG16 and VGG19 architectures are the basis of ground-breaking object recognition models. The VGGNet architecture, developed as a deep neural network to surpass baselines on many tasks and datasets beyond ImageNet, consists of 16 and 19 layers of convolutional and fully connected layers. In competitive LSVRC-2014, the VGGNet won the 1<sup>st</sup> runner-up with less than 10% error rate and deeper layers containing 16 convolutional and fully connected layers. It uses 3 × 3 sized filters, a stride of 1 and 2 × 2 sized pooling, and a stride of 2 from the beginning to the end of the network. It also uses ReLU for nonlinearity function and is trained by batch stochastic gradient descent [15]. The structures of the VGG16 and VGG19 architectures are shown in Fig. 4 and Fig. 5.



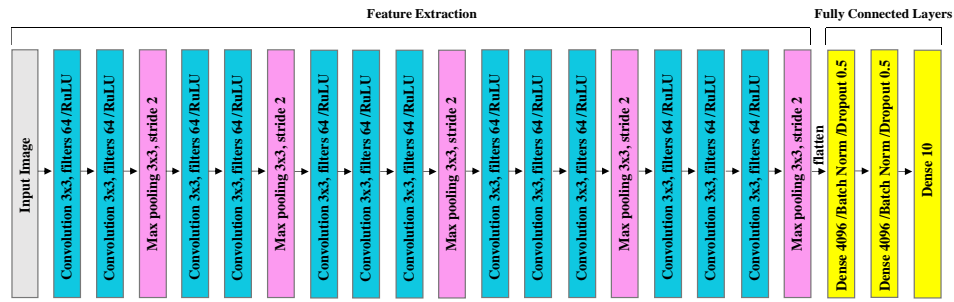


Fig. 4. Architecture of VGG16.

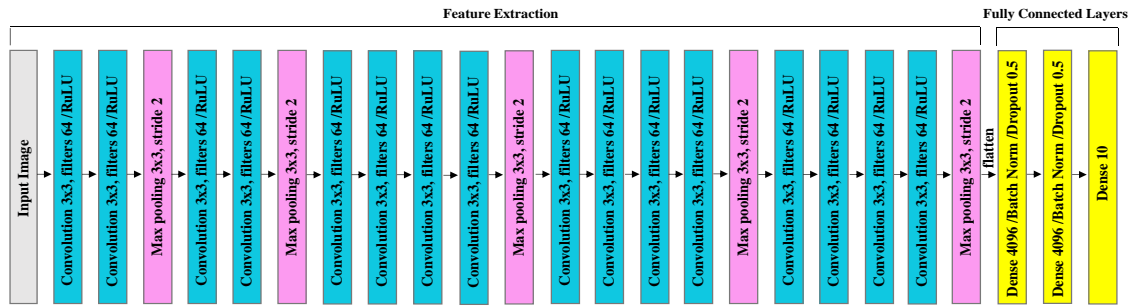


Fig. 5. Architecture of VGG19.

The number 16 and 19 in the name VGG (Visual Geometry Group) refer to the depth of 16 and 19 layers in the deep CNN. This means that VGG16 and VGG19 are extensive networks, where each of them has a total of around 138 million parameters. While VGGNet is popular in the modern standard, it is a huge network. However, the simplicity of the VGGNet architecture makes this network being more appealing. For example, there are a few convolution layers followed by a pooling layer that reduces the height as well as the width. When considering the number of filters, 64 filters are available and can be double to 128 filters and 256 filters. Finally in the last layer, we can use 512 filters.

In summary, the major differences of three architectures (LeNet, AlexNet, VGGNet) are focused on the architecture size and the activation function. In the initial periods of CNNs, the CNN architecture was a small structure with limited computational resources. Later, the larger CNN architectures have been constructed in response to the development of computational resources to be able to support the larger architecture designs. However, in this era the development of many CNN designs aims to decrease loss and increase accuracy, while being able to train models in fast or efficient time.

### C. Guide to Improving CNN

1) *Optimizer*: Optimizers can be explained as a mathematical function to modify the weights of the network, according to the gradients and additional information, which depend on the formulation of the optimizer. The optimizers are built upon the idea of gradient descent, the greedy approach of iteratively decreasing the loss function by following the gradient. However, different optimizers will affect the model sensitivity and learning accuracy [16-19]. As

a result, it is essential to use an appropriate optimizer for data and developed models.

2) *Regularization*: Regularization is the process of learning from the training datasets and modifying the model to be more efficient at predicting and reducing loss from the unseen data. The regularization is used to solve the issues of underfitting or overfitting. To address the underfitting problem of the neural network model, usually the number of layers and nodes in each layer can be increased but this can cause the overfitting [20-22]. Therefore, the regularization is a frequently mentioned solution, which is very simple to be implemented. The regularization technique consists of augmentation, batch normalization, and dropout, where their functions are defined as follows:

a) *Augmentation*: Augmentation is a technique to increasing the amount of data to train by generating the more data. In the case of image data, increasing a variety of images includes rotating images, zooming images, shifting images horizontally, shifting images vertically, and shear images.

b) *Batch normalization*: Batch Normalization is a technique for scaling the data to adjust their values to the specified limits before exporting from the node to the next layer input. For example, a feature engineering procedure converts the grayscale image from 0-255 to 0-1 by dividing the original color value by 255. For data normalization, several well-known methods can be utilized, such as min-max normalization or standardization.

c) *Dropout*: Dropout is an effective process of regularizing neural networks to avoid the overfitting. During training, the dropout layer cripples the neural network by removing the hidden units stochastically.



3) *Efficient shallow learning as an alternative to deep learning*: In 2022, Y. Meir et al. [23] discusses the realization of complex classification tasks using deep learning architectures with many convolutional and fully connected hidden layers. The authors demonstrate that with a fixed ratio between the depths of the first and second convolutional layers, the error rates of shallow architectures like the LeNet and VGG-16 can decay as a power law with the number of filters in the first convolutional layer. This phenomenon suggests a quantitative hierarchical time-space complexity among machine learning architectures and calls for further examination using various databases and architectures. The conservation law along the convolutional layers is found to minimize error rates. The study emphasizes the efficient shallow learning and its potential for implementation using dedicated hardware developments.

D. Hierarchical Classification

Hierarchical classification is a system of grouping things (or objects) according to a hierarchy, such as levels and orders. A hierarchical classifier classifies the input data according to the output categories, which are defined subsumptively. Classification begins at a basic level with the fine-detailed input data. The classifications of the separate bits of the image data are then integrated and elevated to a higher level iteratively until a single or defined output is obtained. This final output represents the overall result of the data classification.

In 2015, Yan et al. [24] proposed the first trial of hierarchical image classification using a deep learning approach. To resolve class confusion in the proposed model, Hierarchical Deep Convolutional Neural Networks (HD-CNN) employed an initial coarse classifier CNN to differentiate easily separable classes (or coarse classes) from fine classes. Additionally, the HD-CNN model could be implemented without increasing the training complexity. However, that model encountered some limitations, which were that it required two steps of training. The first step was to train the coarse and fine categories and the second step was to fine-tune the coarse and fine categories. Moreover, the HD-CNN model could not be used to classify many levels of hierarchy since it included one coarse category and one fine category only for an overall of two levels.

Later in 2017, the Branch Convolutional Neural Network (B-CNN) was proposed by Zhu and Bain [25] to solve the limitation of HD CNN.

Due to previous CNN research during 2015 - 2019, the hierarchical CNN study along with the particular application could improve the accuracy in the experiment. Therefore, implementing the hierarchical classification to optimize the CNN models to respect the diversity of datasets, applications, and CNN architectures is interesting.

In 2019, Seo and Shin [7] introduced the Hierarchical Convolutional Neural Networks (H-CNN) for the categorization of fashion images in the Fashion MNIST image data, where the fashion imagery obtained from Zalando is similar to the MNIST Dataset's handwritten numeric dataset, a refined fashion image.

That study employed the large-scale VGGNet neural networks as an experimental model. In performance evaluation (on the Fashion-MNIST dataset), accuracy results of the usage of H-CNN under the VGGNet architecture outperformed those of the simple VGGNet network.

In 2021, Q. Zhu et al. [26] discusses the use of drone imagery in automated inspection for surface defects in infrastructure. The proposed approach in the paper is a deep learning method that uses hierarchical convolutional neural networks with feature preservation (HCNNFP) and an intercontrast iterative thresholding algorithm for image binarization. The technique is applied to identify surface cracks on roads, bridges, or pavements, and is compared with existing methods on various datasets using evaluation criteria including the average F-measure. The proposed technique outperforms existing methods on various tested datasets, especially for the GAPS dataset, demonstrating the merits of the proposed HCNNFP architecture for surface defect inspection.

This study is interested in developing the H-CNN (Hierarchical CNN) under the more efficient architectures for the fashion applications (in Section III). Therefore, the previous study [7] is the main related work, see detail in Section II E.

E. Original Hierarchical Convolutional Neural Network (H-CNN) Model

With regards to the original H-CNN model under VGG16 and VGG19 architectures [7], both VGG16 and VGG19 are composed of five building blocks as shown in Fig. 6 and Fig. 7.

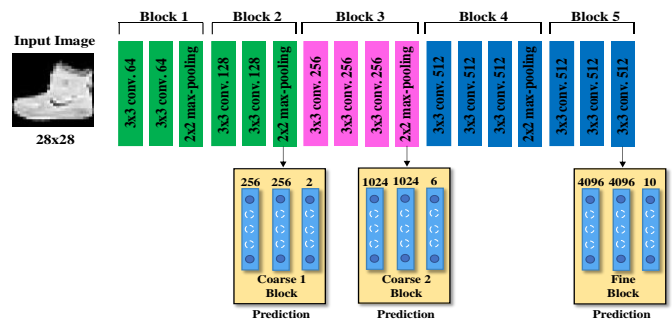


Fig. 6. Architecture of VGG16 H-CNN model.

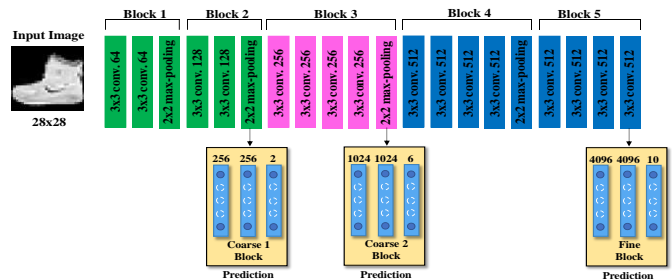


Fig. 7. Architecture of VGG19 H-CNN model.

In the VGG16 H-CNN model, the first and second building blocks consist of two convolutional layers and 1 pooling layer, the third and fourth blocks consist of 3 convolutional layers and 1 pooling layer, and the fifth building block has 3 convolutional layers.

In the VGG19 H-CNN model, the first and second building blocks have 2 convolutional layers and 1 pooling layer, the third and fourth blocks have 4 convolutional layers and 1 pooling layer, and the fifth building block consists of 4 convolutional layers.

The filter size and number of filters in the convolution layer are the same for both VGGNet architectures, with the filter size being 3x3 throughout the model. For the number of filters, they can be divided as follows: In the first block, there are 64 filters, the second block 128 filters, the third block 256 filters, and the fourth and fifth blocks 512 filters.

Moreover, these H-CNN models also use ReLU for activation function, batch normalization for initialization, and dropout for regularization. In the final block denoted as the fine prediction block, the softmax function is used to classify 10 fine classes.

However, this model has three additional blocks below followed by a prediction block. In each block, there are labels for 3 levels of classification, which makes it different from the basic model. The first block is for course-level, the second block is for course-level, and the last block is for fine-level. All three additional blocks are composed of fully connected neural networks. As the input image goes through the H-CNN model, three prediction values of coarse 1 level, coarse 2 level, and fine level will be computed in order. For example, when an input image of a sweater is inserted, the first coarse level block will indicate ‘clothes’, the second coarse level block will indicate ‘tops’, and the final block will indicate ‘pullover’ as output predictions.

### III. PROPOSED METHOD

Applying the convolutional neural network (CNN), especially the efficient deep learning, to fashion applications (to achieve not only the high accuracy but also the fast training) is challenging under the massive visual data emerged on the current social networks. Recently (2019), the hierarchical CNN (H-CNN) was proposed to classify the fashion-MNIST datasets with a capability of high accuracy. However, in that H-CNN the applied VGGNet (the deep architecture) is composed of many layers, many filters (in the convolution layer), and many neurons (in the fully connected layer), leading to computational complexity and long training-time.

According to the hypothesis (in the fashion classification) believe that the shallow architecture plus a few proper functions can yield good results as the deep architecture, while can take faster training-time to solve computational complexity problems. In benefit summary of existing architectures, the (deep) VGGNet architecture requires many layers, many filters, and many neurons with long training-time for high accuracy, while the (shallow) AlexNet architecture require less training time (with shallow layers) but less accuracy. Therefore, we focus on studying the novelty and strength of the architecture for the H-CNN model to decrease loss, increase accuracy, and fast training-time.

This study proposes to classify the apparel images with the H-CNN model using the new CCP-3 Block architecture to retain the accuracy as the VGGNet architecture within the less

training-time as the AlexNet architecture, where each building block consists of double convolutional layers (CC) and one pooling layer (P). As mentioned earlier, our proposed CCP-3 Block architecture was inspired by the fast LeNet and AlexNet microarchitectures (with shallow layers).

In Section III A, the new CCP-3 Block architecture is proposed first for classifying the apparel/fashion image. In Section III B, the H-CNN model using the CCP-3 Block architecture is presented for the completed classification. In Section 4, the experiment is conducted on the fashion-MNIST datasets to compare the performance of CCP-3 Block architecture. Finally, the experimental results are presented in Section V.

#### A. CCP-3 Block Architecture

The CCP-3 Block architecture is a shallow-layer architecture, see details in Fig. 8, which can reduce the number of layers (in the network), the number of filters (in the convolution layer), and the number of neurons (in the fully connected layer) of the deep-layer architecture, while adding a new connection between the convolution layer and the pooling layer.

The CCP-3 Block architecture has only three blocks shown in Fig. 9. Each building block consists of two convolutional layers and one pooling layer. The 3x3 sized filters with a stride of 1 are used in all convolutional layers. In the first building block, 64 filters are concatenated and in the second block, first convolution has 128 filters, second convolution has 256 filters and 512 filters in the third block. For the pooling layers, the 2x2 size max-pooling is done with a stride of 2. In a fully connected layer, there are 3 layers, where in the first and second layers we define the number of neurons as 1024 neurons, and in the last layer, we define 10 neurons into 10 classes using the softmax function.

Moreover, ReLU was used for the activation function, batch normalization for initialization, and dropout for regularization. In the structure of CCP-3 Block architecture, batch normalization will be implemented in order to ensure that for any parameter value after the convolution layer, the network always produces activations with the desired distribution. So, the batch normalization layer is inserted right after the convolution layer, but before feeding into ReLU activation [27]. To reduce overfitting, dropout was added into both building blocks and the fully connected layer. In the building block, dropout was defined between the convolution layer and after the pooling layer. The fully connected, dropout was defined after batch normalization layer. Throughout the architecture, we set the dropout value to 0.3.

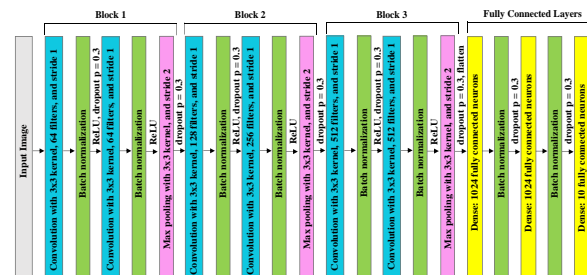


Fig. 8. Details of CCP-3 block architecture.

### B. H-CNN using CCP-3 Block Architecture

The H-CNN model was implemented in conjunction with CCP-3 Block architecture by adding additional blocks below each main block, followed by a prediction block, shown in Fig. 9. The additional blocks have the same functions and properties as those blocks in the original H-CNN. Each additional block contains labels indicating one of three classification levels. The first block is intended for course-level instruction, the second block is intended for course-level instruction, and the final block is intended for fine-level instruction. Each of these three blocks is composed entirely of fully connected neural networks. As the input image passes through the H-CNN model, three prediction values will be computed in order: coarse 1 level, coarse 2 levels, and fine level.

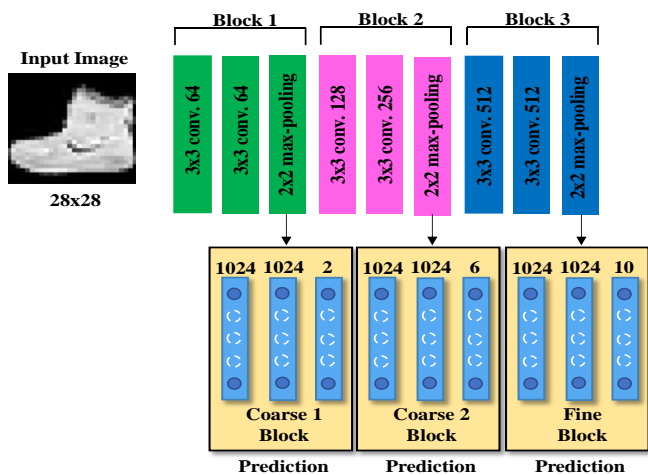


Fig. 9. Architecture of H-CNN CCP-3 block model.

## IV. EXPERIMENTS

To evaluate the performance of CCP-3 block architecture, the H-CNN model was implemented in incorporated with CCP-3 Block architecture. The experimental results were compared to those of the original H-CNN model using VGG16 and VGG19 architectures on the same environment. See the improved results in Section V in terms of increased accuracy and decreased computing-time.

### A. Environment Setup

This experiment implemented and operated the above 3-model programs on the google colaboratory. This programming environment investigated a GPU runtime (speed up execution), the GPU machine used in this operation is the Tesla P100-PCIe.

### B. Dataset

This paper uses Fashion MNIST image dataset (see Table I). This fashion image dataset is collected from Zalando, which is similar to the MNIST dataset handwritten digit classification. In this standard dataset, each grayscale image is a square size of  $28 \times 28$  pixels and all images are divided into 10 classes: t-shirt, trouser, pullover, dress, coat, sandal, shirt, sneaker, bag, and ankle boot. Each class contains an equal number of samples. The 60,000 samples are used for training and the 10,000 samples are used for testing. In the hierarchical

structure, these 10 classes can be restructured into two coarse classes and one fine class as shown in Fig. 10.

Each first-level coarse class consists of the second-level coarse classes and each second-level class consists of the fine-level classes. The first-level coarse class consists of 'clothes' and 'goods'. In the second-level coarse class, the 'clothes' contain 'tops', 'bottoms', 'dresses', and 'outers' as well as the 'goods' contain 'accessories' and 'shoes'. Below the second-level coarse classes, there are fine-level classes consisting of 't-shirt', 'pullover', and 'shirt' in 'tops', 'trouser' in 'bottoms', 'dress' in 'dresses', 'coat' in 'outers', 'bag' in 'accessories'; 'sandals', 'sneaker', and 'ankle boots' in 'shoes'. For hierarchical matching in the H-CNN models, the first-level coarse classes are represented by green, second-level classes are represented by pink, and fine-level classes are represented by blue [7]. Each color in Fig. 10 matches the original H-CNN models in Fig. 6 and Fig. 7 and the H-CNN using CCP-3 Block architecture in Fig. 9.

TABLE I. FASHION-MNIST DATASET

Label	Description	Example
0	T-Shirt/Top	
1	Trouser	
2	Pullover	
3	Dress	
4	Coat	
5	Sandals	
6	Shirt	
7	Sneaker	
8	Bag	
9	Ankle boots	

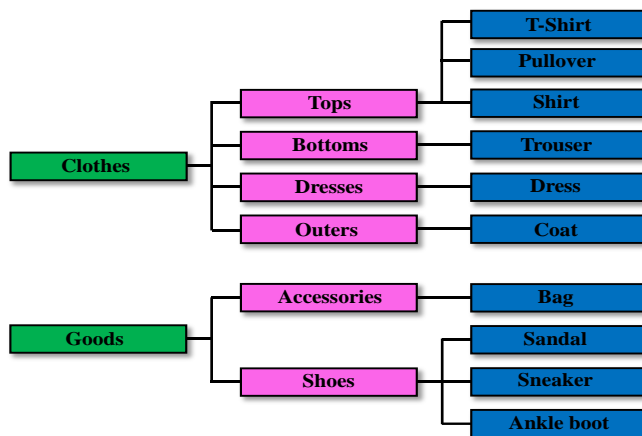


Fig. 10. Hierarchical classes of dataset of the original H-CNN.

### C. Parameter Setting

1) *Parameter setting of the original H-CNN using VGG16 and VGG19* [7, 16, 28, 29]: To train two original H-CNN models, the parameters were set as follows: A number of epochs were set to 60 times and the size of the batch was set to

128. There were variations in learning rate as 0.001 used in the initial stages, 0.0002 after the 42<sup>th</sup> epoch, and 0.00005 after the 52<sup>th</sup> epoch. Stochastic gradient descent was applied by using 0.9 of momentum. To reflect differences in the importance of each level of the class the loss weight values were added when training models. The changes in loss weights were set to [0.98, 0.01, 0.01] in the first epoch, [0.10, 0.80, 0.10] in the 15<sup>th</sup> epoch, [0.1, 0.2, 0.7] in the 25<sup>th</sup> epoch, [0, 0, 1] in the 35<sup>th</sup> epoch.

2) *Parameter setting of the H-CNN using CCP-3-Block:* In this study, we set similar parameters as the original H-CNN models, such as a number of epochs, learning rates, the changes in loss weights. However, the stochastic gradient descent is not used in the model because the architecture of the CCP-3 block is small. In addition, an appropriate optimizer was used to reduce overall losses and improve accuracy [30, 31]. Adaptive moment estimation is applied by using 0.9 of beta1, 0.999 of beta2, and 1e-07 of epsilon.

## V. RESULTS

In order to evaluate the performance of the H-CNN model using CCP-3 Block architecture, the performance was compared of the H-CNN CCP-3 Block model to the original H-CNN models using VGG16 and VGG19 architectures. Table II shows the results (the final loss, accuracy of the test, and the training time) of each model. The CCP-3 Block architecture has a loss of 0.2714, while the VGG16 and VGG19 architectures have the loss of 0.3781 and 0.3863. About the accuracy of 0.9490, while the others have the accuracy of 0.9352 and 0.9341. The CCP-3 Block model has the fastest training time of 18.21 minutes, while the others have 20.33 and 27.28 minutes (H-CNN CCP-3 Block is 10.32 percent faster than H-CNN VGG16 and 32.87 percent faster than H-CNN VGG19.). In comparison, the CCP-3 Block model has lower loss, greater accuracy, and less training time than the other two models.

Table III shows the test accuracy results (0.8970-0.9410) of previous researches (i.e., data mining methods and other CNN models), compared to the test accuracy (0.9490) of the CCP-3 Block architecture on the Fashion MNIST dataset. The existing CNN2 and CNN2 + BatchNorm + Skip models were presented by Bhatnagar, Ghosal, and Kolekar (2017), where the CNN model consisting of two convolutional and max-pooling layers (or CNN2), trained by batch normalization (or BatchNorm) with residual skip connections (or skip) to compare the results with those of Support Vector Classifier (SVC) and Evolutionary Deep Learning (EDEN). Later, the accuracy results were improved by the VGG16 and VGG19 based models. Finally, the accuracy result was improved by the CCP-3 Block based model and in this study the CCP-3 Block architecture could generate the best test accuracy when combined with the hierarchical CNN (H-CNN) model.

This study focused to improve the H-CNN model by using the CCP-3 Block architecture over the VGGNet architecture (VGG16 and VGG19). Overall, the loss and accuracy were compared (in training and testing) of each H-CNN model in Table IV. For testing set, the H-CNN using the CCP-3 Block

architecture (H-CNN CCP-3 Block) has lower loss (0.2714) than those (0.3781 and 0.3863) of VGG16 and VGG19 and higher accuracy (0.9490) than those (0.9352 and 0.9341) of VGG16 and VGG19. However, when looking at the training set, the H-CNN CCP-3 Block model had a loss of 0.0218 and an accuracy of 0.9920, while the original H-CNN (VGG16, VGG19) models have the better training results because in the H-CNN CCP-3 Block model we added the dropout to both of the building block and in the fully connected layer to solve the overfitting problem, leading to a reliable final-loss and a realistic accuracy (0.9920 < 1.0 (overfitting)) in the training but the better performance in the testing (on the unseen data) with the less final-loss and the higher accuracy.

TABLE II. THE COMPARISON OF FINAL LOSS, ACCURACY, AND TRAINING TIME OF THE EXISTING H-CNN MODELS (H-CNN VGG16, H-CNN VGG19) AND OUR H-CNN CCP-3 BLOCK MODEL

Model	Test		Training Time (minutes)
	Loss	Accuracy	
H-CNN VGG16	0.3781	0.9352	20.33
H-CNN VGG19	0.3863	0.9341	27.28
<b>H-CNN CCP-3-Block</b>	<b>0.2714</b>	<b>0.9490</b>	<b>18.21</b>

TABLE III. THE COMPARISON OF CLASSIFICATION RESULTS ON FASHION MNIST DATASET BY PREVIOUS AND OUR RESEARCHES

Model	Test accuracy
SVC	0.8970
EDEN	0.9060
CNN2	0.9117
CNN2 + Batch Norm + Skip	0.9254
VGG16 based model	0.9289
VGG19 based model	0.9290
<b>CCP-3 Block based model</b>	<b>0.9410</b>
<b>H-CNN CCP-3 Block model</b>	<b>0.9490</b>

TABLE IV. THE TRAIN AND TEST COMPARISON (IN FINAL LOSS AND ACCURACY) OF THE EXISTING H-CNN MODELS (VGG16 H-CNN, VGG19 H-CNN) AND OUR CCP-3 BLOCK H-CNN MODEL

	Train		Test	
	Loss	Accuracy	Loss	Accuracy
H-CNN VGG16	0.0002	1.0000	0.3781	0.9352
H-CNN VGG19	0.0004	1.0000	0.3863	0.9341
<b>H-CNN CCP-3-Block</b>	<b>0.0218</b>	<b>0.9920</b>	<b>0.2714</b>	<b>0.9490</b>

Moreover, observe that the H-CNN CCP-3 Block model could converge faster than the H-CNN VGG16 and VGG19 models, as shown in Fig. 11 (H-CNN VGG16), Fig. 13 (H-CNN VGG19), and Fig. 15 (H-CNN CCP-3 Block). The more epochs the less in loss until 60 epochs the losses were stable. Meanwhile, the accuracy value of our H-CNN CCP-3 Block model was greater and converged more quickly than the existing models, as shown in Fig. 12 (H-CNN VGG16), Fig. 14 (H-CNN VGG19), and Fig. 16 (H-CNN CCP-3 Block). In

particular, Table V shows the improved performance (a numbers of specific loss and accuracy values) in each epoch (from epoch 1 to epoch 60) of each model.

In summary, the H-CNN CCP-3 Block model can achieve the better performance than the H-CNN VGG16 and VGG19

models (Table II, Table IV, Table V) and other state-of-the-art models (Table III) to classify images in the Fashion-MNIST dataset based on deep learning architectures. The CCP-3

TABLE V. LOSS AND ACCURACY PER EPOCH OF THREE H-CNN MODELS (VGG16, VGG19, AND OUR CCP-3 BLOCK)

Epoch	H-CNN VGG16 Model				H-CNN VGG19 Model				H-CNN CCP-3-Block Model			
	Train		Test		Train		Test		Train		Test	
	Loss	Accuracy	Loss	Accuracy	Loss	Accuracy	Loss	Accuracy	Loss	Accuracy	Loss	Accuracy
1	2.4639	0.3160	1.0611	0.6521	2.8517	0.2341	1.2562	0.5871	0.6346	0.7744	0.6681	0.7867
5	0.7418	0.7664	0.5173	0.8187	0.7884	0.7494	0.5454	0.8048	0.2772	0.8963	0.2869	0.8949
10	0.5202	0.8335	0.4425	0.8560	0.5629	0.8204	0.4583	0.8445	0.2307	0.9137	0.3253	0.8861
15	0.4298	0.8609	0.4331	0.8630	0.4351	0.8601	0.4154	0.8646	0.1846	0.9311	0.2048	0.9283
20	0.3224	0.8936	0.2938	0.9005	0.3410	0.8875	0.3643	0.8803	0.1572	0.9417	0.1972	0.9315
25	0.1999	0.9315	0.2874	0.9095	0.1978	0.9312	0.2881	0.9049	0.1241	0.9532	0.2135	0.9279
30	0.1332	0.9533	0.2820	0.9142	0.1419	0.9504	0.2725	0.9198	0.0998	0.9625	0.2017	0.9374
35	0.0515	0.9823	0.3646	0.9138	0.0533	0.9811	0.3678	0.9097	0.0763	0.9716	0.2112	0.9370
40	0.0471	0.9837	0.3758	0.9147	0.0480	0.9834	0.3415	0.9201	0.0627	0.9770	0.2309	0.9410
45	0.0044	0.9988	0.3598	0.9313	0.0043	0.9988	0.3353	0.9304	0.0364	0.9865	0.2395	0.9473
50	0.0012	0.9998	0.3494	0.9328	0.0013	0.9997	0.3708	0.9325	0.0293	0.9895	0.2600	0.9459
55	0.0007	1.0000	0.3768	0.9348	0.0005	1.0000	0.3832	0.9338	0.0228	0.9918	0.2689	0.9495
60	0.0002	1.0000	0.3781	0.9352	0.0004	1.0000	0.3863	0.9342	0.0218	0.9920	0.2741	0.9490

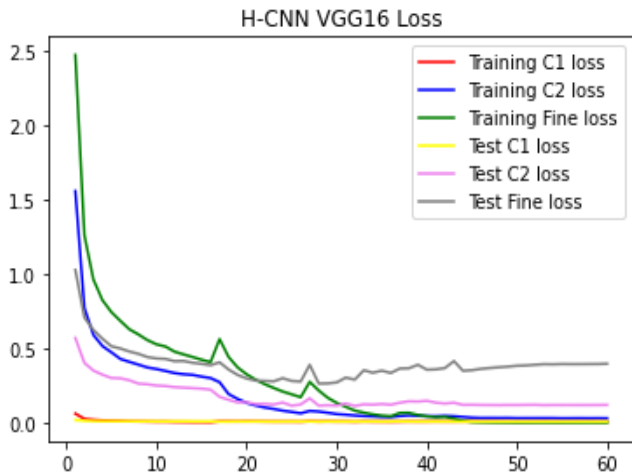


Fig. 11. Loss per epoch in H-CNN VGG16 model.

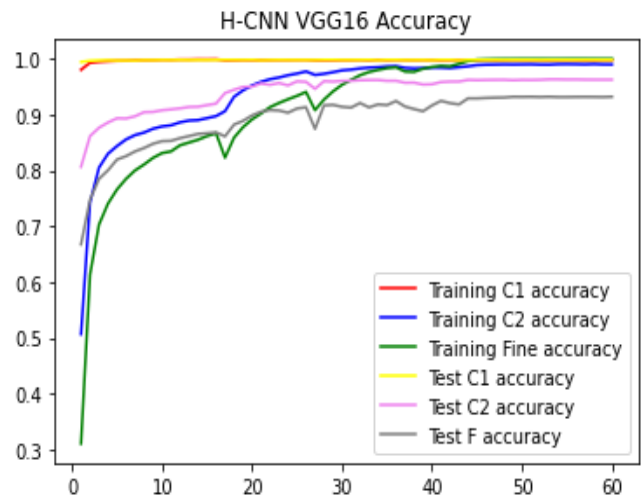


Fig. 12. Accuracy per epoch in H-CNN VGG16 model.



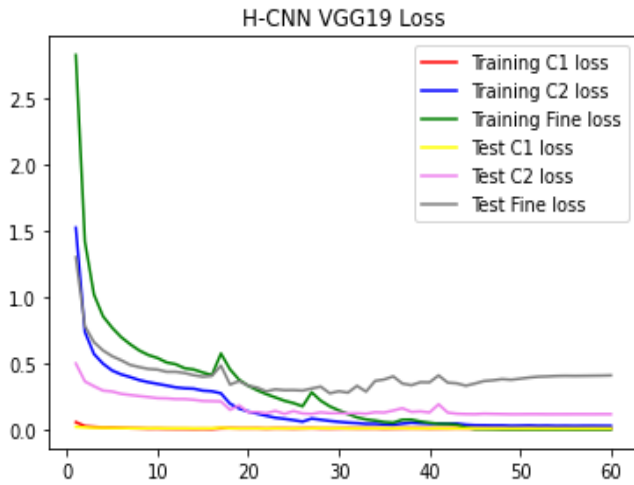


Fig. 13. Loss per epoch in H-CNN VGG19 model.

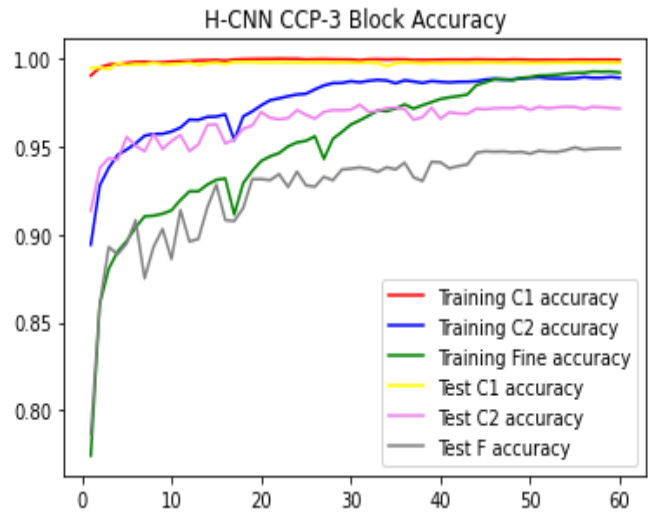


Fig. 16. Accuracy per epoch in H-CNN CCP-3 Block model.

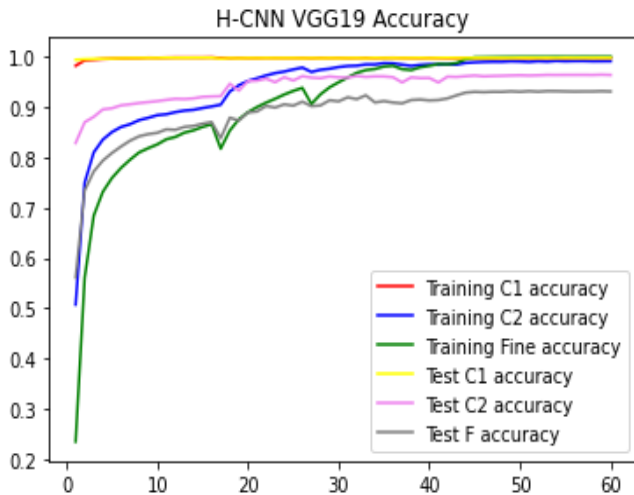


Fig. 14. Accuracy per epoch in H-CNN VGG19 model.

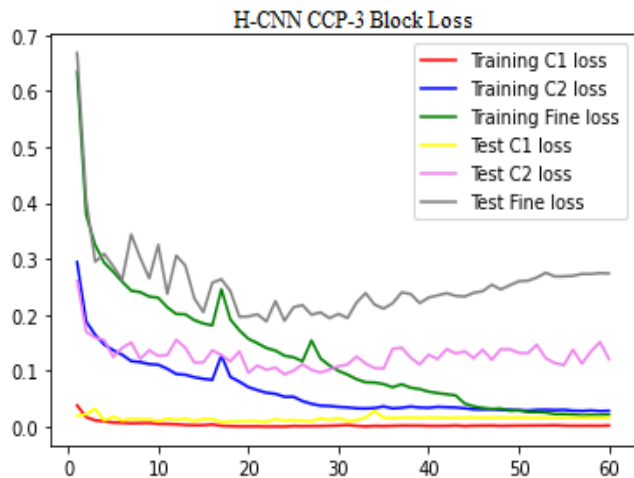


Fig. 15. Loss per epoch in H-CNN CCP-3 Block model.

Block design starts with a shallow-layered architecture (combine two convolution layers followed by a pooling layer) and redesign with only three blocks followed by the fully connected layers and add the batch normalization before the activation function so that networks can learn independently and train quickly as well as add the dropout layer in feature extraction and fully connected to reduce the overfitting. Moreover, an optimizer (adaptive moment estimation) was used to solve the decaying of gradients, which can improve the network performance. As a result, the H-CNN CCP-3 Block model has a faster training time and the better performance in testing (decreased loss and increased accuracy). For the image classification in the Fashion-MNIST dataset, the problem of multi-class classification error can be solved by the H-CNN CCP-3 Block model.

## VI. DISCUSSION

As presented in the test results section, the H-CNN model uses a shallow layered CCP-3 Block architecture, which provides the best performance in both training speed and classification accuracy. However, when considering the CCP-3 Block architecture used in the classification of apparel images, our design is simplified combine two convolution layers followed by a pooling layer, designed with only three blocks followed by fully connected layers, and adding batch normalization before the activation function. Moreover, adaptive moment estimation is also used to optimize the model (see detail in Section III A). We call this the CCP-3 block base model. Table V shows the test accuracy of the CCP-3 Block base model is 0.9410, which is more accurate than the H-CNN used VGG16 and VGG19 architectures but we perceive something in the table confusion matrix of the CCP-3 Block base model.

Table VI shows the confusion matrix of the CCP-3 block base model. In the case of the shirt category, misclassification samples of 88 T-shirt images, 43 pullover images, and 49 coat images reveal that these three categories locate closer among the 10 categories. The same is the case for the ankle boots category, with misclassification samples of 6 sandal images,



and 34 sneaker images; when these categories are similar. It is reasonable to categorize similar images into a hierarchy.

Observing Table VI, it is possible that the accuracy of the CCP-3 block base model could be increased further if the training images were hierarchically categorized. Therefore, we have applied the Seo and Shin [7] fashion image classification inference to categorize images into a hierarchy as shown in Fig. 10. It is used in conjunction with the CCP-3 Block architecture, which we have designed to support hierarchical classification (see detail in Section III B). The results showed that with the use of hierarchical image classification in combination with the CCP-3 block architecture, accuracy increased to 94.90%. (shown in Table III). When considered in the confusion matrix of the H-CNN CCP-3 Block model (shown in Table VII), in the case of the shirt category, the misclassification was reduced. T-shirt, pullover, and coat were previously misclassified from 88, 43, and 49 images reduced to 66, 33, and 40 images respectively. The same is the case for the ankle boots category, the misclassification is reduced as well. Sandal and sneaker were previously misclassified from 6 and

34 images and reduced to 4 and 26 images respectively. Therefore, categorizing similar images into a hierarchy for classification can increase their accuracy.

The CCP-3 Block base model, a simplified version of the H-CNN model, achieves high accuracy in apparel image classification. However, the model experiences misclassifications within visually similar categories such as shirts and ankle boots. To address this, we propose a hierarchical classification approach using the Seo and Shin fashion image classification inference. By combining this approach with the CCP-3 Block architecture, the model's accuracy improves significantly to 94.90%. The hierarchical classification effectively reduces misclassifications within similar categories, demonstrating the value of categorizing visually similar images into a hierarchy for improved accuracy. Additionally, pre-defining hierarchical labels of the dataset can also be done by the data-driven method before training the model we want. By considering the classification of the data based on the consideration of the result of the confusion metric.

TABLE VI. CONFUSION MATRIX OF CLASSIFICATION RESULT WITH FASHION MNIST DATASET USING CCP-3 BLOCK BASE MODEL

		Predict label									
		T-shirt	Trouser	Pullover	Dress	Coat	Sandal	Shirt	Sneaker	Bag	Ankle Boots
True label	T-shirt	<b>896</b>	2	15	10	3	1	69	0	4	0
	Trouser	2	991	2	4	0	0	1	0	0	0
	Pullover	15	1	<b>916</b>	5	44	0	19	0	0	0
	Dress	9	2	7	<b>954</b>	18	0	10	0	0	0
	Coat	0	0	13	19	<b>928</b>	0	40	0	0	0
	Sandal	0	0	0	0	0	<b>989</b>	0	7	0	4
	Shirt	88	0	43	22	49	0	<b>796</b>	0	2	0
	Sneaker	0	0	0	0	0	2	0	<b>989</b>	0	9
	Bag	2	1	1	2	2	1	0	0	<b>991</b>	0
	Ankle Boots	0	0	0	0	0	6	0	34	0	<b>960</b>

TABLE VII. CONFUSION MATRIX OF CLASSIFICATION RESULT WITH FASHION MNIST DATASET USING H-CNN CCP-3 BLOCK MODEL

		Predict label									
		T-shirt	Trouser	Pullover	Dress	Coat	Sandal	Shirt	Sneaker	Bag	Ankle Boots
True label	T-shirt	<b>898</b>	1	17	8	2	1	71	0	2	0
	Trouser	0	<b>990</b>	0	6	1	0	1	0	2	0
	Pullover	15	1	<b>937</b>	6	19	0	22	0	0	0
	Dress	7	4	8	<b>952</b>	12	0	17	0	0	0
	Coat	0	0	23	11	<b>931</b>	0	35	0	0	0
	Sandal	0	0	0	0	0	<b>991</b>	0	8	0	1
	Shirt	66	0	33	18	40	0	<b>840</b>	0	3	0
	Sneaker	0	0	0	0	0	1	0	<b>990</b>	0	9
	Bag	4	0	0	3	0	1	0	0	<b>992</b>	0
	Ankle Boots	0	0	0	0	0	4	0	26	0	<b>970</b>

## VII. CONCLUSION

CNN has been applied in a wide variety of fields as a powerful result of the development of deep learning techniques. In fashion application, CNN can support human tasks in image detection, apparel classification, apparel retrieval, and automatic apparel tagging, while the complexity of hierarchy and categories is a challenge in fashion classification. In the past, a hierarchical image classification process was considered in previous studies to improve the accuracy of the classification of apparel. Recently, a hierarchy was used in the Fashion-MNIST data which is  $28 \times 28$  sized grayscale images of 10 classes consisting of 60,000 training images and 10,000 test images, where the Hierarchical Convolutional Neural Network (H-CNN) was proposed in combination with VGGNet architectures (VGG16 and VGG19). Each of these deep VGGNet architectures consists of five building blocks of multiple convolutional, max-pooling, and fully connected layers. However, many filters (in the convolution layer) and many neurons (in the fully connected layer) of each VGGNet (for the Fashion-MNIST data) a required the long training-time.

This study focuses on designing a new efficient architecture for H-CNN to improve not only the accuracy of apparel classification but also the training time. Therefore, the CCP-3-Block architecture was proposed, a shallow-level architecture. A new design combines two convolution layers followed by a pooling layer, designed with only three blocks followed by fully connected layers, and adding batch normalization before the activation function so that networks can learn independently and train quickly, as well as adding the dropout layer in feature extraction and fully connected to reduce overfitting. Moreover, an optimizer (adaptive moment estimation) is added to solve the decaying of gradients, which can improve the overall network performance. In the experiment, the performance was compared of the H-CNN CCP-3-Block model and the original H-CNN VGGNet model (using VGG16 and VGG19 architectures). The results showed that the H-CNN CCP-3Block model performed the better performance with lower loss, higher accuracy, and faster training time than the original H-CNN (VGG16, VGG19) models. This result confirmed the hypothesis that the shallow layered CCP-3 Block architecture performs better performance than the deep VGGNet architectures in the hierarchical classification (H-CNN) of apparel images on the Fashion-MNIST dataset. Thus, for fashion business/applications, the H-CNN CCP-3-Block model can be applied on a variety of real online apparel images with the hierarchical classification.

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# Towards Point Cloud Classification Network Based on Multilayer Feature Fusion and Projected Images

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**Abstract**—Deep Learning (DL) based point cloud classification techniques now in use suffer from issues such as disregarding local feature extraction, missing connections between points, and failure to extract two-dimensional information features from point clouds. A point cloud classification network that utilizes multi-layer feature fusion and point cloud projection images is suggested to address the aforementioned problems and produce more accurate classification outcomes. Firstly, the network extracts local characteristics of point clouds through graph convolution to strengthen the connection between points. Then, the fusing attention mechanism is introduced to aggregate the useful characteristics of the point cloud while suppressing the useless characteristics, and the point cloud characteristics are fused by multi-layer characteristic fusion. Finally, a 3D point cloud network plug-in model based on point cloud projection image (3D CLIP) is proposed, which can make up for the defects of other 3D point cloud classification networks that do not extract two-dimensional information characteristics of point clouds, and solve the problem of low accuracy of similar category recognition in datasets. The ModelNet40 dataset was used for classification studies, and the results show that the point cloud classification network, without the addition of a 3D CLIP plug-in model, achieves a classification accuracy of 92.5%. The point cloud classification network with a 3D CLIP plug-in model achieved a classification accuracy of 93.6%, demonstrating that this technique can successfully raise point cloud classification accuracy.

**Keywords**—Point cloud; classification; graph convolution; attention mechanism; CLIP

## I. INTRODUCTION

As Artificial Intelligence (AI) has continued to advance, point cloud data has also evolved into a type of fundamental data [1-3]. To gather point cloud data and perform 3D reconstruction, the classification of point cloud data is crucial. As a result of the disorderly and irregular nature of data from point clouds, this poses a challenge to the task of point cloud classification.

Early Deep Learning (DL) based point cloud classification methods transform raw point cloud data into pictures or voxels before extracting point cloud characteristics using traditional classification networks. However, some of the point cloud information disappears during the point cloud transformation procedure, which lowers the network classification accuracy [4-6]. Researchers have presented point cloud classification methods using original point cloud data, which don't require

the transformation of the point cloud data, in response to the drawbacks of the point cloud classification methods. The extraction of local information characteristics from the point cloud is ignored by the present classification methods. Channel information and spatial information in the point cloud are not extracted. It is neglected how points relate to one another. The point cloud two-dimensional information is not taken into consideration. Aiming at the above problems, the primary contributions of this research paper are described below:

- A network GFANet based on fused attention mechanism and graph convolution is proposed for existing point cloud classification networks that do not extract point cloud features well. Using the ModelNet40 dataset, experimental findings demonstrate that the suggested network obtains 92.5% classification accuracy.
- A point cloud classification approach that utilizes a 2D point cloud projection image is proposed because current point cloud classification networks are not focused on the two-dimensional information of the point cloud. According to experimental findings, 3D CLIP can be plugged into a 3D point cloud classification network to increase the network classification accuracy.
- For the proposed two-point cloud classification network models, GFANet and 3D CLIP are combined to produce superior point cloud classification outcomes. On the ModelNet40 dataset, experimental findings show the point cloud classification method utilizing GFANet and 3D CLIP achieves 93.6% classification accuracy.

Based on the above, the focus of this research paper is on ways to improve the extract of the point cloud's local and global features as well as its two-dimensional information features in hopes of improving the accuracy of the point cloud classification network.

The paper is organized as follows: Section-II presents the related works for point cloud categorization. Section-III describes the proposed methodology of GFANet and 3D CLIP. Section-IV discusses the experimental results. Section-V concludes the overall research paper.

## II. RELATED WORKS

The point cloud is a collection of points that can be represented as a collection of three-dimensional points ( $x, y, z$ ). In addition to the information on each point location, point clouds also include details about its color, illumination level, category labels, normal vectors, grayscale values, and other characteristics. Applications for classifying point cloud data include automated driving [1], facial recognition [2], 3D reconstruction [3], and many more. The conventional point cloud categorization methods cannot be used directly on point clouds due to their irregularity and disorder.

Considering the disadvantages of conventional point cloud categorization techniques [7-9], deep learning techniques are now widely used in research to categorize point cloud data [10]. Early researchers transformed irregular 3D point cloud data into regular 3D grid data or images [11], [12] and then used 3D CNN for classification. Voxeling a point cloud primarily involves converting the point cloud data fed to the network into a grid, after which 3D CNN is used to extract features. The point cloud classification task is realized after obtaining global features through feature stitching. Other networks that convert point clouds into voxelated representations include FPNN [13], OctNet [14], and KD-NET [15]. The point cloud is projected onto a two-dimensional picture such as MVCNN [16], which projects 3D point cloud data from multiple perspectives to obtain two-dimensional images, uses a convolutional neural network to process and extract features, and then inputs the aggregated features into the convolutional neural network to realize point cloud classification. Other similar networks include GVCNN [17], SnapNet [18], and View-GCN [19].

The above two point cloud classification methods will lose some information during the conversion of point cloud data, resulting in a decline in classification accuracy. The point cloud classification method that utilizes original points may process the original point cloud directly, maximizing the retention of original point cloud data and significantly enhancing classification accuracy and algorithm performance compared to the other two point cloud classification methods mentioned above. Qi et al. suggested applying a model using deep learning on the PointNet [20] of the original point clouds, which performs well in both classifications [21] and segmentation tests [22] for point clouds. The network employs maximum pooling aggregate point features to ensure displacement invariance of point clouds and three-dimensional spatially transformed network STNs [23] to guarantee rotational consistency for point clouds. Although PointNet has several benefits, it simply extracts the point cloud global information properties. Based on the shortcomings of PointNet such as its inability to obtain local feature information and poor classification ability. Qi et al. then proposed an optimized network PointNet++ [24]. This network suggests a multi-level structure based on the PointNet for layer-by-layer extraction of local characteristics from a point cloud. However, PointNet++ also independently handles points in the point cloud, without paying attention to the connection between points. After that, researchers have also proposed some point cloud classification networks, such as ECC [25], DGCNN [26], LDGCNN [27],

and GAPNet [28], but the categorization accuracy of point clouds has not been significantly improved.

Although the categorization of the point cloud method based on original points solves the shortcomings brought by some characteristics of point clouds [29], there are still shortcomings such as insufficient feature extraction and lack of point cloud feature information. To efficiently extract both local as well as global characteristics of point clouds, enhance the network feature extraction capabilities, and make up for the lack of two-dimensional information in the point cloud include an extraction process, a point cloud classification network constructed using multi-layer feature fusion and projected images is presented in this paper.

## III. METHODOLOGY

There are two main components to the entire network, the network of one part is called GFANet, and the plug-in network of the other part is called 3D CLIP.

The GFANet, mainly includes the input transformation module, Graph Conv module, F-Attention module, and multi-layer feature fusion module. In the input transformation module, the input point cloud data is multiplied with a transformation matrix that the T-Net network has learned in order to ensure the consistency of the input point cloud data sequence and standardize the point cloud. In the Graph Conv module, its input is pointing to cloud features of  $N \times f$ ,  $N$ , and  $f$  represent the number and dimension of points respectively. The KNN algorithm is used to create a graph out of data from a point cloud. Then the graph of point cloud data is passed through  $n$  multilayer perceptions ( $\text{mlp} \{L_1, L_2, \dots, L_n\}$ ) to extract edge features. And finally, the  $N \times L_n$  dimension features are obtained. The spatial and channel information characteristics from the point cloud are extracted using F-Attention to improve the network's feature extraction capabilities. Obtain global and local features of point clouds using multi-layer feature fusion. Three completely connected layers were used to achieve the point cloud final classification outcome.

The existing 3D point cloud classification network mainly extracts 3D point cloud features and then performs classification tasks. The point cloud 2D information properties are not its primary concern, so some single categories with similar features cannot be classified well. The 2D information features can provide more object representations in the network classification task and improve the network classification accuracy. A point cloud categorization approach called 3D CLIP is proposed as a result of this issue and relies upon 3D point cloud projection images. The point cloud projection image features are extracted and categorized using a 2D image classification network to increase the 2D representations available for 3D point cloud classification tasks and boost network accuracy. The key components of 3D CLIP are the text encoder and the image encoder. The network mainly uses the trained text encoder and image encoder in 2D CLIP to obtain the text description features and the projected image features of the point cloud. In the text encoder, using text-transformer to obtain the point cloud's textual description features. In the image encoder, the point cloud projection image features are extracted using ResNet. Then the

correspondence between text features and image features is found from the pre-trained model. Finally, the final

classification results are obtained. The network is shown in Fig. 1.

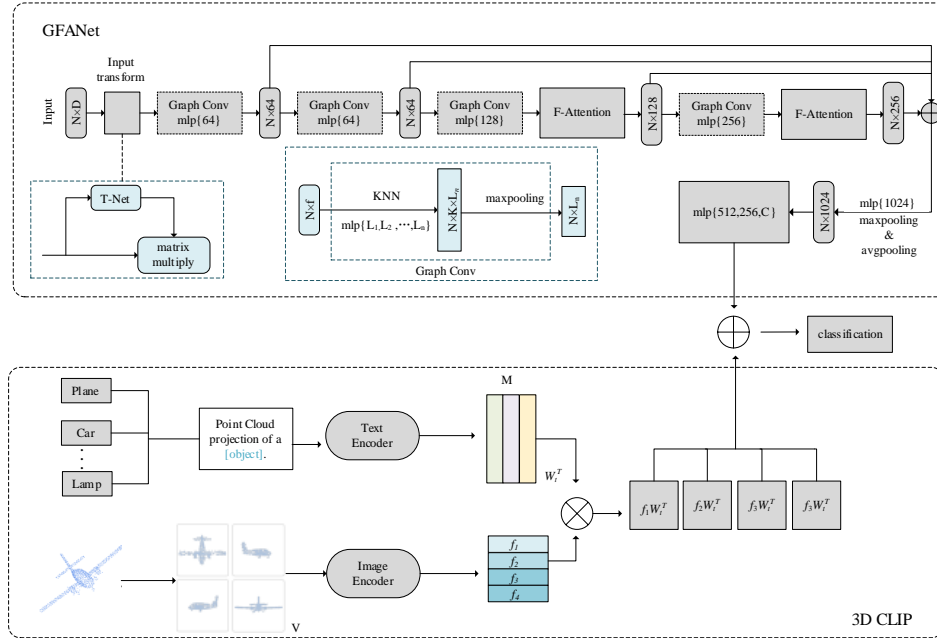


Fig. 1. GFANet and 3D CLIP structure.

### A. The GFANet

1) *Graph conv module*: There are two types of graph convolution: spatial domain convolutions of graphs [30] and spatially domain graphs convolution [26]. Additionally, the information properties of the area of the node can be better obtained using the spatial dimension of graphs convolution. Therefore, the spatial dimension of convolutions of graphs is used to build this model.

For GFANet, model inputs can be expressed as:

$$X = \{x_1, \dots, x_n\} \subseteq R^D \quad (1)$$

Where  $X$  is the point clouds collection,  $x_i$  is a point in the collection, and  $D$  is each point's distinctive dimension.

A directed graph with the formula  $G = (V, E)$  represents the point cloud local arrangement. where  $V$  represents a collection of  $N$  point locations and  $E$  represents the collection of edges connecting nodes.

The directional graph  $G$  for GFANet is built using the k-nearest-neighbor classification (KNN) technique. The central node of a point cloud and the  $K$  nearest neighbor points which include the central node can be calculated using the KNN algorithm.

In the Graph Conv module, local features of point clouds are extracted using the edge function and the aggregation process. As below:

$$h_\theta(x_i, x_j) = h_\theta(x_i) \quad (2)$$

Where  $x_i$  and  $x_j$  are the attributes of node  $i$  and its neighboring nodes  $j$ ,  $h_\theta$  is a linear product of parameter  $x$  that

can be learned, and  $\theta$  is the collection of weight and other parameters in the network.

However, point cloud global information is the sole focus of the edge function. The local information was ignored. In Formula 3, a new edge function is created that takes into account the point cloud local as well as global information.

$$h_\theta(x_i, x_j) = h_\theta(x_i, x_j - x_i) \quad (3)$$

For aggregation operation,  $x_i'$  is the collection of edge characteristics for the central node  $x_i$  at the  $k$  points about it.

$$x_i' = \sum_{j:(i,j) \in E} h_\theta(x_j - x_i) \quad (4)$$

In Fig. 2, to create a graph structure, the KNN method is utilized. And the Graph Conv module is used to learn aggregating edge characteristics from one set of point clouds to another [31].

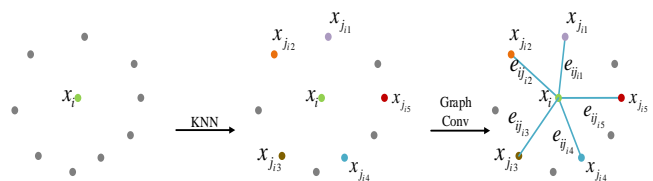


Fig. 2. Graph convolution process.

2) *F-attention module*: The attention mechanism [32] is divided into the space attention mechanism and the channel attention mechanism. In order to emphasize useful information features for classification tasks while suppressing useless information features, a new fusion attention mechanism was



designed, which incorporate the point cloud channel information characteristics with spatial information characteristics.

The structure of the new fusion attention mechanism (F-Attention) is shown in Fig. 3.

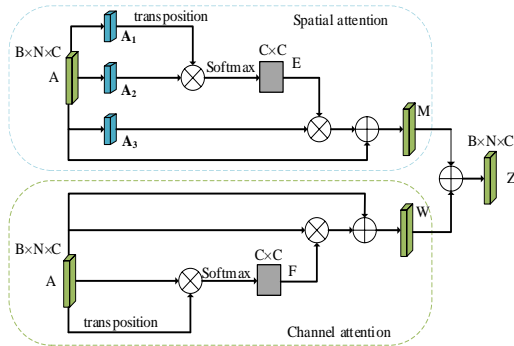


Fig. 3. Fusion attention module (F-Attention).

a) *Spatial attention module:* In Fig. 3, A is defined as the input point cloud feature matrix and  $B \times N \times C$  is the dimension of A in the Spatial attention module. The new feature matrices  $A_1$  and  $A_2$  can be obtained by linear transformation by A, which contains more spatial features. The two matrices have the dimensions  $B \times N \times C$ . Matrix  $A_1$  is transposed and multiplied with matrix  $A_2$ , and then the spatial attention coefficient matrix  $E (C \times C)$  is got using the SoftMax function, which is calculated as follows:

$$a_{ji} = \frac{\exp(A_{1i} \cdot A_{1j})}{\sum_{i=1}^N \exp(A_{1i} \cdot A_{1j})} \quad (5)$$

Where  $a_{ji}$  is the outcome of the SoftMax function calculation, which depicts the effect of the location  $i$  on  $j$  within matrices  $E$ .

$A_3$  is a new feature matrix, which is got by inputting A into the  $1 \times 1$  convolutional layer. The dimension of  $A_3$  is  $B \times N \times C$ . By multiplying matrices  $A_3$  and  $E$ , an outcome feature with a dimension of  $B \times N \times C$  is obtained. In order to adjust weights during training, the output feature is given a linear variable  $\lambda$ . As illustrated in Formula 6, the final output  $M$  of feature A is created by adding the elements of the characteristic matrix refreshed on the attention mechanism to those of the initial characteristic matrix A one by one.

$$M_j = \lambda \sum_{i=1}^N (a_{ji} A_{3i}) + A_j \quad (6)$$

To assign more weights by training the network,  $\lambda$  is initialized to 0. Both the initial point cloud characteristics and the location in space characteristics of the point cloud are included in the final feature  $M$ .  $M$  more effectively aggregates the information about the global context.

b) *Channel attention module:* The channel attention module input feature matrix is also defined as A. And the dimension of A is also  $B \times N \times C$ . The matrix A is first inverted.

After that, the original matrix is multiplied by the transposed matrix. The SoftMax function is then used to produce a channel attention factor matrix F having a size of  $C \times C$ .

As shown in Formula 7:

$$b_{ji} = \frac{\exp(A_i \cdot A_j)}{\sum_{i=1}^N \exp(A_i \cdot A_j)} \quad (7)$$

Where  $b_{ji}$  represents the impact of channel  $i$  on channel  $j$ .

The characteristic matrix A and the attention factor matrix F are multiplied to obtain a feature output with  $B \times N \times C$ . A parameter  $\chi$  is introduced to adjust the weights in the network training. The final result W of characteristic A is derived by adding the elements of the original characteristic matrix A and the updated feature matrix produced by the channel mechanism, as illustrated in Formula 8:

$$W_j = \chi \sum_{i=1}^N (b_{ji} A_i) + A_j \quad (8)$$

Similarly, to assign more weights by training the network,  $\chi$  is initialized to 0.

The final characteristic Z is obtained by fusing the characteristic M with point cloud spatial information and the characteristic W with point cloud channel information.

3) *Multi-layer feature fusion module:* In 3D point cloud classification tasks, fusing information features of different scales can effectively improve the classification performance of the network. Low-level features contain more location and detail information from point cloud data, but low-level features do not undergo much feature extraction, resulting in more noise and decreased semantic content. A high-level characteristic has more robust semantics, but they have poor feature resolution and poor detail perception. Therefore, before obtaining global features of point clouds through the network, it is necessary to perform feature fusion for features of 64, 128, and 256 dimensions.

In terms of the feature fusion method, select the concat feature fusion method, which essentially combines the number of feature channels, as shown in Fig. 4.

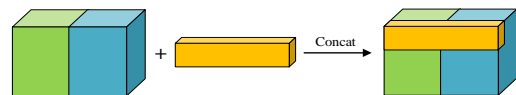


Fig. 4. Concat feature fusion.

For the two input features X and Y, if their feature dimensions are  $m$  and  $n$ , the output feature dimension after the concat operation is  $m+n$ . If the channels of input are  $X_1, X_2, \dots, X_c$ , and  $Y_1, Y_2, \dots, Y_c$ , respectively, the result after concat can be written as follows:

$$Z_{concat} = \sum_{i=1}^c X_i * K_i + \sum_{i=1}^c Y_i * K_{i+c} \quad (9)$$

The 64, 128, and 256-dimensional features obtained from the network are spliced using a multi-level feature fusion method, enabling the final global features to better focus on the global context information of the point cloud, enabling the network to achieve better classification accuracy. The fusion method is shown in Fig. 5.

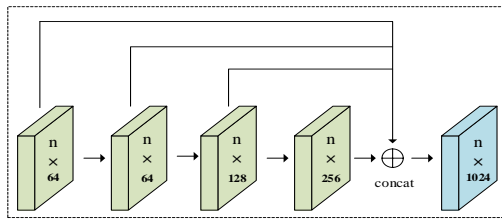


Fig. 5. Multi-layer feature fusion.

### B. The 3D CLIP

The 3D CLIP plug-in network can directly perform classification tasks without pre-training. In order to obtain the text description characteristics of point clouds as well as the image features for point cloud projection images, this model primarily uses the trained text encoder and image encoder in the two-dimensional CLIP [33] and finds the corresponding relationship between text features and image features from the pre-trained model. Then, each image feature is weighted and summed with all text features, and the cosine similarity is calculated. The category corresponding to the maximum similarity text is the final classification result.

1) *Text encoder*: First, construct an appropriate descriptive text for each object class in the dataset. Then input these description texts into the text encoder to extract text features.  $M$  text features will be obtained after extracting the features through the text encoder. The text features extracted by the text encoder can be represented as  $W_t \in \mathbb{R}^{M \times C}$ . The model text encoder employs text-transform, and the primary method of extracting textual characteristics is depicted in Fig. 6:

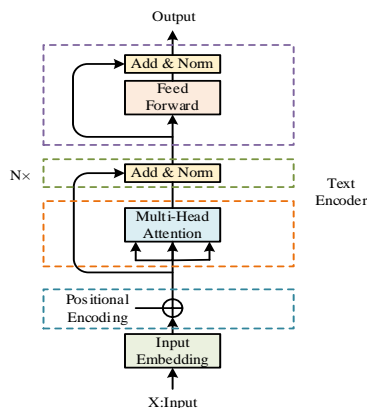


Fig. 6. Text feature extraction.

In this structure, the input of the text encoder is  $X$ , which represents a sentence. The final text features of the sentence are obtained after feature extraction from several modules of the encoder.

The input embedding module, the main purpose of this module is to transform the characters in a sentence into a vector.  $X$  can be converted into a  $X_{embedding}$  vector after this module. This vector's three dimensions stand for the total number of sentences, the number of words in a sentence, and the size of each individual word.

In the positional encoding module, the position of each word in the input sentence is encoded and marked. The encoding calculation process can use the sine and cosine function, which is calculated as:

$$PE(pos, 2i) = \sin(pos / 10000^{2i/d_{model}}) \quad (10)$$

$$PE(pos, 2i+1) = \cos(pos / 10000^{2i/d_{model}}) \quad (11)$$

where  $i$  indicates the size of the word vector and  $pos$  the position of each word within the phrase.

After the position encoding module, an encoding array  $X_{pos}$  with the same dimension as the input sentence can be obtained. And the new word vector can be obtained by superimposing  $X_{pos}$  with the original vector:

$$X_{embedding} = X_{embedding} + X_{pos} \quad (12)$$

In the multi-head attention module, this module enables the model to learn the expression of multiple meanings. The module uses the self-attention attention mechanism to linearly map the inputs to obtain  $Q, K, V$ :

$$\begin{aligned} Q &= X_{embedding} * W_Q \\ K &= X_{embedding} * W_K \\ V &= X_{embedding} * W_V \end{aligned} \quad (13)$$

where the dimensions of  $Q, K,$  and  $V$  are the same as the  $X_{embedding}$  dimensions.

In the add and norm module, the main operations are residual concatenation and normalization. The preceding layer input  $X$  is added to the output via the residual join. The normalization operation is to subtract the mean value of each row and divide it by the standard deviation of the row to obtain the normalized value.

The feedforward module contains two layers of linear mapping and activation using the activation function. The final output is obtained after the same add and norm operation.

2) *Image encoder*: Because the images input by the CLIP model when using the image encoder to extract image features are all two-dimensional, it is necessary to perform two-dimensional processing of three-dimensional point cloud data. The specific operation is to project the three-dimensional point cloud data in the dataset from multiple perspectives into a two-dimensional depth image.

The spatial coordinates of a point cloud for 3D data in a dataset can be represented as  $(x, y, z)$ . When projecting in the  $z$ -direction, the point can be transformed into  $([x/z], [y/z])$ . The advantage of this projection is that it can make the image closer to a natural image. Because the image encoder of the CLIP

model processes three-channel RGB images, to obtain point cloud-related features from the projected image, the projected image is copied twice to become a three-channel image before being input to the image encoder.

The mapping formula for projecting 3D point cloud data point  $A$  to 2D coordinate system point  $B$  is as follows:

$$\vec{A} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \rightarrow \vec{B} = \begin{bmatrix} \alpha \cdot \frac{x}{z} + C_x \\ \beta \cdot \frac{y}{z} + C_y \end{bmatrix} \quad (14)$$

In the selection of the image encoder, since the ResNet [34] is used in the 2D CLIP to achieve better results in classification tasks, the ResNet will also be used for feature extraction in the 3D CLIP selection of the image encoder.

ResNet is a residual network, and a residual network is composed of a series of residual blocks. For ResNet, it contains two basic modules, identity block, and conv block, and the module structure is shown in Fig. 7:

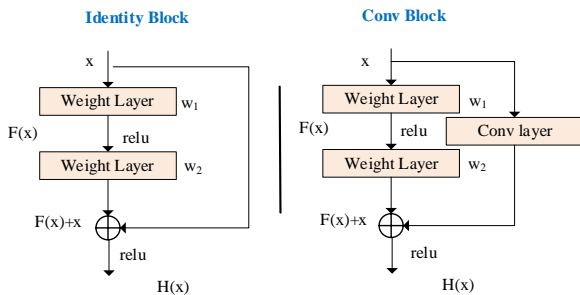


Fig. 7. ResNet main module.

In the identity block module,  $x$  is the input and  $H(x)$  is the output:

$$H(x) = F(x, \{w_i\}) + x \quad (15)$$

where  $F(x, \{w_i\})$  denotes the residual, which is the target to be learned. It represents the operator relationship between the weights and the input,  $F(x) = H(x) - x$ .

Unlike the identity block module, the conv block module adds the conv layer convolution operation on top of it. The shape of the input matrix can be adjusted so that the residual edges and the convolution in the module can be summed.

For depth, images projected from  $V$  different angles of view, use an image encoder to extract image features. The extracted image features have a total of  $f_i$ , where  $i = 1, \dots, V$ .

During the classification process, since the 3D CLIP has already obtained  $w_i$  text features and  $f_i$  image features, it is only necessary to calculate the classification  $logits_i$  of each projection view separately. Finally, weighted summation can be used to get the point cloud final classification  $logits_h$ , and the classification outcome. The calculation formula is as follows:

$$logits_h = \sum_{i=1}^V f_i W_i^T, i = 1, \dots, V \quad (16)$$

$$logits_h = \sum_{i=1}^V logits_i \quad (17)$$

## IV. EXPERIMENTS AND RESULT

### A. Datasets

For accurately assessing the network categorization performance for this article, the open dataset ModelNet40 proposed by Princeton University was selected for training and testing the network. There are a total of 12311 CAD models in the dataset, with 9843 models used for training and 2468 models used for testing. Each model has its corresponding category and is divided into 40 categories of artificial objects. Select four categories from the ModelNet40 dataset: airplane, plant, chair, and person for visualization. The results are shown in Fig. 8:

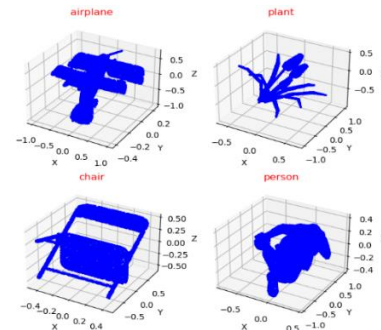


Fig. 8. Partial category visualization.

Because the point cloud set contains a sizable number of useless and noise points. The point cloud categorization network capacity to extract features will decline. In addition, when the number of points used to input the network is too large, it can generate many parameters during training. It will affect the training speed of the network. The subsampling algorithm can remove noise points and ensure the same number of points input to the model.

Fig. 9 displays the visualization of point cloud data following sampling. The original point cloud contains 10000 points. After sampling, 1024 points can be obtained. These points can represent the object well and contain rich object details.

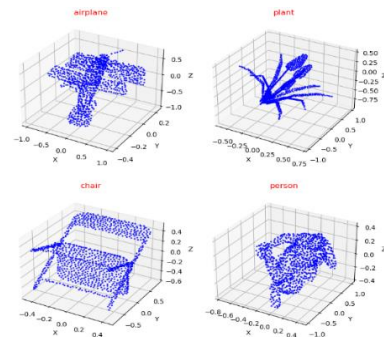


Fig. 9. Point cloud data sampling.

### B. Experimental Setting

The hardware environment required for this model is Intel core i5-9400, the software environment consists of Python 3.7,

CUDA10.1, PyTorch 1.6, and Ubuntu 20.04.2 LTS. The learning rate for the experimental parameters has been set to 0.001. There are 250 iterations in total. 32 is the set batch size. The Adam optimizer is used.

The evaluation metrics of the network are the overall classification accuracy (OA) and the average classification accuracy (mAcc). As follows:

$$OA = \frac{TP + TN}{TP + TN + FP + FN} \quad (18)$$

$$Precision = \frac{TP}{TP + FP} \quad (19)$$

$$mAcc = \frac{\sum_{m=1}^M Precision_m}{M} \quad (20)$$

where *TP* is the number of samples with accurate predictions. *TN* represents the number of samples with incorrect predictions. The sample quantity of false positives is denoted by *FP*. The sample quantity of false negatives is denoted by *FN*. *Precision* is the accuracy rate. *M* is the classification number.

### C. Experimental Results Analysis

1) *Pooling method selection*: To study the effects of various pooling methods on the classification precision of network models, max pooling, average pooling, and a combination of the two pooling methods were compared in the process of getting the global feature. Assume that method A uses only average pooling, method B uses only max pooling, and method C uses both average pooling and max pooling. Where  $\checkmark$  indicates using this method,  $\times$  indicates that this method is not used, and the classification accuracy is shown in Table I.

TABLE I. GFANET CLASSIFICATION ACCURACY UNDER DIFFERENT POOLING MODES

Pooling method	Avg. Pooling	Max Pooling	mAcc/%	OA/%
A	$\checkmark$	$\times$	89.3	91.5
B	$\times$	$\checkmark$	89.2	91.6
C	$\checkmark$	$\checkmark$	<b>90.2</b>	<b>92.5</b>

According to the test results of AvgPooling and MaxPooling in Table I, the combined use of max pooling and average pooling improves classification accuracy compared to utilizing either pooling approach alone. The average classification accuracy of using method C is 0.09% and 0.1% higher than that of method A and method B, respectively. And the overall classification accuracy of method C is 0.1% and 0.09% higher than that of method A and method B, respectively. This demonstrates that the information lost during the global feature selection process can be reduced by combining average pooling and max pooling. As a result, for

feature extraction during the construction of GFANet, average pooling, and max pooling are combined.

2) *Analysis of network classification accuracy*: To compare with the GFANet, many traditional point cloud classification networks are used. The ModelNet40 dataset is selected as the testing dataset. The classification accuracy of different networks on the ModelNet40 dataset is shown in Fig. 10 and Fig. 11.

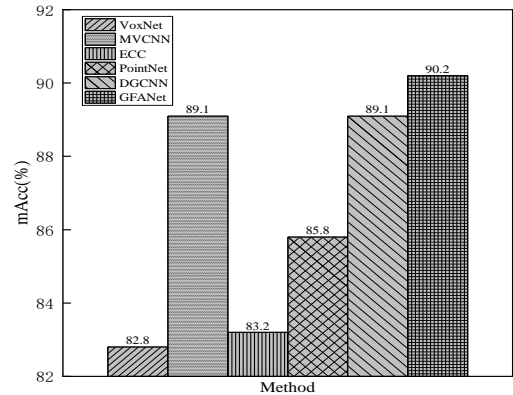


Fig. 10. Average classification accuracy of different networks.

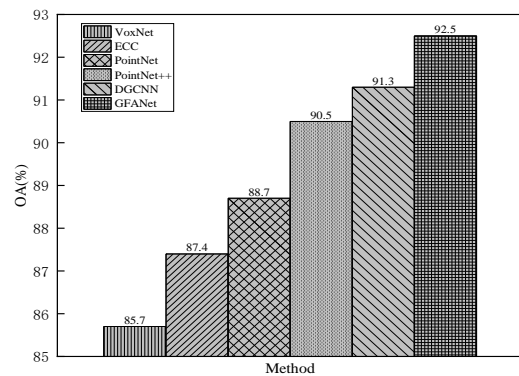


Fig. 11. Overall classification accuracy of different networks.

In contrast to traditional point cloud categorization networks, the GFANet has higher classification accuracy. Compared with PointNet, the GFANet has an overall classification accuracy improvement of 3.8% and an average improvement in classification accuracy of 4.4%. The reason is that GFANet concentrates on the point clouds local and global information characteristics. The GFANet exhibits an overall classification accuracy improvement of 2.0% when compared to PointNet++. The reason is that the connection between points is strengthened and the information feature between point pairs is focused in GFANet. While PointNet++ just processes points separately. Compared with DGCNN, the GFANet has an overall classification accuracy improvement of 1.2% and an average improvement in classification accuracy of 1.1%. The reason is that the information of point pairs is focused on GFANet. And a fusion attention mechanism is added in GFANet. In addition, the spatial and channel information properties of point clouds are extracted by GFANet.

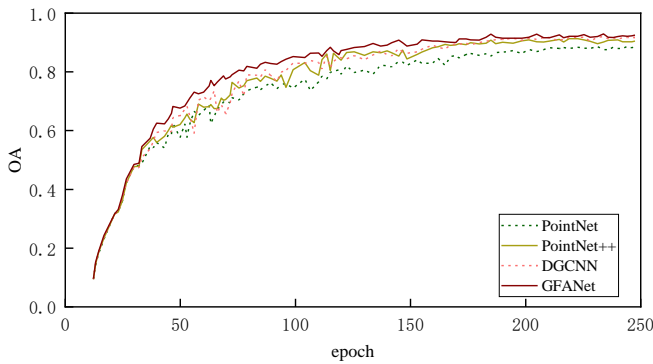


Fig. 12. Network classification accuracy.

For the ModelNet40 dataset, the classification accuracy curve obtained through 250 iterations for PointNet, PointNet++, DGCNN, and GFANet is shown in Fig. 12.

The GFANet has significantly better classification accuracy than the other three networks in most training cycles, especially in the middle and late stages of training. It has been demonstrated that GFANet can increase the classification accuracy of point clouds.

3) *Comparative experiments of different categories:* Like the PointNet, the GFANet is a classification net that accepts data from point clouds directly. And the construction of the GFANet also refers to the PointNet. The comparison results of GFANet with PointNet and PointNet++ on ModelNet40 data set for individual classification of each category are shown in Table II.

Compared with PointNet and PointNet++, the GFANet has higher accuracy for most categories. For the categories with obvious features, such as the Bench, Guitar, and Lamp, the classification accuracy of GFANet is 5%, 2%, and 1.3% higher than that of PointNet, and is 3%, 0.5% and 0.7% higher than that of PointNet++. For the categories with no obvious features, such as the Bathtub, Door, and Wardrobe, the classification accuracy of GFANet is 5%, 1.2%, and 4% higher than that of PointNet, and is 3%, 1%, and 3% higher than that of PointNet++.

The reason is that both the local information characteristics and the global information characteristics for data points are considered in GFANet. Additionally, GFANet takes into account the channel information features as well as the spatial information features for data points.

TABLE II. COMPARISON RESULTS FOR 40 CATEGORIES

Category	PointNet	PointNet++	GFANet	Category	PointNet	PointNet++	GFANet
Airplane	1.000	1.000	1.000	Laptop	1.000	1.000	1.000
Bathtub	0.870	0.890	0.920	Mantel	0.930	0.940	0.950
Bed	0.960	0.964	0.970	Monitor	0.950	0.960	0.980
Bench	0.700	0.720	0.750	Night_stand	0.742	0.753	0.776
Bookshelf	0.910	0.918	0.930	Person	0.920	0.930	0.950
Bottle	0.940	0.952	0.960	Piano	0.900	0.910	0.930
Bowl	0.900	0.920	0.940	Range_hood	0.920	0.930	0.952
Car	0.960	0.971	0.980	Sink	0.780	0.800	0.850
Chair	0.970	0.974	0.980	Sofa	0.960	0.963	0.970
Cone	0.950	0.960	1.000	Stairs	0.800	0.840	0.900
Cup	0.780	0.790	0.800	Stool	0.850	0.860	0.800
Curtain	0.900	0.910	0.920	Table	0.800	0.830	0.870
Desk	0.800	0.880	0.900	Tent	0.950	0.951	0.953
Door	0.800	0.860	0.920	Toilet	0.980	0.982	0.970
Dresser	0.696	0.700	0.726	Tv_stand	0.800	0.830	0.860
Flower	0.220	0.230	0.250	Vase	0.820	0.825	0.830
Glass	0.950	0.960	0.970	Wardrobe	0.750	0.760	0.790
Guitar	0.980	0.985	1.000	Xbox	0.650	0.680	0.750
Keyboard	1.000	1.000	1.000	Plant	0.760	0.770	0.780
Lamp	0.950	0.956	0.963	Radio	0.750	0.770	0.800



4) Analysis of adding 3D CLIP classification accuracy:

The effectiveness of the 3D CLIP network is demonstrated by comparing the accuracy of point cloud classification with and without adding 3D CLIP in PointNet, PointNet++, DGCNN, and GFANet. The classification accuracy is shown in Table III.

TABLE III. CLASSIFICATION ACCURACY OF DIFFERENT NETWORKS

Method	3D CLIP	mAcc/%	OA/%
PointNet [20]	×	85.8	88.7
	√	87.3	90.1
PointNet++ [24]	×	—	90.5
	√	—	91.4
DGCNN [26]	×	89.1	91.3
	√	90.4	92.7
GFANet	×	90.2	92.5
	√	<b>91.1</b>	<b>93.6</b>

The overall accuracy of classification of PointNet is 1.4% higher and the average accuracy of classification is 1.5% higher when the 3D CLIP is used. The overall accuracy of the classification of PointNet++ is 0.9% higher when the 3D CLIP is used. The overall accuracy of classification of DGCNN is 1.4% higher and the average accuracy of classification is 1.3% higher when the 3D CLIP is used. The overall accuracy of classification of GFANet is 1.1% higher and the average accuracy of classification is 0.9% higher when the 3D CLIP is used. The experiment results indicate that point cloud classification networks with 3D CLIP have a certain improvement in classification accuracy compared to networks without 3D CLIP. The reason is that 3D CLIP can extract two-dimensional feature information of point clouds. The GFANet with 3D CLIP has the highest classification accuracy compared to other networks with 3D CLIP. It proves the effectiveness of the GFANet and 3D CLIP. It also demonstrates the potential of 3D CLIP to enhance the classification accuracy of point cloud categorization networks.

5) Analysis of 40 categories classification results of GFANet adding 3D CLIP: According to Table II, for the categories with similar characteristics in the ModelNet40 dataset, such as cup and vase, flower\_pot and plant, nightstand, and wardrobe. GFANet and the existing classical point cloud classification network cannot be well classified, and these categories are shown in Fig. 13. The primary cause is that the network only concentrates on the three-dimensional information feature information of the point cloud and does not extract the two-dimensional information feature of these categories, making it difficult for the network to distinguish and identify, and resulting in a relatively small improvement in the classification accuracy of these single categories. In this experiment, the 3D CLIP is added to the GFANet to prove that the 3D CLIP can help the GFANet to better distinguish

different categories with similar features and improve the classification performance of the network. The findings of the experiment are displayed in Table IV.

Table IV shows that in comparison to GFANet alone, the network comprising GFANet and 3D CLIP has somewhat increased the classification accuracy of the 40 categories of the ModelNet40 data set. For the cup and vase categories with similar features, the accuracy of classification is increased by 2% and 1.8%, respectively. For the flower\_pot and plant categories with similar features, the accuracy of classification is increased by 3% and 2%, respectively. For the nightstand and wardrobe categories with similar features, the accuracy of classification is increased by 3% and 2%, respectively. The classification accuracy of the network is improved by 2.6% and 3%, respectively. This is so that the network can both extract the three-dimensional information features of the point cloud and learn the two-dimensional information representation of the point cloud. The 3D CLIP is an addition to the GFANet that can provide more two-dimensional information about the point cloud for the network. Thereby the network can better distinguish between different categories with similar features and raise the classification accuracy of various categories. Improve the classification accuracy of the network.

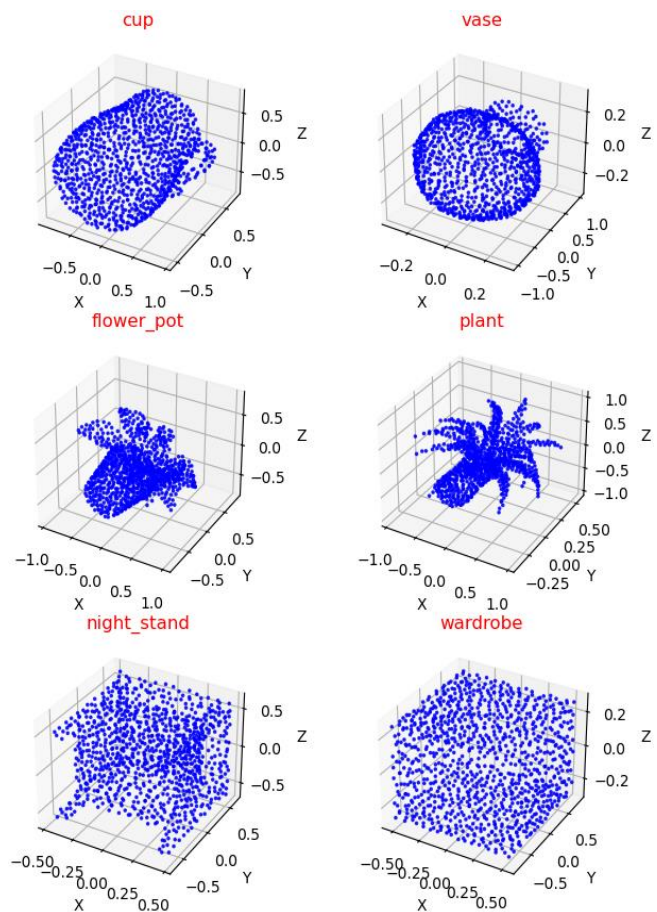


Fig. 13. Different categories with similar features in the ModelNet40 dataset.



TABLE IV. ANALYSIS OF 40 CATEGORY CLASSIFICATION RESULTS

Category	GFANet	GFANet+3D CLIP	Category	GFANet	GFANet+3D CLIP
Airplane	1.000	1.000	Laptop	1.000	1.000
Bathtub	0.920	0.930	Mantel	0.950	0.960
Bed	0.970	0.978	Monitor	0.980	0.983
Bench	0.750	0.800	Night_stand	0.770	0.802
Bookshelf	0.930	0.940	Person	0.950	0.960
Bottle	0.960	0.970	Piano	0.930	0.940
Bowl	0.940	0.950	Range_hood	0.952	0.962
Car	0.980	0.987	Sink	0.850	0.860
Chair	0.980	0.983	Sofa	0.970	0.980
Cone	1.000	1.000	Stairs	0.900	0.920
Cup	0.800	0.820	Stool	0.800	0.850
Curtain	0.920	0.930	Table	0.870	0.900
Desk	0.900	0.910	Tent	0.953	0.961
Door	0.920	0.926	Toilet	0.970	0.980
Dresser	0.726	0.862	Tv_stand	0.860	0.880
Flower	0.250	0.280	Vase	0.830	0.848
Glass	0.970	0.975	Wardrobe	0.790	0.820
Guitar	1.000	1.000	Xbox	0.750	0.800
Keyboard	1.000	1.000	Plant	0.780	0.800
Lamp	0.963	0.986	Radio	0.800	0.880

#### V. CONCLUSION

Targeting the issues that the current point cloud classification methods disregard the point cloud's local feature extract, lack the connection between points and points, and do not extract the two-dimensional information features of the point cloud when obtaining the point cloud features. To obtain a more precise classification result, a point cloud categorization network using a multi-layer fusion of features and point cloud projection image was proposed. The network employs dynamic graph convolution to enhance the association between points by extracting local characteristics from the point cloud. The point cloud features were fused via multi-layer feature fusion, and the fusion attention method was devised to collect the useful characteristics of the point cloud while suppressing the useless features. Finally, a 3D point cloud network plug-in model based on a point cloud projection image, 3D CLIP, is used to make up for the lack of extracting two-dimensional information features of the point cloud, to increase the network accuracy at classifying objects.

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#### CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest to report regarding the present research paper.

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# Early Detection of Autism Spectrum Disorder (ASD) using Traditional Machine Learning Models

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**Abstract**—Autism Spectrum Disorder (ASD) is a mental disorder among children that is difficult to diagnose at an early age of a child. People with ASD have difficulty functioning in areas such as communication, social interaction, motor skills, and emotional regulation. They may also have difficulty processing sensory information and have difficulty understanding language, which can lead to further difficulty in socializing. Early detection can help with learning coping skills, communication strategies, and other interventions that can make it easier for them to interact with the world. This kind of disorder is not curable but it is possible to reduce the symptoms of ASD. The early age detection of ASD helps to start several therapies corresponding to ASD symptoms. The detection of ASD symptoms at an early age of a child is our main problem where traditional machine learning algorithms like Support Vector Machine, Logistic Regression, K-nearest neighbour, and Random Forest classifiers have been applied to parents' dialog to understand the sentiment of each statement about their child. After completion of the prediction of these models, each positive ASD symptoms-related sentence has been used in the cosine similarity model for the detection of ASD problems. Samples of parents' dialogs have been collected from social networks and special child training institutes. Data has been prepared according to the model for sentiment analysis. The accuracies of these proposed classifiers are 71%, 71%, 62%, and 69% percent according to the prepared data. Another dataset has been prepared where each sentence refers to a particular categorical ASD problem and that has been used in cosine similarity calculation for ASD problem detection.

**Keywords**—Support vector; logistic regression; cosine similarity; K-nearest neighbor; random forest

## I. INTRODUCTION

People with ASD [1] often have difficulty in understanding the social cues and expectations that are necessary for meaningful conversations and relationships with others. This can lead to isolation, difficulty in forming relationships, and, in some cases, difficulty in gaining recognition in society as in [2]. Early detection can help identify the illness sooner, allowing for personalized treatments or preventive measures to be put in place that can help reduce the severity of the illness and improve the chances of recovery as in [3]. It is caused by a combination of genetic and environmental factors that affect the development of the brain. It is characterized by difficulty in social interaction, communication, and repetitive behaviors. Research has been done to identify the causes of this syndrome, which include

genetic predisposition, environmental factors, and lifestyle choices. Although the exact cause is still unknown, the available evidence shows that it is a multi-faceted condition. In addition, the lack of trained professionals and resources to diagnose and treat ASD [1] has created a huge gap in access to care. Furthermore, due to the complexity of the disorder, it can be difficult to diagnose and properly classify it, leading to misdiagnosis or delayed diagnosis. This is because autism is a complex disorder, and it can manifest itself differently in each affected individual [4]. As such, it is difficult to create a single biomarker that can accurately detect the disorder. Additionally, research into developing tools and applications, data analysis, and pattern recognition [5][6] to help identify children with autism is challenging, as it requires creating a comprehensive program that can detect subtle signs of autism across a range of contexts as in [7]. People with autism may struggle with understanding social cues, interpreting and responding to others' emotions, and forming relationships. They may also have difficulty with processing sensory information or have strong interests in certain topics or activities. Diagnosis is based on observed behavior, and the process can involve interviews and questionnaires, cognitive assessments, physical examinations, and genetic and neurological tests. All of these evaluations can take time and money, and the cost can be prohibitive for some families. These tests are designed to identify patterns of behavior and symptoms associated with autism, by asking parents and professionals to observe the individual. They then analyze the responses and compare them to a set of criteria established to identify autism or other developmental disorders. For example, if a person is using a metal detector, they must have an understanding of the type of metal they are looking for and the size of the object they are searching for. The quality of the metal detector will also have an impact on the accuracy and efficiency of the screening method. Such systems can use algorithms to analyze large amounts of data and detect patterns with high accuracy, potentially leading to earlier and more accurate diagnoses. Additionally, such systems can help to automate certain labor-intensive tasks and reduce the amount of time needed to complete diagnostic tests. This is because machine learning algorithms can analyze large amounts of data and identify patterns and correlations that would be difficult or impossible for humans to find. The algorithms can then be used to develop predictive models that can accurately identify potential diagnoses and suggest

therapies as in [8]. Some research scholar has done some work on ASD diagnosis using machine learning. The aim of this research is to reduce the classification time of ASD diagnosis process after the detection of the most influential ASD diagnosis items as in [9][10][11][12]. Machine learning (ML) is a powerful tool that can be used to analyze vast amounts of data and identify patterns that can be used to detect mental health issues. ML can also be used to develop personalized treatments based on individual patient characteristics. This could potentially lead to more targeted and effective treatments for mental health issues. Through the use of data-driven techniques, ML enables the analysis of large amounts of data to uncover previously unknown patterns, trends, and correlations. ML can be used to develop predictive models or to recommend interventions that may be tailored to individual needs. These challenges include the need to ensure responsible data collection and storage, to develop equitable access to ML-enabled solutions, to ensure ethical and responsible use of ML and AI, and to ensure that privacy and confidentiality are maintained as in [13].

The proposed work is based on the detection of ASD symptoms from the parents' dialogue. Parents of autistic children have the best experience with their autistic children's symptoms. The data has been collected from many social sites and organizations for special children. The data is related to the parents' dialogue in text mode and a dataset has been prepared using these parents' text inputs. Traditional machine learning models like SVM, Logistic Regression, K-nearest neighbor (KNN), and Random Forest have been used to detect the symptoms from the parents' text. The sentiment analysis process has been used to detect sentences from the parents' text. After completion of the prediction using the proposed machine learning models, the positive sentences have been used as input in the cosine similarity model. This model will calculate the cosine similarity of input sentences and ASD symptoms sentences to detect ASD problems. Many machine learning-based applications related to mental disorders have been discussed in Section II. The proposed dataset, detailed architecture of the proposed system, and machine learning models have been discussed in Section III. The results of this proposed system have been discussed in Section IV. The limitation has been given in Section V whereas conclusion has been discussed in Section VI and ends with the future work in Section VII.

## II. RELATED WORKS

Today, Autism Spectrum Disorder (ASD) is a highly prevalent disorder problem among children. Now it is one of the main components in the healthcare domain and much research has been done using Artificial Intelligence (AI). A few important AI-based research works on Mental Health related issues have been included in this related work section.

These NLP software tools use a combination of natural language processing (NLP) algorithms and domain-specific ontologies to identify and extract biomedical concepts from unstructured texts. The ontologies provide an organized representation of biomedical concepts and the NLP algorithms enable the software to accurately identify the concepts in the text. This is due to the fact that the existing literature on these

disorders is often written in a complex, highly technical language that is difficult to parse and interpret with natural language processing tools. Additionally, many of the diseases are multi-faceted and involve a variety of clinical terms that need to be identified by the NLP tools in order to accurately extract relevant information. The authors evaluated the predictive performance using precision, recall, and F1 score. We also ran a manual evaluation to compare the manual annotation of ASD-related terms with the tools' extracted terms, and found that CLAMP outperformed the other two tools in terms of precision, recall, and F1 score on both the abstracts and full-text articles. The F1 score combines the precision and recall of a system, so it takes into account both the accuracy and completeness of the system. In this case, CLAMP had the highest F1 score, meaning it had both a higher precision and a higher recall than the other two systems. This type of analysis protocol allows researchers to better identify, classify, and quantify the symptoms of a disorder, even when there is not a well-defined terminology set to describe it. This makes it easier to compare the presentation of the disorder across different populations and can help to identify potential biomarkers for the disorder as in [14]. People with ASD had more difficulty in expressing emotions and abstract concepts than typically developing individuals, as well as difficulty in using language to describe events and convey information. This suggests that impairments in the use of pragmatic language are an important aspect of ASD and should be addressed in interventions. This suggests that the differences in narrative production between ASD and control groups are related to difficulties in understanding and expressing emotions, as well as producing more abstract language. The individuals with typical development had a more varied range of vocabulary, which included more words with both positive and negative sentiments, while the participants with ASD displayed a limited vocabulary, resulting in a greater tendency to use negative words. The lower level of language abstraction in the ASD narratives could be due to the limitation of their vocabulary and the difficulty of expressing abstract concepts. This suggests that language abstraction and emotional polarity can be used to measure the narrative abilities of individuals with ASD without relying on age or IQ scores. The strong positive correlation between linguistic abstraction and emotional polarity indicates that the more abstract language used, the more likely it is to contain emotional content. The difference in emotional polarity between the two groups could be due to the fact that individuals with ASD may have difficulty recognizing and expressing emotions. In addition, they may have difficulty understanding abstract language concepts, which could explain why they used fewer abstract words in their narratives as in [15]. One of the most promising areas for developing assistive tools is the use of artificial intelligence (AI) and machine learning (ML) algorithms. These algorithms can be used to analyze data from various sources and can provide insights that may help diagnose ASD earlier and more accurately. The proposed approach is expected to find the underlying patterns in the eye-tracking records which can be used to accurately diagnose the disorders. The results of this study could provide clinicians with a powerful tool that could potentially improve the

accuracy and speed of diagnosis. By applying NLP methods to the raw eye-tracking data, the study was able to extract meaningful features from the data that could be used to train classification models. The experiment showed that using these features could yield better results than using the raw data alone. The authors [16] used a customized loss function to adjust the weights of the model, which allowed them to achieve a high level of accuracy. Additionally, authors [16] utilized transfer learning to fine-tune the model, allowing us to further improve the accuracy of the model. The author's [16] approach could realize a promising accuracy of classification (ROC-AUC up to 0.8) as in [16]. Social behavior issues are often the most noticeable in children with autism, and they may include difficulty forming relationships, lack of eye contact, and difficulty understanding nonverbal communication. Clinical tests can also be used to look for developmental delays, such as difficulty with speech and language, as well as repetitive behaviours like hand flapping or rocking. The assessment process is designed to identify key characteristics of autism in individuals, such as difficulty in communication and social interaction, and to determine the severity of the condition. By using semi-structured data posted in Twitter, the team of doctors can gain insight into the individual's behavior, which can then be used to develop a more accurate and effective assessment. Analyzing the tweets, it allows researchers to detect the sentiment of people's opinions on autism, the topics that are most commonly discussed, and the language used to discuss autism. This helps researchers gain a better understanding of how people think and talk about autism, and can help inform policy decisions. NLP and topic modeling allow for more efficient processing of data by automatically recognizing patterns and keywords, saving time and effort. Furthermore, the results of the analysis are highly accurate, making them an ideal choice for studying topics such as genetic analysis, the effect of vaccination, and behavior analysis. The 10k tweets dataset is enough to provide in-depth analysis and insight into these topics. The analytical results are used to learn the genetic impact on ASD, the vaccination effect on ASD and also used to learn the behavior changes and population of autistic children as in [17]. It is characterized by a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development. It is often accompanied by other mental health disorders, such as anxiety and depression, which can further impair functioning and quality of life. We applied the CNN model to the EEG data in order to distinguish between ADHD patients and healthy controls. The CNN was able to accurately classify the EEG data with an accuracy of 90.3%, significantly outperforming other methods, particularly of event-related potentials (ERP) from ADHD patients ( $n = 20$ ) and healthy controls ( $n = 20$ ) collected during the Flanker Task, with 2800 samples for each group. By exploiting invariances, deep networks are able to classify data even when there are variations in the data, such as changes in lighting or orientation of an image. Compositional features are combinations of basic elements that form a more complex representation of the data, such as edges and shapes in an image. Deep networks are able to identify these features, which enables them to accurately classify data. This was achieved by using a Convolutional Neural Network (CNN)

that was trained on EEG data from patients with Parkinson's Disease in order to classify them as either having the disease or not. The CNN was able to extract relevant features from the data without any manual input, resulting in a higher accuracy than other machine learning approaches. This is because CNNs can learn more complex patterns from the data and have the ability to generalize to new data. Event-related spectrograms capture more information about the events of interest, which can be used to extract more accurate features than resting state EEG spectrograms. This suggests that these techniques can be used to identify and visualize the underlying physiological differences between neurological disorders and healthy brains, potentially leading to a better understanding of their underlying pathophysiology. Deep networks are useful because they can extract meaningful patterns from EEG signals and are capable of handling large amounts of data. These results suggest that deep networks can also be used to analyze EEG dynamics from smaller datasets, which could be used to develop biomarkers for clinical use as in [18]. EEG can provide valuable information to help diagnose ADHD in children because it can measure electrical activity in the brain and detect any abnormal electrical activity that may be indicative of ADHD. Additionally, EEG can help to differentiate ADHD from other mental disorders that may be present in the child. Symptoms of ADHD include difficulty paying attention, impulsivity, and hyperactivity. These symptoms can interfere with a child's ability to learn, manage emotions, and interact with peers. Video long-range EEG monitoring can provide more accurate and detailed information about the brain activity of children with ADHD compared to ambulatory EEG monitoring, as it allows for more frequent data collection and better visualization of the EEG data. It also helps to identify abnormal brain electrical activities which may be associated with ADHD, thus aiding in the diagnosis of the condition. By doing this, they were able to accurately identify children with ADHD and study their behavioral patterns in order to better understand and treat the disorder. This allowed for a more precise and detailed analysis than traditional methods of observation. Comparing the results of various models can help to identify which model is best suited for recognizing signs of ADHD in EEG data. By selecting the most accurate and appropriate model, researchers can then use it to build a recognition method that can diagnose children with ADHD more accurately. This is because long-term video EEG can detect the abnormal EEG patterns associated with ADHD, such as slow wave activity, and can also detect the degree of attention fluctuation in children with ADHD as in [19]. With the recent advances in artificial intelligence, computers can now analyze EEG data and provide results much faster than a neurologist. This has enabled the field of neurology to become much more efficient and provide more accurate results in a fraction of the time. This is made possible because AI is able to quickly analyze and process large amounts of data. It can quickly identify patterns and draw conclusions from the data that would take human hours or even days to detect ADHD. Additionally, AI can look for indicators of diseases or abnormalities that would be difficult for humans to find on their own. This is because it can automate the process of analyzing EEG signals, thus allowing neurologists to quickly and accurately identify

patterns associated with different neurological diseases. Furthermore, this technology can also help neurologists to identify subtle changes in EEG signals that could potentially signal the onset of a neurological disorder. The ML model can process the EEG signals quickly and accurately to detect patterns that may indicate ADHD. By making use of the data generated from the EEG signals, the ML model can diagnose ADHD more accurately and quickly than traditional methods. By analyzing the EEG signals, the ML model can identify patterns that are indicative of ADHD. Additionally, the ML model can be trained to recognize these patterns more quickly and accurately than traditional methods. With the right pre-processing techniques and machine learning algorithms, the ML model can provide a more accurate diagnosis of ADHD than traditional methods as in [20]. This allows individuals to stay connected with their friends and family and to keep up with what is going on in the world. Additionally, it makes it easier to stay in touch with people who are not in the same physical location, making it a great way to stay connected during this time. The pandemic has had a negative impact on the mental health of many people, and it has become harder for them to access in-person support. As a result, online tools and resources have become more important than ever for those struggling with mental health issues, allowing them to get the help they need even when they are unable to leave their homes. Mental health conditions can have a significant impact on an individual's overall well-being, affecting their ability to work and their relationships with others. Additionally, research has found that mental illnesses can increase an individual's risk of developing chronic physical health conditions, such as heart disease and diabetes. AI methods can help mental health providers to detect patterns in patient data that might otherwise go unnoticed, as well as to generate insights into the patient's current state. This can lead to more accurate diagnoses and better treatment plans, leading to better overall outcomes for the patient. AI can help to analyze patient data quickly and accurately, identify patterns and correlations, and make predictions about the best course of action for a patient's diagnosis and treatment. AI can also help reduce the time and resources required for manual data analysis and provide more efficient and cost-effective care. The models were tested on a labeled dataset of Reddit posts from users with self-reported mental illnesses and compared against a baseline model. The results showed that the machine learning, deep learning, and transfer learning models outperformed the baseline model in correctly classifying the different mental illnesses. This will help to reduce the amount of time it takes to identify and respond to medical emergencies, which will ultimately lead to more lives being saved. Additionally, it will also help to reduce the burden on healthcare workers, which will make the public health system more efficient and cost-effective as in [21]. A variety of factors can contribute to depression, such as genetics, brain chemistry, environmental influences, traumatic experiences, and other medical conditions. Additionally, depression can be caused by a combination of these factors, making it difficult to pinpoint a single cause. Genetics and brain chemistry can predispose someone to depression, while environmental factors and traumatic experiences can trigger its onset. Other medical conditions such as chronic illnesses can also be

associated with depression. Recognizing the early signs of depression can help to identify and address the issue before it becomes a more serious problem. The CNN is used to extract high-level features from speech signals, while the SVM classifier is used to classify the extracted features. The hybrid model is trained on a dataset of Arabic speech from people with depression and those without, to produce a model that is capable of distinguishing between the two. The hybrid model uses a combination of convolutional neural networks (CNNs) and support vector machines (SVMs) to analyze while 30% of data were used to test the proposed model. A hybrid model (CNN + SVM) attained a 90.0% and 91.60% accuracy rate to predicting the depression from the data and make predictions. This combination of techniques allows for the model to process the data quickly and accurately, resulting in the high accuracy rates it achieved. This is likely because the hybrid model combines the strengths of both models. The RNN can accurately make predictions based on the context of the data, while the CNN can detect the most important features in the data. By combining both models, the predictive power of the hybrid model is enhanced, the RNN achieved an 80.70% and 81.60% accuracy rate. This indicates that the combined model was more effective in classifying depression than either of the individual models alone. The results suggest that incorporating multiple models into one prediction system can increase the accuracy of the diagnosis. This is because the achieved findings can be used to identify key indicators of depression in spoken Arabic, such as speech patterns, intonation, and pauses. These indicators can then be used to identify individuals who may be suffering from depression and help physicians, psychiatrists, and psychologists provide more effective treatment as in [22]. The mental health issues, such as depression and anxiety, are becoming more common, and people are recognizing the need to prioritize their mental health as well as their physical health. Additionally, with the development of telehealth services, it's become easier for people to access mental health services regardless of their location. This means that most people who suffer from mental health issues are unable to get access to the right diagnosis and treatment, resulting in an overall decrease in the mental health of the population. The model will be trained on a dataset of speech samples from people with and without depression. Exploring the acoustic features and patterns in the speech samples of people with depression will help to identify the differences between those with and without depression. By doing so, it will be possible to detect signs of depression in an individual and provide an initial diagnosis of mental health problems. This model uses Natural Language Processing (NLP) techniques to analyze the text and determine the sentiment of the posts. The sentiment of the posts is then used to assess an individual's mental health status as in [23].

A comparative analysis has been done on proposed systems that are equipped with machine learning models and similar types of systems that are also based on machine learning models. Table I contains 'Models' as the first attribute where each model name is defined. The 'Description' attribute contains details about the models. The third attribute is 'Dataset' which refers to the dataset details and the fourth attribute is 'Accuracy' where each model's accuracy has been given. The last attribute is 'Remarks' about each model. Fig. 1



shows the accuracy graph of similar machine learning models and proposed machine learning models.

TABLE I. COMPARATIVE STUDY OF PROPOSED MODELS WITH SIMILAR TYPE MODELS IN MENTAL DISORDERS

Sl.No.	Models	Description	Dataset	Accuracy	Remarks
Similar Type Machine Learning Models in Mental Disorders					
1	CNN, RNN, SNN [18]	Deep learning CNN, Recurrent Neural Network, and Recurrent Neural Network are used for classification and comparison to detect Attention deficit hyperactivity disorder (ADHD).	EEG data has been used.	88%, 86%, and 78%	EEG is a medical test that measures electrical activity in the brain. This data is a very high volume and time and cost-effective.
2	Fully connected neural network model [19]	Neural Network-based Deep Learning Model to detect disorders like ADHD.	Deep learning long-range EEG big data.	97.7%	The data is long-range EEG big data which is a very high volume data for analysis.
3	KNN, SVM, and RF [20]	KNN, SVM, and RF Models are used trained with the EEG signals data to detect ADHD.	EEG signals data of ADHD	69%, 72%, and 74%	Much time has to be given for preprocessing to improve the quality of EEG signals.
4	Linear Support Vector Classifier, LR, NB, and RF [21]	Depression, anxiety, bipolar disorder, ADHD, and PTSD detection from unstructured data.	Unstructured user data on the Reddit platform has been used.	79%, 79%, 74%, and 75%	Reddit's post-dataset cleaning process is related to removing personal information, punctuation marks, and URLs.
5	CNN+SVM[22]	Intelligent system to detect depressive symptoms using speech analysis	Basic Arabic Vocal Emotions Dataset (BAVED)	90 and 91.60	The dataset has been prepared from the audio format for sentiment analysis.
6	RNN+CNN [22]	Intelligent system to detect depressive symptoms using speech analysis	Basic Arabic Vocal Emotions Dataset (BAVED)	88.50 and 86.60	The dataset has been prepared from the audio format for sentiment analysis.
Proposed Models in Mental Disorder (Autism Spectrum Disorder)					
7	Proposed SVM	SVM model to predict positive ASD symptoms from parents' dialogue.	Parents' Dialogues of Autistic Children in text format from SAHAS- Durgapur, India, and Social Sites.	71%	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.
8	Proposed Logistic Regression	SVM model to predict positive ASD symptoms from parents' dialogue.	Parents' Dialogues of Autistic Children in text format from SAHAS- Durgapur, India, and Social Sites.	71%	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 K Nearest Neighbor (KNN)	SVM model to predict positive ASD symptoms from parents' dialogue.	Parents' Dialogues of Autistic Children in text format from SAHAS- Durgapur, India, and Social Sites.	62%	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.
10	Proposed Random Forest	SVM model to predict positive ASD symptoms from parents' dialogue.	Parents' Dialogues of Autistic Children in text format from SAHAS- Durgapur, India, and Social Sites.	69%	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.

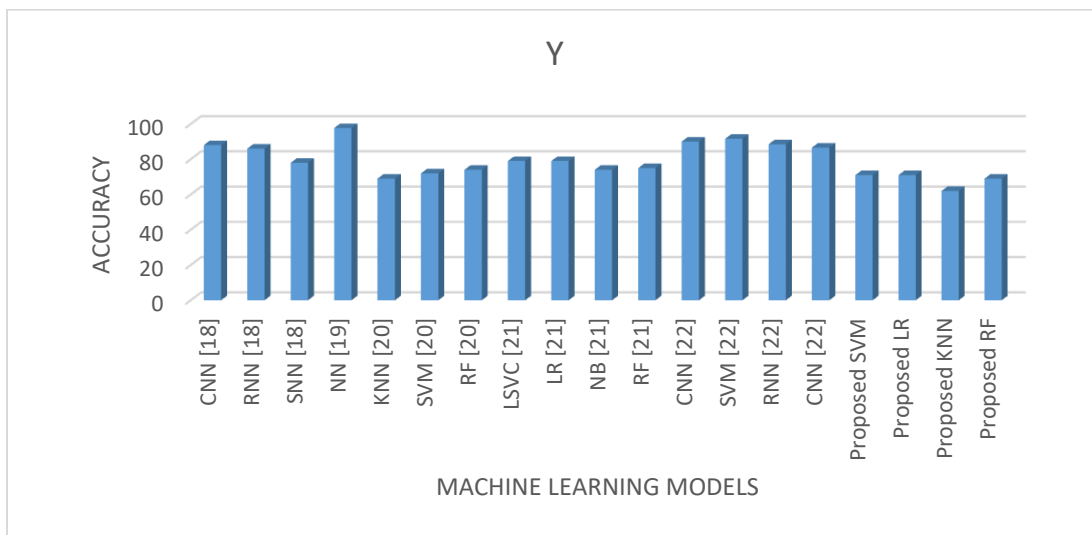


Fig. 1. Accuracy graph of similar ML models and proposed ML models.

### III. ARCHITECTURE OF PROPOSED MODELS

A few traditional machine learning classifiers have been used to identify ASD symptoms from parents' dialogues. SVM has been used as the first classifier to identify the symptoms from the parents' dialogue. Logistic regression is a second classifier that is also identifying the 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 of Proposed System

The Dataset has been prepared using the parents' dialogue where parents are describing their thoughts and experiences about their own autistic child. These data have been collected from several different social networks and organizations where special children are taking their therapies on communication, speech, and behavior. A few parent dialogue example has been given in Table II. Parents' dialogues are very important data from where all possible symptoms of ASD can be identified. The given dialogues are used to make the dataset for proposed machine learning models training and testing.

TABLE II. EXAMPLE OF PARENTS' DIALOGUES

Sl. No.	Parents' Dialogues
1.	My second son is 4 and also autistic; he's on the move always and always into something and he's also a big momma's boy, loves hugging and cuddling me. I'm nervous about bringing baby home. Idk how he'll handle it. Any advice?
2.	Hi. Please I need some advice. My son is 10 and from a few years is very hard to make him do some activities (writing and staff like that) At school he refuse. They are not able to make him do anything. At school just play and if say no to him he just scream. He doesn't want to do anything; (in terms of studying or activities). I really don't know what to do.
3.	I'm currently having problems with washing my (almost 2 year old) daughter's hair. Whenever i try, she basically goes ballistic and throws a fit. She's scared and I'm trying to figure out how to support her and make her feel safe because she does have to get hair washed. Any suggestions and things that have worked for you?

4.	My youngest with autism, learning disabilities and is non-verbal, will be 4. She has to be in a pushchair whilst out and about for safety as has zero sense of danger. I'm struggling to find a double pushchair suitable for a newborn and my will be 4 year old. If anyone can send any links or pictures that would be great.
5.	From few days my son eye movements strangely like keeping head down n seeing up and moving eye balls to the corners of the eyes. Can anyone suggest why he is doing so? Please... thanks!

The Dataset has been prepared from the text in Table II. Each sentence has been taken into consideration to identify whether it is a symptom of ASD or not. There are no fixed symptoms in ASD for identification. Increment of those parents' dialogues who are actually parents of autistic children can be a good idea to identify more symptoms as well as a good advantage to train the machine learning models for better accuracy. A few examples of data from the proposed dataset have been given in Table III.

TABLE III. EXAMPLE DATA IN THE PROPOSED DATASET

Sl. No.	Comments	Sentiment
1.	because all they do there is play with toys with him every time	1
2.	I'm confused guys help my son is 3years old now	0
3.	My little girl is 3 and a half and still non verbal	1
4.	he does is mumbles only no proper words	1
5.	I was really surprised when he came home with iep papers	0

The dataset structure in the proposed research has been described in Table III where the first column is Serial Number, the second column is Comments, and the third column is Sentiment. Paragraph text from parents' dialogues has been taken to prepare the dataset. Each sentence has been taken from the paragraph text and identifies whether it is a symptom of ASD or not. If it is a symptom of ASD then it is labeled as 1 (true) otherwise 0 (false). According to Table III, Sentences in the Comments column with serial numbers 1, 3,

and 4 are true symptoms of ASD whereas serial numbers 2 and 5 are false symptoms. Now this ASD symptom-based dataset has been prepared to train some traditional machine learning models like SVM, Logistic Regression, KNN, and Random Forest.

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 shows that each ASD problem is associated with the label. Label 1 denotes the “Speech Problem” whereas Label 2 and 3 denotes the “Sensory” and “Behaviour” problems. The other problems also mention in the label in Table IV. This table has been used after the prediction of the sentiment of a sentence according to the ASD symptoms. If the sentence is positive (1) then the proposed system will use this positive sentence as input of the Spacy cosine similarity model. Table V shows a dataset that contains a number of positive sentences with labels. Each label indicates an ASD problem according to Table V. Each sentence will be used for a similarity check with predicted positive sentences in the cosine similarity model and that has been discussed in the Proposed System Flow sections.

TABLE V. DATASET FOR COSINE SIMILARITY CHECK

Sl. No.	Positive Sentences	Label
1.	I can't show him how to potty during the day while his dad is at work	7
2.	he does is mumbles only no proper words	1
3.	when I call him he doesn't come to me	10
4.	He needs to visualize what I'm saying	6
5.	She gets so frustrated it breaks my heart I guess I'm looking for success stories	9

Each model has been described with the proposed algorithm in the next sections where this dataset has been utilized to train these models and the result of each model has been discussed in the Result and Discussion section.

**B. Support Vector Machine (SVM)**

Support vector machine (SVM) is the first approach to identify the symptoms of ASD. SVM is a supervised machine learning algorithm that can be used for classification or regression problems. It is a good idea to use SVM on a small

dataset and it generates good predictive results according to the problem. SVM is based on the finding of the best hyperplane that divides data points either in two classes or multiclass. The proposed approach is binary classification where data points either true (1) or false (0).

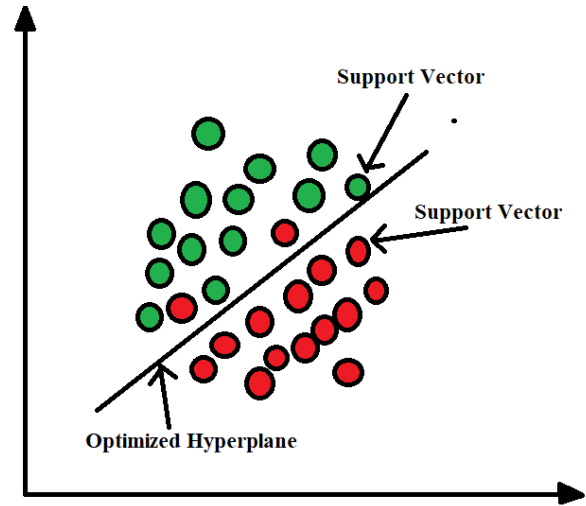


Fig. 2. Support Vector Machine (SVM).

It can be observed according to the above image that it is a two features classification problem. The optimized hyperplane has been drawn to linearly separate support vectors. The support vectors can be seen as red and green circles in Fig. 2. It is a binary classification problem where the SVM algorithm draws many lines to separate vectors according to true and false. After optimization, the SVM algorithm returns the best-fitted line for classifying the support vectors.

According to the equation of hyperplane:

$w \cdot X + b = 0$  Where X is a vector and w is a vector normal to hyperplane and b is an offset value.

The decision rules have been applied to classify the positive and negative value.

$$\vec{X} \cdot \vec{w} - c \geq 0$$

putting  $-c$  as  $b$ , we get

$$\vec{X} \cdot \vec{w} + b \geq 0$$

Hence,

$$y = \begin{cases} +1 & \text{if } \vec{X} \cdot \vec{w} + b \geq 0 \\ -1 & \text{if } \vec{X} \cdot \vec{w} + b < 0 \end{cases}$$

According to the above equation as in [24], the value  $w \cdot X + b > 0$  then it will be detected as a positive value (1) otherwise it will be a negative value (0). The proposed algorithm is used the ASD symptoms dataset to train the SVM model. The proposed algorithm to train the SVM model for the prediction of ASD symptoms has been given below.

*Proposed SVM Algorithm:*

*Pseudo Code:*

*Step 1: Read data from csv file.*

Step 2.  $X$ =data from csv

$x_1=[a_1,a_2, a_3,a_4,a_5, \dots \dots a_n]$  is a user text column inside the dataset.

$x_2=[r_1,r_2, r_3,r_4,r_5, \dots \dots r_n]$  is a label data column inside the dataset.

Step 3. Split the dataset as train data and test data.

```
train, test = train_test_split(X, test_size=0.2,  
random_state=1)  
X_train = train['text'].values  
X_test = test['text'].values  
y_train = train['label']  
y_test = test['label']
```

Step 4. Define NLP functions to pre-process text from  $X_{train}$  and  $X_{test}$ .

```
//Text tokenization  
tokenize_text=tokenizer(text)  
// Stop Words removal from text  
fresh_text = stopwords.words(text)  
// text to vector conversion using vectorization method  
vectorizer = CountVectorizer(  
    analyzer = 'word',  
    tokenizer = tokenize_text,  
    lowercase = True,  
    ngram_range=(1, 1),  
    stop_words = fresh_text)
```

Step 5. Call method to train SVM model.

```
// kfold has been used to send data as a bunch into the SVM model.  
kfold = StratifiedKFold(n_splits=5, shuffle=True, random_state=1)  
// Make the pipeline to send data inside the SVM model.  
pipeline_svm = make_pipeline(vectorizer, SVC(probability=True,  
kernel="linear", class_weight="balanced"))  
// SVM model initialization with parameters  
grid_svm = GridSearchCV(pipeline_svm,  
    param_grid = {'svc__C': [0.01, 0.1, 1]},  
    cv = kfold,  
    scoring="roc_auc",  
    verbose=1,  
    n_jobs=-1)  
// fit data inside the model to train  
grid_svm.fit(X_train, y_train)
```

Step 6. Predict the result using SVM model.

```
model= grid_svm.best_estimator_  
prediction = model.predict(X_test)
```

The result of this proposed algorithm has been discussed in the Result and Discussion section.

### C. Logistic Regression

The next approach is logistic regression which is able to identify ASD symptoms from user text. This is another machine-learning algorithm for binary classification problems. The logistic regression model works on finding the value between 0 and 1 and this algorithm is bounded. The logistic regression does not contain any relationship between input and output variables because of the nonlinear transformation to the odds ratio. Logistic regression can be defined as-

$$\text{Log}(p(M)/1-p(M))=\beta_0+ \beta_1X$$

$p()$ -> refers to the probability function.

$M$ -> refers to the input

Where  $p(M)/1-p(M)$  in the left side is termed as odds and the left side is called logit. The odds are the ratio of chance of success according to the chance of failure. In logistic regression, the linear input combination is transformed to  $\text{log}(\text{odds})$ .

The inverse of the above function will be:  $p(M)=(e^{\beta_0+\beta_1x} / 1+ e^{\beta_0+\beta_1x})$

This function is a sigmoid function that can be produced an S-shaped curve and it returns a value between 0 and 1. The main work of the sigmoid function is to generate a probability value from the expected value and this value always will be bounded between 0 and 1. The mathematical representation of the sigmoid function can be  $f(m) = 1/(1+e^{-m})$

Fig. 3 shows the S-shape curve according to the function-  
 $f(m) = 1/(1+e^{-m})$

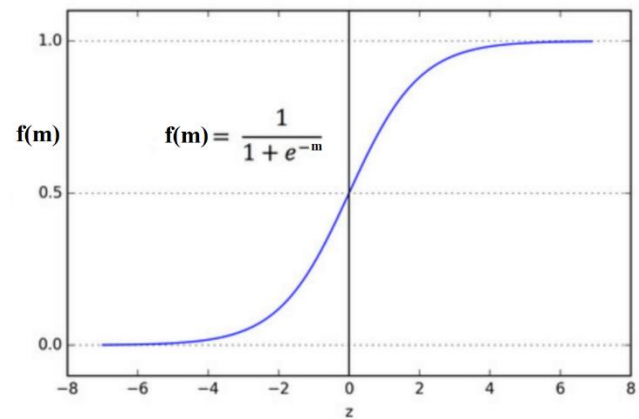


Fig. 3. Sigmoid function according to the equation.

The proposed algorithm which is based on logistic regression has been given below.

Proposed Logistic Regression Algorithm:

Pseudo Code:

Step 1: Read data from CSV file.

Step 2:  $X$ =data from csv

$x_1=[a_1,a_2, a_3,a_4,a_5, \dots \dots a_n]$  is a user text column inside the dataset.

$x_2=[r_1,r_2, r_3,r_4,r_5, \dots \dots r_n]$  is a label data column inside the dataset

Step 3: Features generation using Vectorizer function.

// Vectorizer function converts the string value to number values.

```
vectorizer = CountVectorizer(  
    analyzer = 'word',  
    lowercase = False,)
```

// Feature creation using vectorizer.fit\_transform function

```
features = vectorizer.fit_transform(x_1)
```

// Feature array creation

```
features_nd = features.toarray()
```

Step 4: Model creation and training

//Logistic model creation

```
log_model = LogisticRegression()
```

// Logistic model train

```
log_model = log_model.fit(X=X_train, y=y_train)
```

Step 5: Prediction using Logistic Regression model  
 $y_{pred} = \log\_model.predict(X\_test)$

The output as a result of this proposed algorithm has been discussed in the Result and Discussion section.

#### D. K-Nearest Neighbor (KNN)

The third approach to identifying ASD symptoms from user text. KNN is a supervised algorithm that can be used in classification problems. This algorithm uses feature similarity to predict the value for a new data point that comes as input. KNN uses the similarity between new data points with available categorical data points and identifies this data point in a particular similar data point's category. KNN is very popular in binary classification. Fig. 4 shows before KNN prediction the new data point plotted on a graph where two categories of data points are present. Category A and Category B have been classified according to the nearest data points. According to Fig. 5, after applying the KNN algorithm, the new data point has been assigned as Category B because the nearest neighbor of the new data point is the data point of Category B.

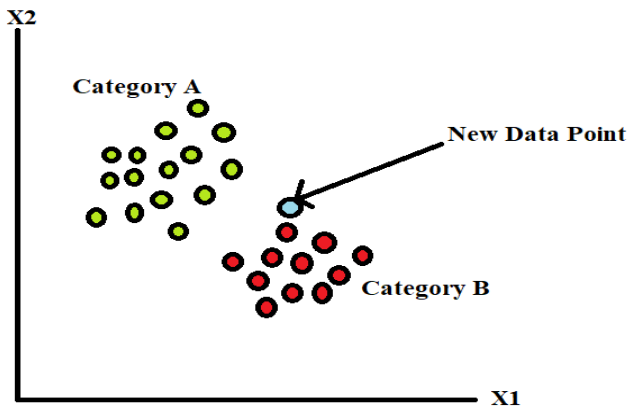


Fig. 4. Before the KNN algorithm is applied on a new data point.

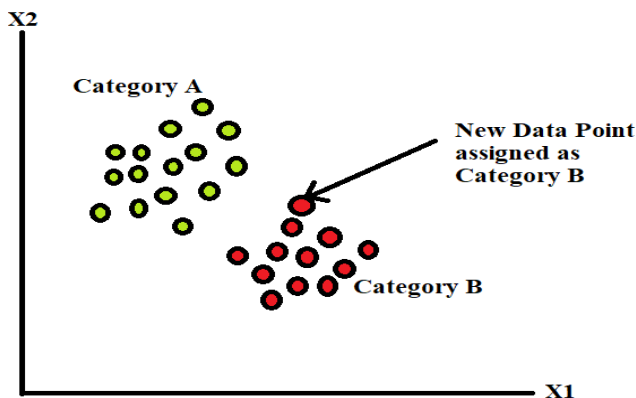


Fig. 5. After the KNN algorithm applied on a new data point.

K is a parameter in KNN that is related to the number of nearest neighbors that are used to count the majority process. The first step of KNN is to transform data points into vectors where the KNN algorithm will calculate the distance of these vectors. KNN computes the distance of each data point of training data then it will calculate the probability of a new data point is similar to the training data. Euclidean, Minkowski or

Hamming distance functions can be used here to calculate the distance. The proposed algorithm is based on KNN that uses the proposed dataset.

Proposed KNN Algorithm:

Pseudocode:

Step 1: Read data from CSV file.

Step 2:  $X = \text{data from csv}$

$x_i = [a_1, a_2, a_3, a_4, a_5, \dots, a_n]$  is a user text column inside the dataset.

$y_i = [r_1, r_2, r_3, r_4, r_5, \dots, r_n]$  is a label data column inside the dataset

// Split the data in train and test format

$x\_train, x\_test, y\_train, y\_test = \text{train\_test\_split}(x_i, y_i, \text{stratify} = y_i, \text{test\_size} = 0.33)$

Step 3: String value to Vectorizer transformation.

// Vector function declaration

vectorizer = CountVectorizer()

// Vector transformation of x\_train

$x\_train\_bow = \text{vectorizer.fit\_transform}(x\_train)$

// Vector transformation of y\_train

$x\_test\_bow = \text{vectorizer.transform}(x\_test)$

Step 4: KNN Model creation

$\text{grid\_params} = \{ 'n\_neighbors': [40, 50, 60, 70, 80, 90], 'metric': ['manhattan'] \}$

$\text{knn} = \text{KNeighborsClassifier}()$

Step 5: KNN model training using prepared dataset

$\text{clf} = \text{RandomizedSearchCV}(\text{KNN}, \text{grid\_params},$

$\text{random\_state} = 0, \text{n\_jobs} = -1, \text{verbose} = 1)$

$\text{clf.fit}(x\_train\_bow, y\_train)$

Step 6: Prediction using KNN model

$\text{Prediction} = \text{clf.predict\_proba}(x\_test\_bow)$

The result of this proposed KNN-based algorithm has been discussed in Result and Discussion section.

#### E. Random Forest

The last approach is a Random forest machine learning algorithm to identify the ASD Symptoms from user text. This is one of the important machine learning algorithms which is constructed from decision tree algorithms. The Random forest algorithm is used to solve regression and classification problems. This algorithm is trained through bagging which is an ensemble algorithm. The ensemble algorithm is used to improve the accuracy of the machine learning algorithms. The outcomes of the random forest are based on the prediction of the decision tree. The mean of various decision trees is used to calculate the prediction value by the random forest algorithm. Decision trees in random forest algorithms use the tree view to generate prediction value from a series of feature-based splits where it starts from a root node and ends in a leaf node with a decision. Feature selection and the splitting process is depending on the impurity which means either result will be 'yes' or 'no'. To know about the impurity of the dataset, the Gini index [25] is a good option and that can be written mathematically-

$$\text{Gini Index} = 1 - \sum (P_i)^2$$

$$= 1 - [(P_+)^2 + (P_-)^2]$$

Where  $P_+$  is denoted as a probability of positive class and  $P_-$  is denoted as a probability of negative class. Gini Index will find out all the possibilities of splits and will choose the root node and this root node will be a low impurity means the lowest Gini index.



The proposed random forest-based algorithm has been given below which is utilizing the proposed dataset to train the model for the prediction of ASD symptoms from user text.

*Proposed Random Forest algorithm:*

*Pseudo code:*

*Step 1: Read data from CSV file.*

*Step 2: X=data from csv*

$x_1=[a_1,a_2, a_3,a_4,a_5,.....a_n]$  is a user text column inside the dataset.

$x_2=[r_1,r_2, r_3,r_4,r_5,.....r_n]$  is a label data column inside the dataset

*Step 3: Features generation using TFIDF Vectorizer function.*

*// Split data and assign for training and testing purpose*

$X_{train}, X_{test}, y_{train}, y_{test} = \text{train\_test\_split}(x_1, x_2, \text{test\_size} = 0.90, \text{random\_state}=42)$

$X_{train}, X_{test}, y_{train}, y_{test} = \text{train\_test\_split}(X_{train}, y_{train}, \text{test\_size} = 0.5, \text{random\_state}=42)$

$X_{val}, X_{test}, y_{val}, y_{test} = \text{train\_test\_split}(X_{test}, y_{test}, \text{test\_size} = 0.5, \text{random\_state}=42)$

*// TFIDF Vectorizer Function declaration*

*def vectorize(data,tfidf\_vect\_fit):*

$X_{tfidf} = \text{tfidf\_vect\_fit.transform}(data)$

$words = \text{tfidf\_vect\_fit.get\_feature\_names}()$

$X_{tfidf\_df} = \text{pd.DataFrame}(X_{tfidf}.toarray())$

$X_{tfidf\_df}.columns = words$

$\text{return}(X_{tfidf\_df})$

$\text{tfidf\_vect} = \text{TfidfVectorizer}(analyzer=\text{clean})$

$\text{tfidf\_vect\_fit}=\text{tfidf\_vect.fit}(X_{train}[\text{'text'}])$

$X_{train}=\text{vectorize}(X_{train}[\text{'text'}],\text{tfidf\_vect\_fit})$

*Step 4: Random Forest model initialization*

$\text{model}=\text{RandomForestClassifier}(\text{bootstrap}=\text{True}, \text{ccp\_alpha}=0.0, \text{class\_weight}=\text{None},$

$\text{criterion}=\text{'gini'}, \text{max\_depth}=20, \text{max\_features}=\text{'auto'},$

$\text{max\_leaf\_nodes}=\text{None}, \text{max\_samples}=\text{None},$

$\text{min\_impurity\_decrease}=0.0,$

$\text{min\_samples\_leaf}=1, \text{min\_samples\_split}=2,$

$\text{min\_weight\_fraction\_leaf}=0.0, \text{n\_estimators}=100,$

$\text{n\_jobs}=\text{None}, \text{oob\_score}=\text{False}, \text{random\_state}=\text{None},$

$\text{verbose}=0, \text{warm\_start}=\text{False})$

$X_{val}=\text{vectorize}(X_{val}[\text{'text'}],\text{tfidf\_vect\_fit})$

$\text{rf1} = \text{RandomForestClassifier}(\text{n\_estimators}=100,\text{max\_depth}=20)$

$\text{rf1.fit}(X_{train}, y_{train}.values.ravel())$

*Step 5: Prediction of Random Forest Model.*

$\text{Prediction} = \text{model.predict}(X_{val})$

The result of this algorithm has been discussed in the Result and Discussion section.

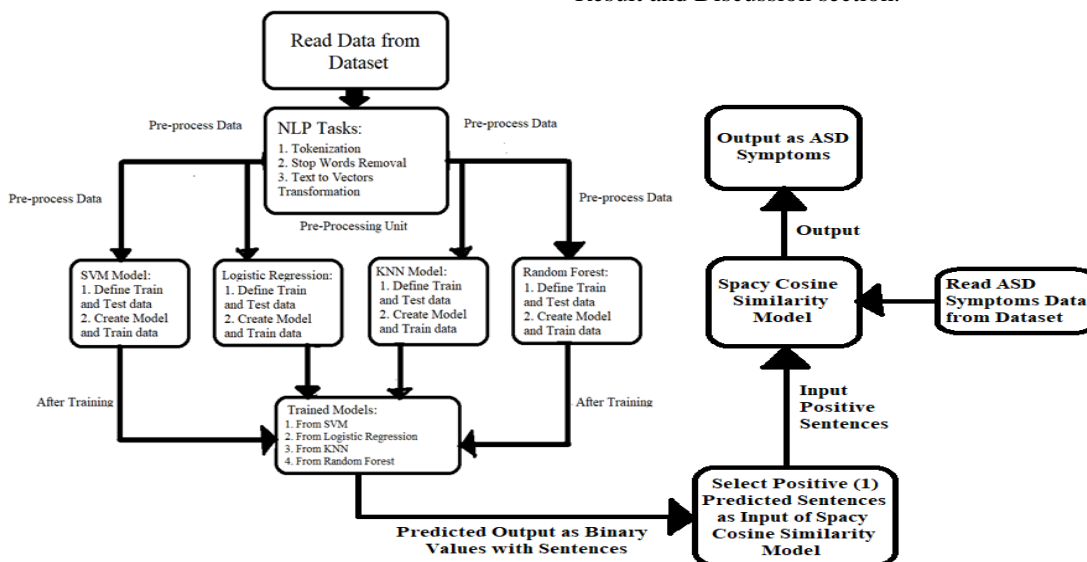


Fig. 6. Flow diagram of Proposed System Architecture

### F. Proposed System Flow

Fig. 6 shows the overall architectural diagram of the proposed system to identify ASD symptoms from user text. The proposed system will read data from the ASD symptoms dataset in the first step. Each sentence will be passed through some NLP tasks like tokenization, stop words removal, and text-to-vector transformation. Sentences are tokenized by the tokenization process of NLP where stop words mean unwanted words (tokens) like ‘am’, ‘is’, ‘a’, ‘an’, etc. are removed from the sentence. The final task is to transform each token into vectors. These vectors are the main input in each machine-learning model with labeled data. After vector transformation, data are separated into two parts which are training and testing data. According to Fig. 6, SVM, Logistic Regression, KNN, and Random Forest models are trained with the training data, and testing the prediction results with test

data. After completion of the model training and testing, the proposed system is ready to accept new paragraph text from the user to identify a number of positive sentences from the given text that denotes ASD symptoms. The predicted sentences will be in two modes either it will positive (1) or negative (0). The proposed system will select only the sentences that are positive and the negative sentences will be discarded in the next step. The selected positive sentences will be the input to the Spacy Cosine Similarity Model. This model will read each positive sentence from the ASD symptoms dataset (Table V) and calculate the cosine similarity with the input sentence. The Spacy cosine similarity model will check a sentence that has the highest cosine similarity score with the input sentence and the Label will be selected of this sentence by the system. The Label will indicate the ASD problem according to Table IV. Each input sentence will be handled by



this cosine similarity model to identify ASD problems. The algorithm has been given below.

```
Proposed Cosine Similarity algorithm:  
Pseudo code:  
Step 1: // Declare Python and Spacy packages  
import spacy  
import pandas as pd  
nlp = spacy.load('en_core_web_lg')  
// Initialize positive ASD symptoms data in a Dataframe  
Step 2: df = pd.read_csv("ASD_Smptoms.csv")  
// Three list variable has been declared to store each cosine  
similarity value with sentence and label  
comments=[]  
sentiment=[]  
cosine_value=[]  
Step 3: Define Cosine Similarity Calculation Method  
def Spacy_Cosine(strs):  
for ind in df.index:  
sen1 = nlp(df['Comments'][ind])  
sen2 = nlp(strs)  
  
sen1_no_stop_words = nlp(' '.join([str(t) for t in sen1 if not  
t.is_stop]))  
sen2_no_stop_words = nlp(' '.join([str(t) for t in sen2 if not  
t.is_stop]))  
  
comments.append(df['Comments'][ind])  
sentiment.append(df['Sentiment'][ind])  
  
score=sen2_no_stop_words.similarity(sen1_no_stop_words)  
# score=sen2.similarity(sen1)  
cosine_value.append(score)  
  
dfc=pd.DataFrame(  
{  
'Comments': comments,  
'Sentiment': sentiment,  
'Cosine_Scores': cosine_value  
})  
  
dfc.to_csv(r'ASD_Cosine_Data.csv')  
dfc['Cosine_Scores']=dfc['Cosine_Scores'].astype('float64')  
i = dfc['Cosine_Scores'].idxmax()  
  
return dfc['Sentiment'][i]  
Step 4: // Select only predicted positive (1) sentences as input  
Strs= List of predicted positive sentences  
for st in str['Comments']:  
result=Spacy_Cosine(st)  
print(st,"=",result)
```

The output of this proposed algorithm has been given and discussed in Result and Discussion section.

#### IV. RESULT AND DISCUSSION

The proposed system uses multiple traditional machine learning models which are SVM, Logistic Regression, KNN, and Random Forest. The proposed dataset has been utilized to train and test these models. The result of each model according to the dataset has been discussed here one by one.

##### A. Result and Discussion of SVM Model

Table VI has been given here to show the SVM model metrics after training and testing.

TABLE VI. SVM MODEL METRICS

Sl. No.	Metrics	Value
1.	AUC	0.77
2.	F1	0.74
3.	Accuracy	0.71
4.	Precision	0.71
5.	Recall	0.77

The SVM model has multiple metrics to understand the model's performance and scalability. According to Table VI, the AUC score is 77% which is a good score for any trained SVM model. The AUC refers to the area under the ROC curve that is a popular metric of SVM. If  $AUC = 1$ , then the model can distinguish correctly between positive and negative. If the condition is  $0.5 < AUC < 1$  then there is a high chance to distinguish between positive and negative. The F1 score of this proposed SVM model is 74% which refers to the combination of precision and recall scores which are 71% and 77% respectively. The overall accuracy of this proposed SVM model is 71% and this score is a good approach. According to the ROC curve, the higher Y-axis value denotes a higher number of true positives than false negatives as well as the higher X-axis value denotes a higher number of false positives than true negatives. According to Fig. 7, the ROC curve of this proposed SVM model shows a higher true positive rate than the false positive rate. This signifies that the proposed is able to generate good prediction results and this ROC curve indication satisfied this.

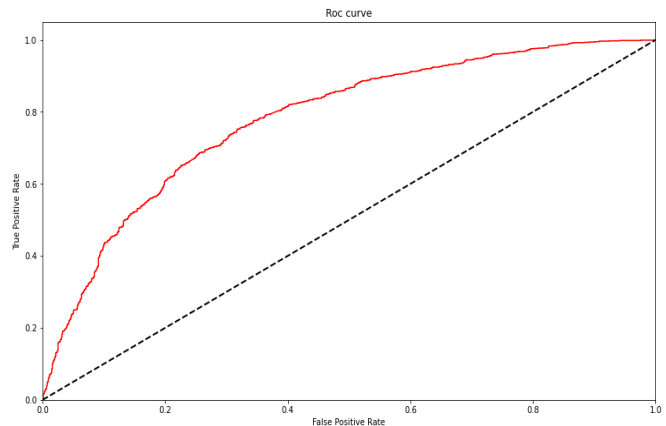


Fig. 7. ROC curve of proposed SVM model.

According to Fig. 8, the training scores line on the graph is between 0.99 and 0.94 (approx.) and the cross-validation scores line is between 0.70 and 0.79 (approx.). The gap between the two score lines is not very high. This proposed model is able to generate good prediction results according to the given Fig. 8.

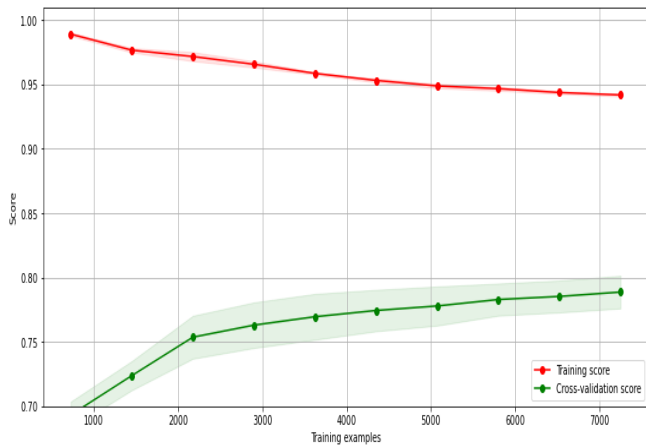


Fig. 8. Training scores and cross-validation scores of SVM.

A few sentences have been sent to the proposed SVM model for the prediction. According to Fig. 9, the proposed model shows the output as 1 or 0, which is attached to each sentence. One (1) refers to a positive sentence regarding ASD detection whereas zero (0) refers to a negative sentence.

```

Result:How does speech therapy help with a nonverbal to speak=[1]
Result:because all they do there is play with toys with him every time=[1]
Result:I'm confused guys help my son is 3years old now=[0]
Result:he does is mumbles only no proper words=[1]
Result:but he goes to speech therapy every month=[1]
Result:Does it help=[0]
Result:My son is 5 and started speech therapy at 3=[1]
Result:My Son can't speak and always spin the wheels of a toy car=[1]
Result:She is 4 years old and reaping words=[1]
    
```

Fig. 9. Prediction result of SVM model as output.

### B. Result and Discussion of Logistic Regression

According to Fig. 10, a confusion matrix has been represented that refers to how many are true actual 1s, actual 0s, predicted 0s, and predicted 1s.

According to the test data, the proposed logistic regression model selects 75 sentences as actual 0s and predicted as 0s. Fifteen (15) sentences are actual 0s but predicted as 1s whereas 31 sentences are actual 1s and predicted as 0s. Forty (40) sentences are actual 1s and predicted as 1s. The following metrics for model evaluation have been given in Table VII. The AUC value is 0.69 (69%) which covers the ROC curve. The F1 score is 0.63 (63%) which combines the precision and recall values. The precision value is 0.72(72%) and the recall value is 0.56 (56%). The overall accuracy of the proposed Logistic regression model is 0.71 (71%). According to Fig. 11, the ROC curve, the higher Y-axis value denotes a higher number of true positives than false negatives as well as the higher X-axis value denotes a higher number of false positives than true negatives. The training accuracy is 0.97 (97%) whereas the testing accuracy is 0.70 (70%) on the proposed dataset according to Fig. 11.

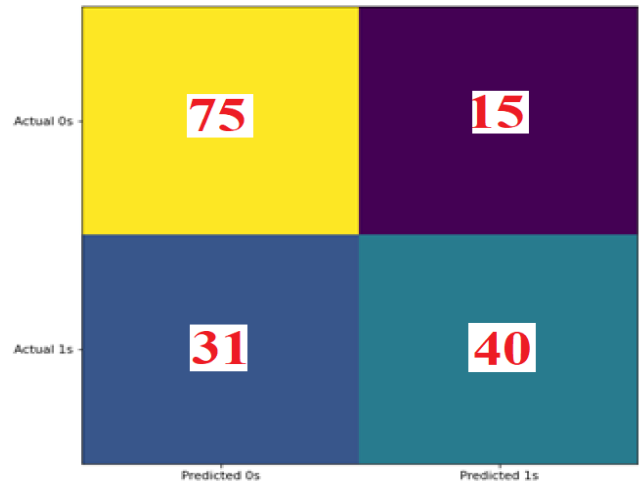


Fig. 10. Confusion matrix of logistic regression model.

TABLE VII. LOGISTIC REGRESSION MODEL METRICS

Sl. No.	Metrics	Value
1.	AUC	0.69
2.	F1	0.63
3.	Accuracy	0.71
4.	Precision	0.72
5.	Recall	0.56

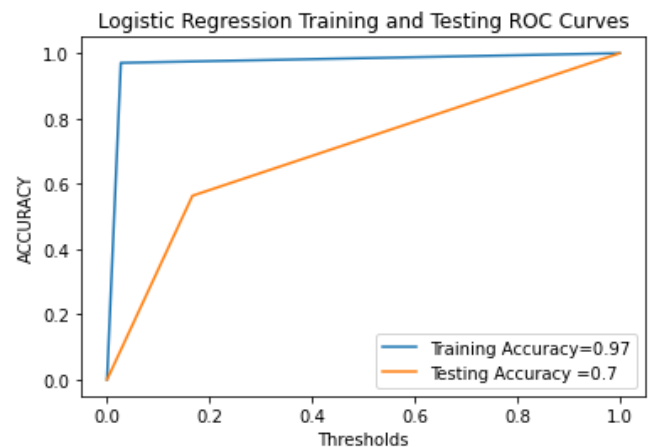


Fig. 11. ROC curves of logistic regression.

### C. Result and Discussion of KNN model

According to Fig. 12, two ROC curve has been represented that shows the accuracy of the proposed KNN model.

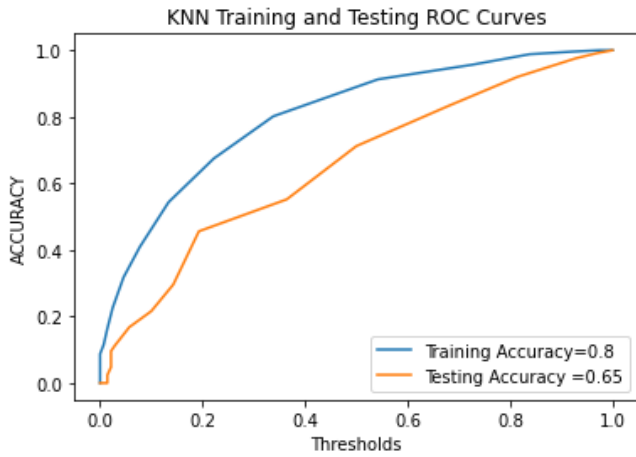


Fig. 12. ROC curves of KNN training and testing.

The AUC value of the proposed KNN model is 0.67 (67%) which refers to the high chance to distinguish positive and negative sentences. The AUC refers to the area of the ROC curves. The given two ROC curves stated that they are moving in almost the same manner from 0 to 1. The training accuracy is 0.80 (80%) as well as testing accuracy is 0.65 (65%) on the proposed dataset. It is another good metric that shows the ability of the prediction of the proposed KNN model. Accuracy is an important metric for machine learning model determination according to the task. The popular metrics have been given in Table VIII are useful to evaluate the machine learning model. The AUC value is already given as 0.67 (67%). The F1 score is 0.65 (65%) which combines the precision and recall values. The precision value is 0.65 (65%) and the recall value is 0.66 (66%). The overall accuracy of the proposed KNN model is 0.62 (62%).

TABLE VIII. KNN MODEL METRICS

Sl. No.	Metrics	Value
1.	AUC	0.67
2.	F1	0.65
3.	Accuracy	0.62
4.	Precision	0.65
5.	Recall	0.66

#### D. Result and Discussion of Random Forest model

The last proposed model is Random Forest which is a good classifier. The proposed dataset has been applied to this model to predict the sentiment of the sentences from the parents' dialogues. This model trains with the features after extracting these from the sentences.

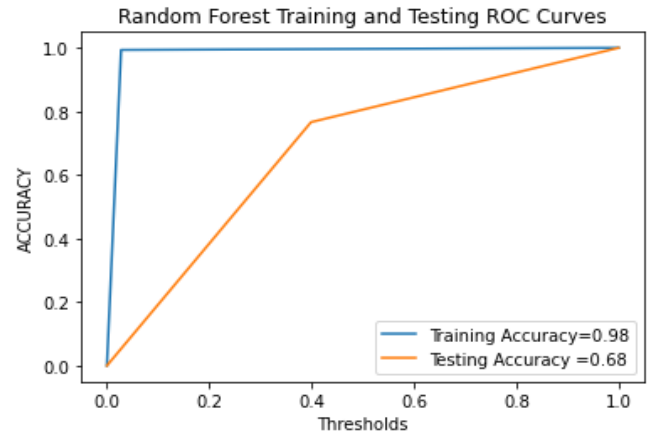


Fig. 13. ROC curves of random forest.

Fig. 13 shows the two lines that are showing the accuracy graph of the proposed Random Forest model. The blue color line shows the accuracy of the training data as well as yellow line shows the accuracy of the testing data. According to Fig. 13, the accuracy score of this model on the testing data is 0.98 (98%), and 0.68 (68%) accuracy score on the testing data. According to Table IX, the F1 score is 0.73 (73%) which is combined two metrics values that are Precision and Recall. Precision refers to the measurement of the positive prediction of a model whereas recall refers to the positive cases that are correctly predicted by the model. The Precision value is 0.70 (70%) and the Recall value is 0.76 (76%). These two values have been defined in Table IX. The overall accuracy value of the proposed model is 0.69 (69%).

TABLE IX. RANDOM FOREST METRICS

Sl. No.	Metrics	Value
1.	AUC	0.68
2.	F1	0.73
3.	Accuracy	0.69
4.	Precision	0.70
5.	Recall	0.76

Fig. 14 shows the top 20 important features from all sentences of the prepared dataset that are also used in the model training. The frequency of each feature can be seen in Fig. 14. "poo", "autism", and "toilet", are three noted words with the highest frequencies. Other words are also given in Fig. 14.

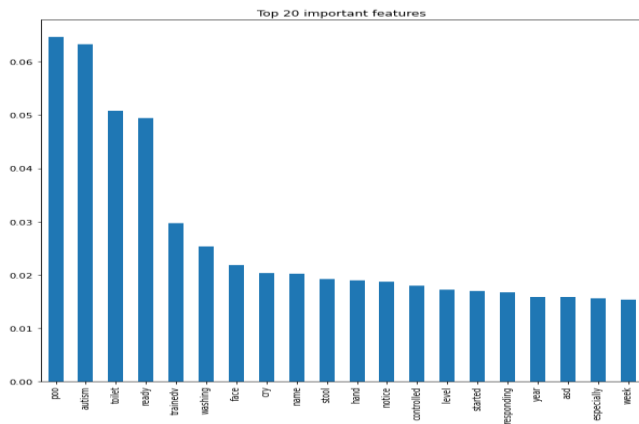


Fig. 14. Important features of proposed dataset.

### E. Result and Discussion of Spacy Cosine Similarity Model

The proposed model returns the ASD problem according to the positive sentences that contain ASD symptoms.

```
In [51]: runfile('F:/DeepL/Spacy_Cosine.py', wdir='F:/DeepL')
she cant understand where to do pee = 7

In [52]: runfile('F:/DeepL/Spacy_Cosine.py', wdir='F:/DeepL')
She is very aggressive and throwing objects to other = 8

In [53]: runfile('F:/DeepL/Spacy_Cosine.py', wdir='F:/DeepL')
Eyes are scrolling and hand flapping = 6
```

Fig. 15. Output of spacy cosine similarity model.

The output can be seen here in Fig. 15 where the sentence “she can’t understand where to pee” is labeled with 7. The sentences like “She is very aggressive and throwing objects to others” and “Eyes are scrolling and hand flapping” are labeled with 8 and 6. According to Table IV, 7 denotes Cognitive Behaviour problems whereas 8 refers to Hyper Active problems and 6 refers to the Eye contact problem. After the detection of ASD problems, therapies can be started according to the detected problem and that will be very helpful to reduce the ASD symptoms.

### V. LIMITATION OF THE PROPOSED SYSTEM

The proposed system has been equipped with traditional machine-learning models. The Probabilistic model like Naïve Bayes or ensemble model like XGBoost models can be applied to this dataset for better accuracy. More data can be collected for the training score and testing score enhancement. More accurate ASD-related parent dialogs-related to ASD are needed to train the model. If the dataset is large then this traditional machine learning model will not work better and that will downgrade the proposed system. If one part of this system is not responding then the cosine similarity part will not work perfectly.

### VI. CONCLUSION

The proposed system will accept natural language text from the parents’ dialogues. The proposed system will

generate positive or negative sentences using sentiment analysis. A sentence that contains ASD symptoms is 1 and a sentence that does not contain any ASD symptoms is 0. The sentiment analysis has been done using SVM, Logistic Regression, KNN, and Random Forest models. These models are trained with the proposed dataset. After prediction, the proposed system will select all positive sentences as input for the cosine similarity model. An ASD symptoms dataset has been proposed where each sentence is labeled with a value that indicates particular ASD symptoms. The proposed system will calculate the cosine similarity value between the input sentence and each ASD sentence of the ASD symptoms dataset. The proposed system will select a label value of an ASD symptoms sentence that has the highest cosine similarity value with the input sentence and this label value will indicate the ASD problem. This system is based on text and does not need to use MRI or Image data for the prediction of ASD at the early age of a child. This system may be used in many health centers in rural areas because people in rural areas are not aware of ASD as well as many of them are financially weak to spend money for MRI or other ASD diagnosis processes.

### VII. FUTURE WORK

The proposed dataset can be utilized to train the Naïve Bayes and XGBoost models for better output and accuracy. The cosine similarity model of this system depends on the prediction result of the traditional machine learning models. These models are good for small datasets but these models will not work with the best performance when the dataset is large. XGBoost is an ensemble model which is a very powerful model for prediction as well as the Naïve Bayes model is a probabilistic model that works on Bayes theorem. These two models implementation using a proposed dataset for ASD detection is the future development of this proposed system.

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# Speaker Recognition Improvement for Degraded Human Voice using Modified-MFCC with GMM

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**Abstract**—Speaker’s audio is one of the unique identities of the speaker. Nowadays not only humans but machines can also identify humans by their audio. Machines identify different audio properties of the human voice and classify speaker from speaker’s audio. Speaker recognition is still challenging with degraded human voice and limited dataset. Speaker can be identified effectively when feature extraction from voice is more accurate. Mel-Frequency Cepstral Coefficient (MFCC) is mostly used method for human voice feature extraction. We are introducing improved feature extraction method for effective speaker recognition from degraded human audio signal. This article presents experiment results of modified MFCC with Gaussian Mixture Model (GMM) on uniquely developed degraded human voice dataset. MFCC uses human audio signal and transforms it into a numerical value of audio characteristics, which is utilized to recognize speaker efficiently with the help of data science model. Experiment uses degraded human voice when high background noise comes with audio signal. Experiment also covers, Sampling Frequency (SF) impacts on human audio when “Signal to Noise Ratio” (SNR) is low (up to 1dB) in overall speaker identification process. With modified MFCC, we have observed improved speaker recognition when speaker voice SNR is upto 1dB due to high SF and low frequency range for mel-scale triangular filter.

**Keywords**—GMM; artificial intelligence; MFCC; fundamental frequency; mel-spectrum; speaker recognition

## I. INTRODUCTION

Voice as a human identity is still a challenge for machine. Now businesses need to have effective speaker recognition though his/her voice in silent or in noise environment. Medical industries are also moving toward human voice based medical diagnosis. So human voice is not only identity of a person but also an aid in medical problem diagnosis. A human’s voice is identical to himself and always different from each other. Human creates audio from mouth and throat. Fundamental frequency is prime frequency, and it is transformed due to different vocal cord shapes and that create every human’s voice as identical voice.

Any speaker recognition process starts with voice feature extraction which is highly dependent on voice characteristics. Speaker recognition system is always designed similar to the mechanism that humans use to recognize two different speakers. A human generally identifies another human’s voice based on few classifications. Generally, humans first identify speaker’s gender, whether it’s male voice or female voice. Key differentiation between female and male voice is tone/pitch and

frequency. After gender identification human brain considers multiple voice features to classify speaker. Every person’s voice is identical, and it’s based on different voice characteristics like amplitude, pitch, frequency, jitter and spectral power. Male voice has 0-900 hz as prime or fundamental frequency and similarly fundamental frequency for female voice is 0-1500Hz. If we average out male fundamental frequency, then it is 110 hz and female average fundamental frequency is 211 Hz [1].

Human lungs generate air pressure to start sound and this sound is articulated by vocal cord. Teeth, jaw, and tongue are main articulators of vocal tract which modulate fundamental frequency (F0) [2][3]. This air pressure creates sound with prime or fundamental frequency. Fundamental frequency sound is transformed by the vocal tract to generate different sound changes. Human prime frequency or fundamental frequency is base frequency for any speaker recognition system. Following sub sections define different key voice features which are used for feature extraction in speaker recognition process.

### A. Fundamental Frequency and Pitch

Human voice signal consists of different sine waves with multiple frequencies. If we segregate all these waves and identify lowest sinusoidal wave frequency, then that frequency is considered as fundamental frequency (F0) of the human voice signal. F0 is also considered to calculate the pitch of the human audio signal. The perception of F0 and equivalent harmonics is generally known as voice pitch. The fundamental frequency value should come into a certain frequency range. Else, the pitch of the human voice signal is either extremely high or extremely low. Basically, fundamental frequency is indirectly proportional to the period of the human voice signal or directly proportional to sampling frequency [4]. If N is number of overlapped segments which divide complete voice signal and  $T_i$  denotes  $i$ th-segment period, then

$$F0 = \frac{1}{N} \sum_{i=1}^N \frac{1}{T_i}$$

### B. Jitter

Jitter is another audio characteristic of voice signal. It analyzes as periodic variation in F0 of voice signal. Frequency variation in voice signal is represented by Jitter. Jitter can be calculated as per [5]



$$Jitter = \frac{\frac{1}{N-1} \sum_{i=1}^{N-1} |T_i - T_{i+1}|}{\frac{1}{N} \sum_{i=1}^N T_i}$$

### C. Shimmer

Shimmer also represents variation, but focuses mainly on amplitude. When a speaker generates voice then that voice amplitude may vary. It may be high or low. This amplitude variation is the shimmer of the voice signal. If  $A_k$  is amplitude of cycle  $k$  and  $M$  is number of cycles of the voice signal then shimmer defined as

$$Shimmer = \frac{1}{M-1} \sum_{k=1}^{M-1} 20 \log_{10} \frac{A_k}{A_{k+1}}$$

Shimmer, fundamental frequency, pitch, and jitter are voice characteristics and are helpful during voice feature extraction process, which is defined in next section.

Speaker recognition is not easy when high background noise comes with speaker voice. When high noise comes with speaker voice then key human voice feature subsides and creates issue in speaker recognition. Most of previous research work uses MFCC as feature extraction method but it's still challenging with degraded human voice to extract optimized human voice features. The purpose of this research is to identify optimized feature extraction.

The paper is organized as follows: Section II is more about related work in same research topic; base model for speaker recognition is discussed in Section III which defines all necessary steps for speaker recognition system. In this section we also discuss about what is degraded human voice, and the data set. In Section IV we present baseline model results, proposed model with modified MFCC and results comparison, then we have concluded discussion in Section VI.

## II. RELATED WORK

N. V. Tahliramani and N. Bhatt [7] study presents that speaker can be recognized by a machine from the speaker's voice. MFCC is used to extract voice features during training and can also be used for speaker identification. Silence and noise can also be present alongside the speaker's actual voice during speaker recognition. According to the proposed model, noise and silence (between words) are removed before comparing the voice for similarity with the stored voice sample of the same speaker. Framing, windowing, low-pass filtration, and transformation techniques are employed to identify voice features. GMM is used during training and testing for speaker recognition. GMM increases the probability of correctly recognizing the speaker, even when noise is present in the speaker's voice.

S. Park, Y. Park, A. Nasridinov and J. Lee [6] study presents that conference call (closed user group) over any conference application requires gender identification. Gender can be recognized based on frequency of the speaker's voice and effectiveness of the speaker recognition process. Correct meeting notes can be created based on gender and speaker recognition methods. Female voice frequency (average 188-221Hz) is commonly high as compared to the male voice frequency (average 100-146Hz). Difference in frequency is used to recognize gender and correctly assign the person's ID.

"Text To Speech" API from Google is used to transform voice to text and create runtime Minutes of Meeting (MoM).

N. Gupta and S. Jain [21] presented that speaker recognition is possible through Convolutional Neural Network (CNN) based speaker recognition system. Siamese and CIFAR network architecture are used in speaker recognition. CNN base layers, convolutional, pooling and dense, are used in the model for pattern matching, recognizing deviation and pattern categorization. Negative and positive voice samplings are used for better speaker identification. Positive human voice sample is recorded when there is less distance between speaker and the microphone. When recording is done with some distance then it is considered as negative sample. Presented model for speaker recognition is built on "CIFAR" network architecture with shared weightage on "Siamese Network". Main purpose of "Siamese Neural Network" (SNN) is to learn the feature vectors. This type of speaker recognition system can be used more in places like bank and telecom.

M. M. Mubarak al Balushi, R. V. Lavanya, S. Koottala and A. V. Singh [23] proposed denoising technique for better speaker recognition. Study proposed that denoising can be performed in transformation domain and it gives different results with different wavelet transformation techniques. Denoising means suppression of the noise from speaker's voice. Denoising filter can suppress either the low frequency in the human voice when it notices it or increase in the voice where identifying that SNR is low. In addition, wavelet filter can filter the voice in the frequency domain. Proposed work is applicable for human and animal voice. Authors used Matlab programming tool to simulate results. Fejer- Korovkin wavelet filter has been compared with other available wavelet transformation filter to analyze noise elimination for better speaker recognition. Fejer- Korovkin & Dmey wavelets were verified for denoising. SNR and Mean Square Error (MSE) used as a parameter to check voice signal quality. Fejer-Korovkin results are 5% better than Dmey wavelet in terms of SNR.

R. M. Lexuşan [16] presented that, which voice features are the best features for human voice. Some of the key features of human voice are MFCC coefficient, energy of the voice signal, fundamental frequency of voice signal, duration and ratio of voice and unvoiced segment. This study also performed experiment which used 172 voice samples with happiness, sadness, and neutral states. Study also using "Support Vector Machine" (SVM) and decision tree as a classification method. Study shown that decision tree gives better recognition rate as compared to liner SVM. Study also concluded that algorithm provides approximately 85% recognition rate. With help of Nao robot, it's capable to recognize speaker emotions from the recording. Similarly, R. Chakroun, L. B. Zouari, M. Frikha and A. Ben Hamida [24] presented that Support Vector Machine (SVM) is more supportive with GMM for speaker recognition. GMM is more successful for speaker recognition when speaker voice is text independent. Study used GMM supervector in SVM, it's combining SVM results with GMM supervectors.

J. G. Liu, Y. Zhou, H. Q. Liu and L. M. Shi [25] studied multiple methods for noise elimination from speech for single channel speech betterment. It's observed that most of speech

enhancement analysis performed in frequency domain. The authors first analyzed Chi priori effects with weighted Bayesian estimator on speech and then incorporated “Speech Presence Uncertainty” (SPU) into the proposed estimator to derive an efficient hybrid priori SNR (HSNR) estimator. These methods give effective result to eliminate musical noise from speech and better speaker recognition process.

Thimmaraja Yadava G et al. [26] presented a pre-processing method for noise elimination which can be used in any speech recognition system specifically for Kannada speech (One of the Indian languages). It’s based on spectral subtraction “voice activity detection” (VAD). As per spectral subtraction, noisy speech data first need to segment first, and that segment need to overlap up to 50% in subsequent frames. The authors analyzed the noisy speech using autocorrelation spectral subtraction and periodogram methods and that is in Linear Prediction Coefficient (LPC). Noise elimination observed when subtracts the periodograms of additive noisy signal from corrupted speech signal.

M. N. A. Aadit et al. [27] have proposed white and colored noise suppression method with adaptive Kalman filter approach. The authors analyzed stationary and dynamic nature noise to retrieve the desired information from noisy Bangle speech. Proposed method is using recursive filter which is based on Kalman filter approach to improve speech signals which is corrupted by both static and dynamic noises. The authors also compare speech signal before noise elimination and after noise elimination to validate performance of proposed filter and it’s based on pitch value of speech, mean square error before and after noise elimination was between -0.4 to 0.2dB where SNR vary from -35 to -20.

Most of the researchers have suggested different type of filters, which are mostly effective when noise before and after human voice or when noise have different frequency which is not in human voice range. It’s easy to eliminate noise when noise has low frequency or high frequency as compared to male and female voice frequencies. Main concern is when human voice and noise comes together, and noise signal strength is high. Our experiment is focused in this area to address this issue.

### III. RESEARCH METHODOLOGY

This section details the speaker recognition baseline model, what is degraded human voice and details of dataset.

#### A. Speaker Recognition Base Model

When speaker voice come with high background noise then it is challenging to identify speaker with any speaker recognition system. Fig. 1 is showing basic process for any Speaker Recognition system.

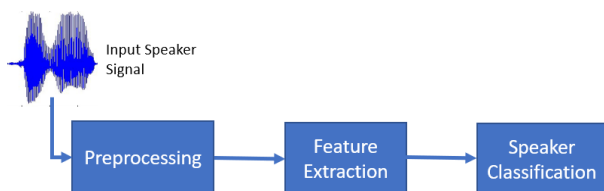


Fig. 1. Speaker recognition process blocks.

1) *Preprocessing*: Preprocessing step is used to clean speaker data. When speaker voice come for identification then it can have high or low frequency noise. Generally different types of filters used to remove such kind of noises. Band Stop Filter (BSF) and “Low Pass Filter” (LPF) are common to filter noise from speaker audio. Butterworth filter is commonly used as band-stop filter [1].

2) *Voice feature extraction*: Voice feature or characteristics extraction is utilized to extract feature from speaker’s audio file. Extracted feature is used for speaker classification. There are multiple voice feature extraction methods and MFCC [6][7][8][9] is widely used. Linear Predictive Coding (LPC) [10] is also used for feature extraction. For feature extraction, MFCC uses following key steps [7][11][12] to identify cepstral coefficients. MFCC converts human voice into cepstral coefficient in matrix form and it is easy to use in classification step. Following steps may be used in combination also, based on application and source speaker voice.

- Framing and Blocking
- Windowing
- Fast Fourier Transform (FFT)
- Triangular Bandpass Filter (Mel Scale)
- Invers FFT

In our experiment we have also used MFCC and modify it for better speaker classification results.

3) *Classification*: MFCC output works as an input for speaker classification. Classification process differentiates one speaker from another speaker through speaker’s voice features. Speaker classification can be performed based on different type of available classifier. Different researcher used GMM [13][14], “Hidden Markov Model” (HMM) [15], “Support Vector Machine” (SVM) [16][17][18][19] and deep learning based “Convolutional Neural Network” (CNN) [10][20][21][22] classifier. In this article we have focused on most common classifier as GMM.

4) *Gaussian mixture model*: GMM is a probabilistic model and it’s another type of clustering algorithm. GMM creates different types of clusters, and every cluster is modeled as per different Gaussian distribution. In another word GMM generates data points which are derived from a mixture of a limited Gaussian distributions that has no known parameters. There are two approaches which help to drive these paraments. One is maximum a posteriori estimation and another is prior trained “Expectation-Maximization” algorithm. Generally, “Expectation-Maximization” clustering aka EM clustering is mostly used for speaker recognition.

#### B. Degraded Human Voice

Nowadays we can’t expect silence in public places and generally lot of background noises are also come with in speaker voice. Current need of speaker recognition system is to identify speaker from noisy environment. Efficiency of good

speaker recognition is dependent on the speaker’s audio quality. If speaker’s voice comes without any background noise, then it’s easy to recognize by machine as compared to high background noise human voice. We consider human voice as degraded human voice when high background noise with human voice. Such degraded human voice is not easy to recognize by machine. There are multiple articles [1][26][27][28] which used frequency-based noise elimination methods. If background noise is continuous and low as compared to speaker’s voice, then probability to recognize the speaker is high. But if background noise is impulsive (sudden high) and high as compared to speaker voice then probability of speaker recognition will decrease. This article mainly focuses on noise between words and sentences.

Generally, voice degradation is defined based on human voice and noise power. SNR signifies ratio of voice signal power to the noise power. SNR is indirectly proportional to the noise signal power. SNR is low when high noise signal power. Low values of SNR indicate highly degraded human voice. For example, if SNR is high like 12dB then that voice signal is good and have almost no noise in other if SNR is 1dB then this signal has lot of noise and hard to recognize speaker from this voice signal. If  $P_s$  is voice signal power and  $P_n$  represent noise signal (background) then SNR is

$$SNR(dB) = 10\log_{10} \left( \frac{P_s}{P_n} \right)$$

OR

$$SNR(dB) = P_s(dB) - P_n(dB)$$

### C. Data Set

In major speaker recognition applications, customer (speaker) training sample recorded in the silent environment or without noise environment but testing sample comes with lot of background noise.

In our experiment we have also used same mechanism that training sample is recorded in silent environment when no background noise is there but testing sample comes with different background levels. In general, two different datasets are used (human audio and noise) and merged them to create degraded human voice dataset. In our experiment we have not mixed two signals (human voice and noise) even instead we have created dataset as per real life scenario like human speaks in noisy environment. We have recorded human voice in noisy environment. It means in same room we have noise source and human voice. It’s not mixed of human voice and noise through any application. We have used 10x10 feet room and recoded human voice with air friction noise. During data creation we have recorded voice through “Microsoft Conexant ISST Audio” with driver version 10.0.18362.1

We have defined five different categories and each category has multiple male speaker voice for training and testing purpose. We have used voice sample from five categories based on SNR range as defined in Table I. SNR calculation is based on voice signal strength (with python noisereducer library) and noise signal strength as principally explained in sub section B of Section III.

TABLE I. DATASET SNR RANGES FOR TRAINING AND TESTING

Voice sample Category	SNR (dB) Range
A	10 to 12
B	8 to 10
C	3 to 5
D	2 to 3
E	1 to 2

Category A data has been used for training purpose and remaining four categories voice samples have been used for testing purpose. Speaker voice from Category-A has SNR in range of 10-12dB and power spectrum as define in Fig. 2.

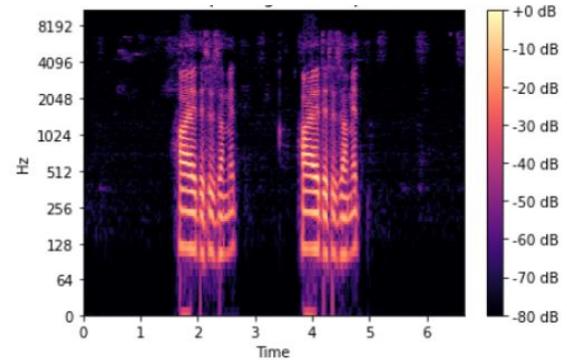


Fig. 2. Power spectrum category-a sample.

Category B data has been used for testing purpose. Speaker voice from Category-B has SNR in range of 8-10dB and power spectrum as defined in Fig. 3. Category-B voice signal has slightly high background noise as compared to Category-A voice signal.

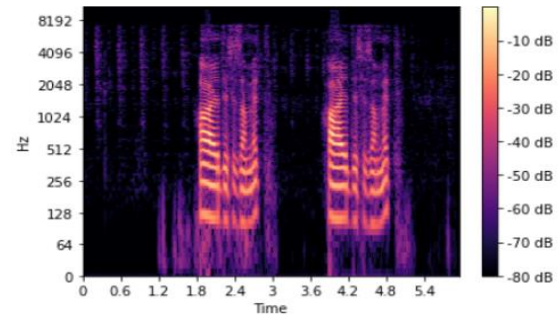


Fig. 3. Power spectrum category-b sample.

Category C data has been used for testing purpose. Speaker voice from Category-C has SNR in range of 3-5dB and power spectrum as defined in Fig. 4. Category-C voice signal has high background noise as compared to Category-A and Category-B voice signal.

Category D data also has been used for testing purpose. Speaker voice from Category-D has SNR in range of 2-3dB and power spectrum as define in Fig. 5. Category-D voice signal has high background noise as compared to Category-A and Category-B voice signal but there is not much different as compared to Category-C voice signal.



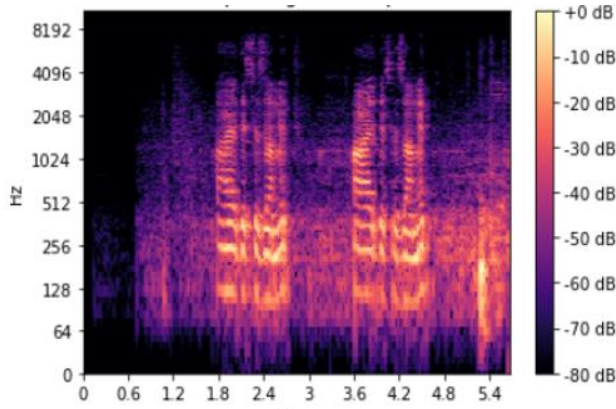


Fig. 4. Power spectrum category-c sample.

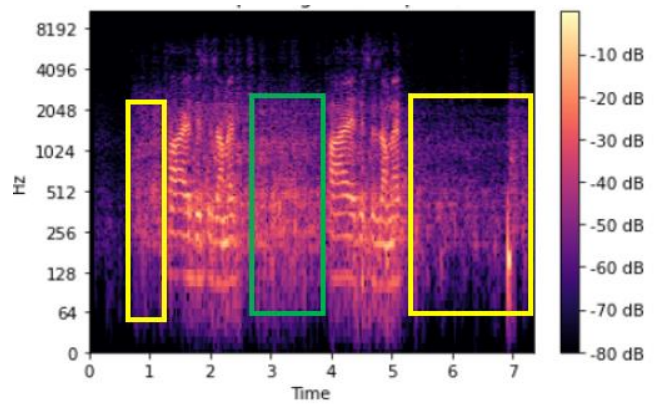


Fig. 7. Power spectrum analysis.

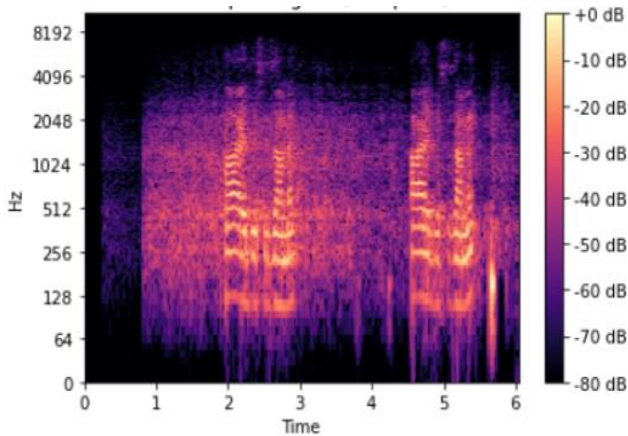


Fig. 5. Power spectrum category-d sample.

Category E data is also used for testing purpose. Speaker voice from Category-E has SNR in range of 1-2dB and power spectrum as defined in Fig. 6. Category-E voice signal has high background noise as compared to Category-A and Category-B voice signal but there is not much different as compared to Category-C and Category-D voice signal.

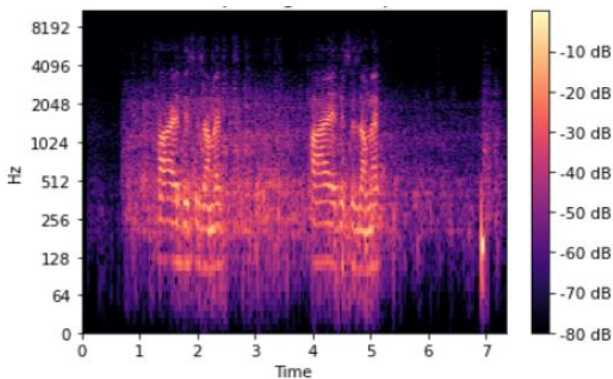


Fig. 6. Power spectrum category-e sample.

When we analyze power spectrum of Category-E sample then as per Fig. 7, yellow highlighted power is noise power before and after human voice and green highlighted is showing noise between words.

#### IV. EXPERIMENT AND RESULTS

##### A. Baseline Model and Results

As discussed in Section III, MFCC is used as voice feature extraction method and GMM for learning and pattern matching. We have used same device to produce different strengths of air friction noise. In all samples voice recorder remains same.

With baseline model, Samples from category A is used for training and other categories sample are used for testing purpose. As per experiment results, if SNR is reduced by 2dB then baseline model can't identify speaker voice as per Table II.

TABLE II. EXPERIMENT RESULT WITH BASELINE MODEL

Voice sample Category	SNR (dB) Range	Identify correctly
A	10 to 12	Training Sample
B	8 to 10	No
C	3 to 5	No
D	2 to 3	No
E	1 to 2	No

##### B. Proposed Model and Results

Proposed model is also based on MFCC and GMM. On top of baseline model, we have performed three steps modification at MFCC level. We proposed GMM model with modified MFCC for feature extraction. When feature extraction provides more information at MFCC coefficient level then GMM also adopts this information and improves speaker recognition performance. Similar approach is used with TIMIT dataset and CNN [28]. Environment and data set are also remaining same as in baseline model. Only modification is performed at feature extraction level.

##### Step-1: High Sampling Rate

Sampling rate is key factor to identify voice feature. High sampling rate captures more signal dissimilarity info as compared to low sampling rate. We have increased sampling rate from 22050 to 44100 and identified test result as per Table III.

TABLE III. EXPERIMENT RESULT WITH PROPOSED MODEL STEP-1

Voice sample Category	SNR (dB) Range	Identify correctly
A	10 to 12	Training Sample
<b>B</b>	<b>8 to 10</b>	<b>Yes</b>
C	3 to 5	No
D	2 to 3	No
E	1 to 2	No

Table III shows slight improvement in test result for classification of the speaker when SNR in range of 8-10dB.

Step-2: Frequency Range for mel-scale triangular filter bank

As per Section III, MFCC uses Mel-scale triangular bandpass filter. These filters use low and high frequency range to create triangular filter bank. Human male fundamental frequency comes in range of 0-900Hz. If we create mel filter bank in just twice from male fundamental frequency ~1800Hz then it mostly captures human voice relevant information for speaker recognition process and avoid noise information which occurs in between the words. Optimization of frequency range for triangular bandpass filter gives benefit to filter out background noise.

Table IV shows results when we create mel-scale filter bank from 0 to 1800 Hz (high frequency as 1800 Hz) during MFCC coefficient calculation.

TABLE IV. EXPERIMENT RESULT WITH PROPOSED MODEL STEP-2

Voice sample Category	SNR (dB) Range	Identify correctly
A	10 to 12	Training Sample
<b>B</b>	<b>8 to 10</b>	<b>Yes</b>
<b>C</b>	<b>3 to 5</b>	<b>Yes</b>
D	2 to 3	No
E	1 to 2	No

Table IV shows good improvement in test result for classification of the speaker when SNR in range of 8-10dB, 3-5dB and 2-3dB sample category. But still Category-E sample is not classified correctly because of very low SNR.

Step-3: Pre-emphasis Effects

Humans generate sound with fundamental frequency at 0-900Hz for male and up to 1500Hz for female. Vocal tract modulates this voice and generates modulated voice. This modulated voice is suppressed by high frequency voice. The objective of pre-emphasis is to compensate on the high-frequency part that was suppressed during the sound generation by the humans [29]. When we look voice power spectrum of data set in Fig. 4 to 7 then we can realize that spectrum power is more on lower frequencies and it's reducing at high frequency. So, it is required to boost the energy levels at the high frequencies. Pre-emphasis is one of the key steps in feature extraction process and is considered during MFCC coefficient calculation. Fig. 8 is showing low power level when frequency is more than 1500Hz (approximately).

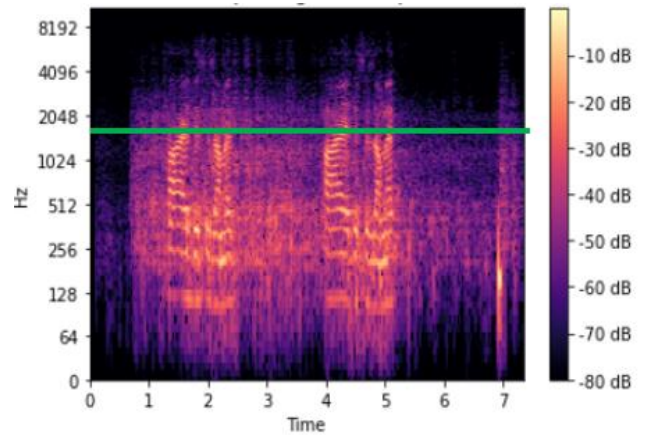


Fig. 8. Power spectrum freq > 1500Hz.

In general, when MFCC coefficient is calculated by different libraries like "python\_speech\_features" then standard value is 0.97 and when we used same pre-emphasis values then we have not received much gain in speaker recognition accuracy. In our experiment we optimized pre-emphasis value and make it at 1.00 then we have received results as per Table V. It's also observed that if we tune pre-emphasis values from .90 till 1.10 then result values getting changed and is not much effective like at pre-emphasis = 1.00.

TABLE V. EXPERIMENT RESULT WITH PROPOSED MODEL STEP-3

Voice sample Category	SNR (dB) Range	Identify correctly
A	10 to 12	Training Sample
<b>B</b>	<b>8 to 10</b>	<b>Yes</b>
<b>C</b>	<b>3 to 5</b>	<b>Yes</b>
<b>D</b>	<b>2 to 3</b>	<b>Yes</b>
<b>E</b>	<b>1 to 2</b>	<b>Yes</b>

## V. CONCLUSION

Different speaker recognition systems are required for various applications. Most applications seek a speaker recognition system that functions well without any background noise during training, but same system should recognize speaker even with degraded human voice. In our experiment, we addressed this issue and utilized speaker voices with minimal background noise (SNR = ~11dB) during training, and tested the system's performance with degraded human voices at SNRs as low as 1dB. According to Section IV of our experiment, we observed that high sampling rate, optimized frequency range for the triangular mel bandpass filter, and optimized pre-emphasis value, all contribute to the effectiveness of the feature extraction mechanism for calculating MFCCs in the speaker recognition process. In future, this experiment could be expanded to include different datasets comprising voices of various genders and languages. Modified MFCC can also tested with K-Nearest Neighbor (KNN) and Random Forest [30].

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# Application of Conv-1D and Bi-LSTM to Classify and Detect Epilepsy in EEG Data

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**Abstract**—EEG is used to study the electrical changes in the brain and can derive a conclusion as epileptic or not, using an automated method for accurate detection of seizures. Deep learning, a technique ahead of machine learning tools, can self-discover related data for the detection and classification of EEG analysis. Our work focuses on deep neural network architecture to visualize the temporal dependencies in EEG signals. Algorithms and models based on Deep Learning techniques like Conv1D, Conv1D + LSTM, and Conv1D + Bi-LSTM for binary and multiclass classification. Convolution Neural Networks can spontaneously extract and learn features independently in the multichannel time-series EEG signals. Long Short-Term Memory (LSTM) network, with its selective memory retaining capability, Fully Connected (FC) layer, and softmax activation, discover hidden sparse features from EEG signals and predicts labels as output. Two independent LSTM networks combine to form Bi-LSTM in opposite directions and appreciate added visibility to upcoming information to provide efficient work contrary to previous methods. Long-term EEG recordings on the Bonn EEG database, Hauz Khas epileptic database, and Epileptic EEG signals from Spandana Hospital, Bangalore, assess performance. Metrics like precision, recall, f1-score, and support exhibit an improvement over traditional ML algorithms evaluated in the literature.

**Keywords**—1D CNN; bidirectional LSTM; dataset (DS); deep learning; electroencephalogram (EEG); LSTM

## I. INTRODUCTION

Epilepsy is a neural sickness portrayed by a sudden attack called seizures due to strange initiation by the networks of neurons [1]. The abrupt behavior of electrical movement causing disorder inside mind is due to abnormalities, lack of oxygen during labor, and reduction in blood sugar. A seizure is a time of irregular excitation of neurons lasting from seconds to a minute [2] and upsets the body. These seizures are not quickly perceived, which is a significant issue. Now researchers are exploring and assessing seizures in the beginning phase utilizing Electroencephalogram (EEG). The strange enactment is the voltage alteration due to the flow of current by the ions in the neurons, demonstrating the cerebrum's bioelectric phenomena [3] converted to electrical action and looked through electroencephalography (EEG). The recording is done to gauge the voltage motions in brain and changed to time series data called signals, characterized by spikes, sharp waves, or a combination of both. EEG signals are preferred in the frequency domain since they are convenient and give clarity [4]. Diagnosing epilepsy with EEG signals is tedious and arduous, and human mistakes are a

possibility, so that a machine-based determination would be better.

Therefore data-preprocessing is done by normalizing the input variables. Features are extracted and selected from EEG signals in time, frequency, or in the time-frequency domain, like spectral, amplitude, entropy, wavelet, statistical, non-linear features, etc., and passed to the classification process. Because EEG patterns are exceptionally unique and may be unsuccessful for slight differences, time-series information is considered for dynamic examination since methodologies based on domain features have impediments.

Machine learning and deep learning strategies are predominant for learning, to prove the model with complex real-world information. We achieve crucial data collection by creating robust features [5], so the deep neural network can distinguish between seizure and non-seizure events. It concentrates on computational models and learns through non-linear transformations like neural networks. Initially, neural networks required more calculation time. Subsequently, they didn't get consideration, yet presently, due to enormous datasets and complex Graphic Processing Units (GPUs), it has given scientists an economical and robust arrangement, permitting them to examine deep learning models. Without prior knowledge of the dataset, neural networks have improved their boundaries repeatedly.

Work here demonstrates a one-dimensional Convolution Neural Network (1D-CNN) model to learn high-level representations from filtered EEG signal data for seizure detection and classification after reviewing the available research. However, increasing the convolutional layers can eventually obtain strong and conclusive features, with simplicity and efficiency being the most important advantages of this type of network. 1D-CNNs are naturally apt for handling biological signals like EEG for seizure detection [6] by using pooling and convolutional layers. In addition to that, signals are 1D in nature, and using preprocessing methods there is no information loss.

Next, the one-dimensional Convolution Neural Network Long Short-Term Memory (1D CNN-LSTM) model is proposed, with preprocessing applied to the raw EEG signal and normalized features effectively extracted by 1D-CNN. The obtained characteristics handled by LSTM layers extract temporal features and passed to fully connected layers before conclusion as epileptic or not. Results obtained demonstrate the proposed model exhibits identification recognition correctness in classifying epileptic seizure recognition tasks as

binary and multiclass, respectively. The 1D CNN-LSTM model comprises one input layer, six convolutional layers, three pooling layers, two LSTM layers, one fully connected (FC) layer, and three dropout layers.

The modified version of the Recurrent Neural Network (RNN) is LSTM, and it is tough to train standard RNNs because of vanishing and exploding gradient problems [7]. The identity function of derivative 1 happens as the activation function, thus preventing the gradient from vanishing or exploding. The Bi-LSTM architecture selected consists of 64 forward and 64 backward LSTM cells per layer. Bidirectional long short-term memory (Bi-LSTM) network explores seizure detection and classification in this research. Bi-LSTM evolved considering the merits of LSTM and Bi-RNN [8]. Processing happens in two opposite directions, thereby improving performance. When compared with CNN models and Bi-LSTM models on time series data, the time dependencies of the signal are described poorly in CNN models but well in Bi-LSTM models.

## II. LITERATURE SURVEY

Numerous procedures are employed to obtain EEG signal features for seizure detection. In [9], integrating with extreme learning machine (ELM), features like approximate entropy and sample entropy are employed. In [10], non-sampled wavelet-Fourier features are incorporated for seizure detection, with a considerable quantity of continuous EEG recordings being the limitation. Combining wavelet decomposition with directed transfer function (DTF) for feature extraction is used in [11]. Still, the limit here is the existence of muscle artefacts in scalp EEG recordings. However, better results can be expected if an intracranial electrocorticogram (ECoG) uses subdural grid electrode implementation. In [12] authors suggested a unique feature as a matrix determinant for EEG analysis. For noise removal, researchers proposed a Bandpass filter to enhance SNR in intracranial EEG signals to obtain a sensitivity more significant than 80% and specificity ranging between 75% and 88%. Correspondingly, sensitivity, specificity, and accuracy of 77.10%, 71.63%, and 75.07% are obtained [13], demonstrating weak execution. Linear Discriminant Analysis (LDA) [14] and Bayesian classifier [15] comprise the machine learning classifiers and Convolutional Neural Networks (CNN) [16] as deep learning classifiers with no perfect prediction available. Positive results are obtained using Long Short-Time Memory Units (LSTMs) [17]. However, the investigation by collecting additional experimental data and fusing it to develop new AI algorithms improves upon existing applications.

Robust features [18] with single-channel epileptic EEG signals automatically learn using machine learning and deep learning techniques. Research should focus on algorithms capable of handling complex multichannel epileptic EEG signals. Using discrete wavelet transform (DWT) and K-means with multilayer perceptron (MLP) for classification in [19] is implemented. Though deep CNN-based architecture obtains prominent features from raw EEG data to detect seizures, overlapping among seizure and non-seizure events happens. It becomes tedious to construct a generic technique

to obtain high sensitivity [20]. In [21] a hybrid ensemble learning framework that systematically combines pre-processing methods with ensemble machine learning algorithms specifically, principal component analysis (PCA) and t-distributed stochastic neighbor embedding (t-SNE) combined along k-means clustering followed by ensemble learning such as extreme gradient boosting algorithms (XGBoost) and random forest is considered. However, in [22], using 13 layers, deep CNN architecture is considered.

Nevertheless, the drawback is the lack of a vast EEG database. Researchers demonstrated the deep belief nets (DBN) mechanism for modelling EEG data [23]. The training time using K Nearest Neighbor (KNN) and Support Vector Machine (SVM) took a few hours to a few days, but with DBNs, it took a few days to more than a week.

Using two parallel 1D-CNN blocks, a stacked 1D-CNN model is implemented with a random selection and data augmentation (RS-DA) strategy to overcome sample imbalance in [24] but with Two-Dimensional Convolution Neural Network (2D-CNN) and LSTM, collectively with RS-DA, thorough assessments with statistical, entropies, frequency, or time-frequency domain features, etc., can be derived and combined to 1D-CNN model as input. A generic auto-detection method, robust to noise, is used in [25]. Inputs are the digital version of the EEG recordings to the model, which aids the neurologists in detection. The limitation is the SNR value decreases the classification accuracy. A key reason for using Bi-directional LSTM in [26] is they look after the time dependencies both in a forward and backward direction. The authors in [27] use spectral feature-based two-layer long short-term memory (LSTM) model. The segments considered are in the frequency domain. In [28], an automated epilepsy detection system implementing wavelet decomposition and a 1D-CNN, along with Bi-LSTM, is incorporated. But the limitation is its inability to detect the occurrence of seizure at 512 Hz as the sample rate. However, the decimation of samples can enable the model at 256 or 512 Hz sampling rate to identify epileptic seizures.

## III. DATASETS

Before we begin the experiment with the results and analysis, discussion on the various datasets being used in the work is being dealt with.

### A. Bonn EEG – UCI Machine Learning Repository: Epileptic Seizure Recognition Dataset

We expect to characterize the different classes of the Bonn EEG dataset into five categories named class1, class2, class3, class4 and class5, each having 100-single channel sections of EEG. Every single channel is 23.6s recording at a sampling frequency of 173.61 Hz. The comparing time series inspects 4097 data focused on separating and rearranging into 23 pieces, each containing 178 data of interest every second. The data of interest is the EEG recording at the alternate moment. The recording is of both healthy and epileptic patients. Class 1 contains EEG signals from epileptic seizure sections, and EEG signals originating from the tumor zone belong to Class 2. Class 3 has signals from the healthy brain area of the tumor found in the brain. Class 4 contains EEG information on

healthy volunteers with closed eyes. EEG data of subjects with open eyes belong to Class 5 (Fig. 1).

The 178 information are X1, X2, X3... X177, X178 the logical factors with various classes labeled y (Fig. 2). For 500 patients, we get 11500 columns (23X500= 11500). Each of the 178 pieces of information is put in sections as columns and 11500 examples as lines or rows and named the information from [1-5] as the last segment (segment y). People other than one category, i.e., 2,3,4,5, classes are non-epileptic.

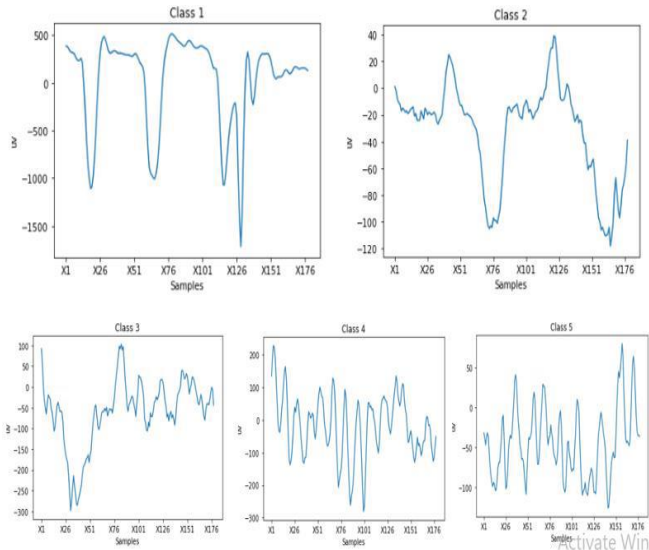


Fig. 1. Plot of each class.

Unnamed: 0	X1	X2	X3	X4	X5	X6	X7	X8	X9	...	X170	X171	X172	X173	X174	X175	X176	X177	X178	y	
0	X21.V1.791	135	190	229	223	192	125	55	-9	-33	...	-17	-15	-31	-77	-103	-127	-116	-83	-51	4
1	X15.V1.924	386	382	356	331	320	315	307	272	244	...	164	150	146	152	157	156	154	143	129	1
2	X8.V1.1	-32	-39	-47	-37	-32	-36	-57	-73	-85	...	57	64	48	19	-12	-30	-35	-35	-36	5

3 rows x 180 columns

Fig. 2. Datapoints with label.

**B. Neurology and Sleep Centre, Hauz Khas, New Delhi**

The EEG recording uses the Comet AS40 EEG machine and 200 Hz as the sampling rate. Signals ranging between 0.5 to 70 Hz undergo filtering and are divided into pre-ictal, interictal and ictal stages. The duration of the EEG portion in this archive is 5.12s with 1024 examples.

There are three folders that are named according to the epileptic seizure stages and each folder contains fifty files of EEG time series. Each segment is considered as an instance. In total, 150 instances are considered belonging to each intended class.

**C. Spandana Nursing Home Dataset, Bangalore**

An ongoing EEG Data is being utilized for the location of epilepsy. Twenty EEG accounts of epileptic patients with 10 EEG signals during seizures and 10 EEG data from a sound volunteer with open eyes are considered. The sampling rate is 175 Hz. Filtering for signals ranging between 0.5 to 60 Hz is done. The universally perceived technique to portray areas of various electrodes on the scalp is utilized, which depends on

the connection between the primary regions of the cerebral cortex. The number '10' - '20' suggests the distance between every terminal from each other is 10% or 20% of the absolute right-left or front-back space of the skull. A letter has been assigned to each site for lobe recognition, and a number is assigned to distinguish the cerebral hemisphere area. Even numbers 2, 4, 6, and 8 indicate the right of the brain for the electrode position of the brain, and odd numbers 1, 3, 5, and 7 mean terminals on the left part. The crude signals acquired are switched over entirely to ASCII design. EDF (European Data Format) Browser programming is utilized, an open source, universal viewer, multiplatform, and tool kit for conversion. The classifier tool is in such a way if the output is '0', it is epileptic or abnormal EEG, and '1' indicates normal EEG or non-epileptic EEG.

**IV. PROPOSED METHODOLOGY: DEEP LEARNING ALGORITHMS AND MODELS**

The proposed technique introduces three different methodologies for adequate recognition and classification of an epileptic seizure. EEG as input is a Comma Separated Values (CSV) document. When the input document is perused and switched over entirely to a python data frame, the information is standardized, split for training, validation, and testing in the proportion of 6:2:2 and labels are changed over into One Hot Encoded design. The architecture's performance is analyzed for Multiclass (1,2,3,4,5) and Binary Classification (1/0). All the presented models are examined by training for up to 40 epochs using Categorical Cross Entropy as a loss function.

**A. Method-1: Based on Conv1D**

In the proposed method 1, the EEG information is examined by applying Convolution, and a deep learning method is prominently used to analyze time series data. Direct and quicker design models are presented because the boundaries are low. Pooling and convolutional layers with bigger size are utilized in 1D models and, when applied, produces a kernel of determined size(m) which is convolved with the input(x) to create the filtered output(y) whose dimensionality will be equivalent to the number of kernels(n). Conv1D is fit for learning features (w) concealed in the series of time sequence data.

$$y_i = \sum_{-m}^m x_{i-k} w_k \tag{1}$$

In the output expressed as the above equation, k is the counter value ranging from -m to +m, covering the length of the kernel. Initially, considering 1D data of the EEG signal with the feature vector, it is convolved along with the filter to acquire a feature map. 1D data is ordered along a single line data organized by time and fits on a 1D line. Convolution takes a kernel (internal weights) of a filter and a sliding dot product with the signal. The process of multiplying each aligned pair of points and adding all products is called the dot product.

Since we are sliding, the data gets overlapped, and the representation is as below.

$$x = \{x_0, x_1, x_2, \dots \dots x_{m-1}\} \tag{2}$$

$$w = \{w_0, w_1, w_2, \dots, w_{n-1}\} \quad (3)$$

$$y = \{y_0, y_1, y_2, \dots, y_{m-1}\} \quad (4)$$

Losses are overcome by backpropagation, and the above equations are explicitly differentiated concerning gradients through layers. The partial derivative of loss for y is propagated back to calculate the partial derivative of loss for x through every network using the chain rule and the loss to each input given by.

$$\frac{\partial L}{\partial x_i} = \sum_{j=0}^{m-1} \frac{\partial L}{\partial y_j} \frac{\delta y_j}{\delta x_i} \quad (5)$$

Therefore, input gradient = output gradient (W), where  $W = \frac{\delta y_j}{\delta x_i}$  should be known and so the layer is differentiable. The architecture consists of a series of Conv1D layers followed by MaxPool layer. It reduces spatial size, number of parameters and computation while aggregating the dominant features, thereby reducing the dimensionality. The most well-known pooling strategy is max pooling. Max pooling alludes to getting maximum value after each pooling activity and the data is flattened. Flatten concatenates the results from the convolution layers to frame a flat structure taken as input to dense layer. A fully connected layer or Dense network helps to classify based on features. It is a dense network of neurons, and every neuron is connected to the previous and subsequent layers. If there are multiple dense layers, then the last layer has output as the same number of the classes or categories. The linearity principle is used in Dense Layer, where the outcome depends on every input. The activation function utilized is the SoftMax activation which adds learning capacity to neural networks by learning complex patterns and multiplying weights with the input features and concluding regarding firing. Activation functions make the network non-linear, else it becomes linear. For example, output relies

linearly upon the input features. SoftMax activation is the most ordinarily busy work as final layer in neural network for multiclass classification, being a blend of different sigmoid which works out the general probabilities and standardizes neural network results to fit between 0 and 1. The SoftMax probabilities will constantly aggregate to 1. The architecture of the proposed Method-1 can be seen in Fig. 3. The results obtained using Method-1 to determine the metrics like Accuracy, Precision, Recall, F1- Score and Support with DS1, DS2 and DS3 for multiclass and binary classification are shown in Table I (A) and Table II (B) respectively.

$$S(Y)_i = \frac{e^{Y_i}}{\sum_{j=1}^n e^{Y_j}} \quad (6)$$

**B. Method-2: Based on Conv1D+LSTM**

The architecture with a mix of Convolution (Conv1D) and Long Short-Term Memory (LSTM) is proposed as method 2. Input is passed to Convolution, MaxPool, and dropout layer before executing with the next layer, where it invalidates a portion of the neurons towards the following layer by randomly setting the input units to 0, thus forestalling overfitting and consequently evades the network from depending on a single neuron. Typically, dropouts are put on fully connected layers. Dropout might be carried out on any hidden layer or input layer in the network, yet not utilized on the output layer.

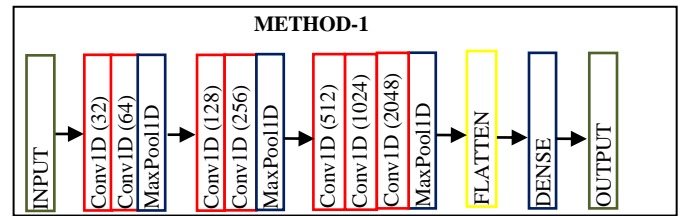


Fig. 3. Architecture of the proposed method-1.

TABLE I. (A) PROPOSED METHOD1 WITH METRICS FOR MULTICLASS CLASSIFICATION OF DATASET1 AND DATASET2

	Conv1D					Accuracy
	Multiclass Classification	Precision	Recall	F1-score	Support	
<b>DS-1 Bonn EEG</b>	Class1 (Epileptic)	0.98	0.97	0.97	457	<b>74.61</b>
	Class 2	0.65	0.66	0.66	477	
	Class 3	0.66	0.61	0.63	472	
	Class 4	0.72	0.79	0.76	422	
	Class 5	0.74	0.71	0.72	475	
<b>DS -2 HauzKhas</b>	0 (Ictal)	1.00	1.00	1.00	10	<b>64.52</b>
	1(Inter ictal)	0.80	0.29	0.42	14	
	2(preictal)	0.38	0.86	0.52	7	

TABLE II. (B) PROPOSED METHOD1 WITH METRICS FOR BINARY CLASSIFICATION OF DATASET1, DATASET2 AND DATASET3

	Conv1D					Accuracy
	Binary Classification	Precision	Recall	F1-score	Support	
<b>DS-1 Bonn EEG</b>	0(Nonpileptic)	0.99	0.99	0.99	1846	98.83
	1 (Epileptic)	0.98	0.96	0.97	454	
<b>DS -2 Hauz Khas</b>	0(Nonpileptic)	0.86	0.71	0.77	17	77.42
	1 (Epileptic)	0.71	0.86	0.77	14	
<b>DS -3 Spandana</b>	0(Nonpileptic)	1.00	0.67	0.80	3	75.00
	1 (Epileptic)	0.50	1.00	0.67	1	

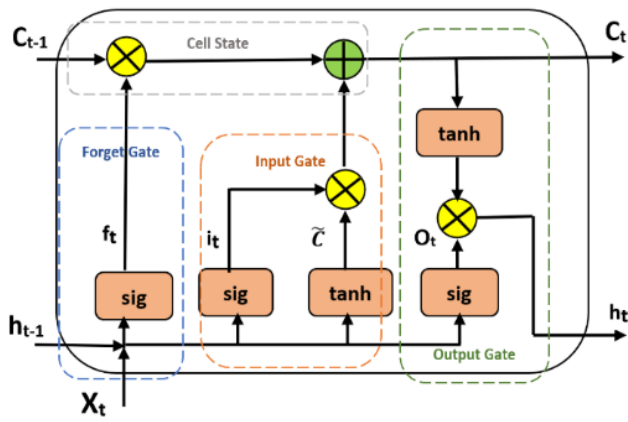


Fig. 4. Cell of LSTM.

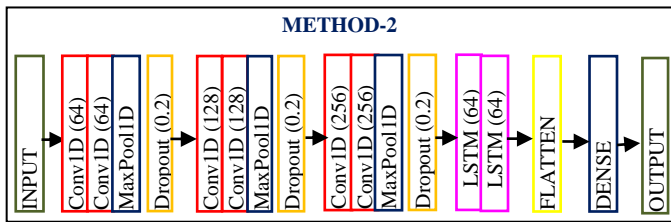


Fig. 5. Architecture of the proposed method-2.

LSTM is based on recurrent neural networks capable of learning, remembering, and processing information from a series of data distributed over time and, accordingly, is slow. LSTMs, with their specially designed gates, process the data linearly while deciding against retaining the learnt feature is good or forgetting it and moving forward. The LSTM gates use sigmoid activation ( $\sigma$ ) as shown in Fig. 4. The architecture of the proposed method 2 is seen in Fig. 5. It has been observed in the conducted research that using many filters results in hindering the model from learning. Long Short-Term Memory (LSTM) networks are fit for learning to rely on the sequence and handle the disappearing gradient issue.

Sigmoid and tanh functions are two normalizing conditions utilized in LSTM. The sigmoid function implies a mechanism attempting to compute a bunch of scalars in the range of 0 and 1. The tanh function tells a system trying to change the information into a standardized data encoding between - 1 and 1. Inputs are multiplied by different frameworks of weights and added together. Feature extraction is done when the sigmoid function crushes the outcome between 0 and 1 when added with bias and applied. Though training is lengthy, it glances at the long sequence of inputs without expanding the network size. An LSTM network empowers to include sequence information in the network and makes forecasts relying on individual time stamps.

The LSTM cell is shown in Fig. 4. To replace memory, the Input gate finds the value. The second sigmoid function accepts current state  $x_t$  and previously hidden state  $h_{t-1}$  and concludes values to let through as 0 (critical) or 1(not critical).

Furthermore, the tanh function gives weightage to the qualities which are passed to create a vector  $\tilde{C}_t$  concluding their degree of significance from - 1 to 1.

$$i_t = \sigma(W_i[h_{t-1}, x_t] + b_i) \quad (7)$$

$$\tilde{C}_t = \tanh(W_c[h_{t-1}, x_t] + b_c) \quad (8)$$

where  $t$  = timestamp,  $i_t$  = input gate at  $t$ ,  $W_i$  = Weight matrix of sigmoid operator between input gate and output gate,  $b_i$  = bias vector,  $\tilde{C}_t$  = value generated by tanh,  $W_c$  = weight matrix of tanh operator between cell state information and network output,  $b_c$  = bias vector concerning  $W_c$ .

Based on the block's input and memory, the output gate result is chosen, and current and previous hidden state values are passed to the third sigmoid. The function tanh accepts new cell state generated, and outputs are multiplied point-by-point. The final value decides the hidden state to carry the information. Therefore, a new cell state and a new hidden state are passed to the next timestamp.

$$o_t = \sigma(W_o[h_{t-1}, x_t] + b_o) \quad (9)$$

$$h_t = o_t * \tanh(C_t) \quad (10)$$

where  $t$  = timestamp,  $o_t$  = output gate at  $t$ ,  $W_o$  = Weight matrix of output gate,  $b_o$  = bias vector with respect to  $W_o$ ,  $h_t$  = LSTM output.

Related data from the earlier process is found by forget gate. The sigmoid function is passed with the current input  $x_t$  and hidden state  $h_{t-1}$ , and value derived is implemented for point-by-point multiplication.

$$f_t = \sigma(W_f[h_{t-1}, x_t] + b_o) \quad (11)$$

where  $t$  = timestamp,  $f_t$  = forget gate at  $t$ ,  $x_t$  = input,  $h_{t-1}$  = previous hidden state,  $W_f$  = weight matrix between forget gate and output gate,  $b_o$  = bias at  $t$ .

The data needs to be stored from the new state in the cell to obtain the end output. The product of previous cell state  $C_{t-1}$  and forget vector  $f_t$ , if found to be 0, then values are eliminated, and point-by-point addition is performed to get a new cell state  $C_t$ .

$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t \quad (12)$$

where  $t$  = timestamp,  $C_t$  is cell state information,  $f_t$  is forget gate at  $t$ ,  $C_{t-1}$  is previous time stamp,  $i_t$  is the input gate,  $\tilde{C}_t$  is a value generated by tanh.

The boundaries in LSTMs are learning rates, information, and result predispositions. In forget gate, a duplicate of the time-stamp information is separated, and in input gate a copy is passed. Using the above method, various metrics like Accuracy, Precision, Recall, F1- Score and Support for various datasets DS1, DS2 and DS3 are calculated and demonstrated in Table III (A) and Table IV (B) for multiclass and binary classification.

TABLE III. (A) PROPOSED METHOD 2 WITH METRICS FOR MULTICLASS CLASSIFICATION OF DATASET1 AND DATASET2

	Conv1D+LSTM					Accuracy
	Multiclass Classification	Precision	Recall	F1-score	Support	
<b>DS-1 Bonn EEG</b>	Class1 (Epileptic)	0.97	0.98	0.97	454	77.52
	Class 2	0.72	0.59	0.65	477	
	Class 3	0.66	0.71	0.68	472	
	Class 4	0.82	0.76	0.79	422	
	Class 5	0.76	0.78	0.77	475	
<b>DS -2 Hauz Khas</b>	0 (Ictal)	1.00	1.00	1.00	10	74.19
	1(Inter ictal)	0.67	0.57	0.62	14	
	2(preictal)	0.33	0.29	0.31	7	

TABLE IV. (B) PROPOSED METHOD 2 WITH METRICS FOR BINARY CLASSIFICATION OF DATASET1, DATASET2 AND DATASET3

	Conv1D+LSTM					Accuracy
	Binary Classification	Precision	Recall	F1-score	Support	
<b>DS-1 Bonn EEG</b>	0(Nonpileptic)	0.99	1.00	0.99	1846	99.40
	1 (Epileptic)	0.98	0.97	0.97	454	
<b>DS -2 Hauz Khas</b>	0(Nonpileptic)	0.82	0.82	0.82	17	80.65
	1 (Epileptic)	0.79	0.79	0.79	14	
<b>DS -3 Spandana</b>	0(Nonpileptic)	1.00	1.00	1.00	3	1.00
	1 (Epileptic)	1.00	1.00	1.00	1	

TABLE V. (A) PROPOSED METHOD 3 WITH METRICS FOR MULTICLASS CLASSIFICATION OF DATASET1 AND DATASET2

	Conv1D+Bi-LSTM					Accuracy
	Multiclass Classification	Precision	Recall	F1-score	Support	
<b>DS-1 Bonn EEG</b>	Class1 (Epileptic)	0.97	0.98	0.97	454	80.43
	Class 2	0.70	0.72	0.71	477	
	Class 3	0.72	0.62	0.67	472	
	Class 4	0.74	0.83	0.78	422	
	Class 5	0.78	0.72	0.75	475	
<b>DS -2 Hauz Khas</b>	0 (Ictal)	1.00	1.00	1.00	10	77.42
	1(Inter ictal)	0.73	0.79	0.76	14	
	2(preictal)	0.50	0.43	0.46	7	

TABLE VI. (B) PROPOSED METHOD 3 WITH METRICS FOR BINARY CLASSIFICATION OF DATASET1, DATASET2 AND DATASET3

	Conv1D+Bi-LSTM					Accuracy
	Binary Classification	Precision	Recall	F1-score	Support	
<b>DS-1 Bonn EEG</b>	0(Nonpileptic)	0.99	0.99	0.99	1846	99.40
	1 (Epileptic)	0.98	0.96	0.97	454	
<b>DS -2 Hauz Khas</b>	0(Nonpileptic)	0.92	0.71	0.80	17	80.65
	1 (Epileptic)	0.72	0.93	0.81	14	
<b>DS -3 Spandana</b>	0(Nonpileptic)	1.00	1.00	1.00	3	1.00
	1 (Epileptic)	1.00	1.00	1.00	1	

C. Method-3: Based on Conv1D+BiLSTM

In the proposed method 3, a more meaningful output is produced by using a powerful tool for modeling the sequential dependencies in both directions. The architecture is planned with a blend of Convolution and Bidirectional Long Short-Term Memory (Bi-LSTM). It offers preferable expectations by two LSTMs. Every component of an input sequence computes the input arrangement from the reverse path to a hidden forward sequence and a backward hidden sequence. Concatenation of the final forward and backward outputs leads to an encoded vector. Thirty-two units of LSTM of 0.2

dropouts, are utilized in a bidirectional manner as depicted in Fig. 6. At every timestamp, each hidden layer yield is created alongside the memory cell state and passed to a 1D convolutional layer of 64 filters of kernel size four as shown in Fig. 7. The past LSTM network trails the remainder of the network. The results show that Bi-LSTM based modeling offers better predictions than regular LSTM based models. Accuracy, Precision, Recall, F1 Score and Support for datasets DS1, DS2 and DS3 for both multiclass and binary classification using Conv1D+ Bi LSTM are referred in Table V (A) and Table VI (B) accordingly.



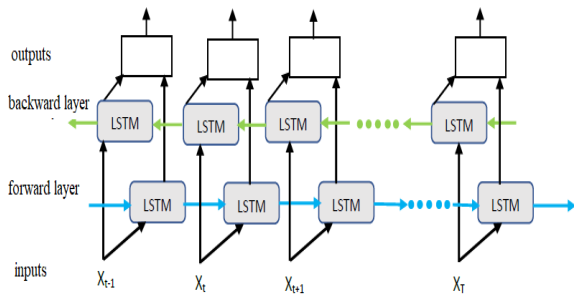


Fig. 6. Bidirectional LSTM.

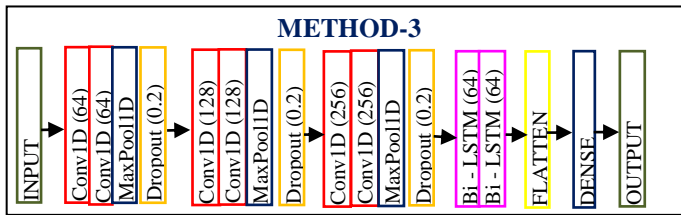


Fig. 7. Architecture of the proposed method-3.

V. RESULT AND DISCUSSION

Precision is defined as the quality of a correct prediction given by the model and is the number of true positives divided

by the total positive predictions. Precision is how good the model is at predicting a specific category. It does not predict negative class, called false negatives [30-32].

$$\text{Precision} = \text{TP} / (\text{TP} + \text{FP})$$

Recall is a measure computing the number of correct predictions from all positive predictions possible. In binary class, recall is computed as the number of true positives divided by the sum of true positives and false negatives.

$$\text{Recall} = \text{TP} / (\text{TP} + \text{FN})$$

The F1 score or F-measure gives the harmonic average of precision and recall together to measure the efficiency of two classifiers.

$$\text{F-Measure} = (2 * \text{Precision} * \text{Recall}) / (\text{Precision} + \text{Recall})$$

Support: The support is several actual occurrences of the class in the specified dataset and got by summing the rows of the confusion matrix.

However, comparing three models with Bonn EEG Dataset, displayed in Table VII illustrates the proposed Deep learning methods with added layers have a higher score than simple CNN approaches, suggesting high classification accuracy.

TABLE VII. COMPARISON OF ACCURACY WITH EXISTING AND PROPOSED METHODS OF DATASET1(BONN), DATASET2(HAUZ KHAS) AND DATASET3(SPANDANA) WITH BINARY CLASSIFICATION

Dataset1(Bonn)								
DL Algorithm and Models	Accuracy (%)	Proposed	Sensitivity	Proposed	Precision	Proposed	F1- Score	Proposed
Conv1D [29]	88.70	98.83	95.00	98	90.00	96	--	97
Conv1D+ LSTM	---	99.04	---	97	---	98	--	97
Conv1D+ BiLSTM	---	99.40	---	96.5	---	98	---	97
Dataset2 (Hauz Khas)								
Conv1D [29]	---	77.42	---	86	---	86	--	77
Conv1D+ LSTM	---	80.65	---	82	---	82	--	83
Conv1D+ BiLSTM	---	80.65	---	93	---	92	---	80
Dataset3 (Spandana)								
Conv1D [29]	---	75.00	---	100	---	100	--	80
Conv1D+ LSTM	---	100.00	---	100	---	100	--	100
Conv1D+ BiLSTM	---	100.00	---	100	---	100	---	100

VI. CONCLUSION AND FUTURE WORK

In Proposed Method 1 (Conv 1D), a CNN model is built on a 1D time series, and architecture consists of a series of Conv1D layers followed by MaxPool. Flatten forms a flat structure which acts as input to dense layer with SoftMax activation adding learning capacity to neural networks for classification. A fully connected layer or Dense network helps to classify based on features. The metrics are improved compared to ML algorithms. A dense or Fully Connected layer is used as a classifier based on extracted features. Generally, the performance of the CNN classifier can be improved by the right choice of parameters like pooling size, learning rate, activation function and optimizer. Our approach

uses CNN to detect epileptic seizures and has improved the classification accuracy along with the generalization ability of the classifier. The tabulated results from Table I (A) and Table II (B) significantly shows the improvement compared to Machine Learning based algorithms.

In Proposed Method 2 (Conv1D + LSTM), the LSTM is based on recurrent neural networks capable of learning, remembering, and processing information from a time series data. LSTMs have gates that process the data and decide on retaining the known feature if it is sound, forgetting if imperfect, and moving ahead. Gates use sigmoid activation ( $\sigma$ ) and are fit for learning order. Though the training time is lengthy, LSTM glances at a long sequence of inputs without

expanding the network size. An LSTM network empowers to include sequence information in succession. It is evident from the measured metrics shown in Table III (A) and Table IV (B) that LSTM, with its selective memory, can successfully empower the network with the retained essential features. This model can also be implemented on different domain signals like frequency and time- frequency domain signals and can compare the performance accuracy. Furthermore, LSTM layers can implement the data in classifying with multiclass exclusively on the Bonn EEG epileptic dataset deeply and classifying better seizure states.

In Proposed Method 3 (Conv1D + Bi LSTM), the Bi-LSTM based model is much better than usual LSTM based models as per the results obtained. Bi- LSTM takes a step further ahead from LSTMs with its capability to view and understand the data in both directions. In contrast, they are utilizing the knowledge of the past and future data present in the time series. Bi-LSTMs can extract the best describing feature vectors from the data. While the proposed methods prove their ability with the Bonn and Hauz Khas dataset, it leads to overfitting with Spandana dataset due to its smaller size. As part of further work, improvement is made by enhancing the dataset from medical agencies, building deeper models, regularization with Batch normalization, augmentation techniques, and reinforcement-based learning remains unexplored. Moreover, when operated to multi-class classification, the present approach does not have a good recognition accuracy that is principally exceptional. Results prove that Bi-LSTMs are an ideal choice for time sequence data as demonstrated in Table V (A) and Table VI (B) correspondingly.

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# A New Fuzzy Lexicon Expansion and Sentiment Aware Recommendation System in e-Commerce

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**Abstract**—Customers' feedbacks are necessary for an online business to enrich themselves. The customers' feedback reflects the quality of the products and the e-commerce services. The companies are in a position to concentrate more and analyze the customers' feedback or reviews carefully by applying new techniques for predicting the current trends, customers' expectations, and the quality of their services. The e-business will succeed when one accurately predicts customer purchase patterns and expectations. For this purpose, we propose a new fuzzy logic incorporated sentiment analysis-based product recommendation system to predict the customers' needs and recommend suitable products successfully. The proposed system incorporates a newly developed sentiment analysis model which incorporates the classification through fuzzy temporal rules. Moreover, the basic level data preprocessing activities such as stemming, stop word removal, syntax analysis and tokenization are performed to enhance the sentiment classification accuracy. Finally, this product recommendation system recommends suitable products to the customers by predicting the customers' needs and expectations. The proposed system is evaluated using the Amazon dataset and proved better than the existing recommendation systems regarding precision, recall, serendipity and nDCG.

**Keywords**—Classification; e-commerce; preprocessing; recommendation system; recurrent neural network; sentiment analysis

## I. INTRODUCTION

E-Commerce technology is growing fast due to rapid population development and technological adaptation. Most people are willing to complete their purchase from their place without visiting the shops online for an affordable cost. Today, people save their money and time with the help of e-commerce technology. They can purchase their items anytime online even though the e-commerce technology is in the position to fulfil the customers' requirements conveniently by providing good quality products. For this purpose, many e-commerce platforms are collecting feedback from their customers and trying to rectify the flaws, if there are any, by analyzing their feedback through sentiment analysis. This sentiment analysis can provide the customers' opinions on services and goods. Moreover, it is useful for enhancing service quality and fulfilling the customers' requirements as per their expectations. Moreover, the customers share their experiences, expectations, and comments about product quality. The sentiment analysis is applied to the review comments of the products and also

predicts the customers' expectations and the current purchase trends [1].

Sentiment analysis is an important part of Natural Language Processing (NLP) which learns the exact meanings and the useful features of a review comment. The major objective of the sentiment analysis is to extract the sentiment entities and the features available in their review comments. Recently, social media usage has been drastically increasing daily, and people are sharing their purchase experiences by posting comments. Moreover, they spread their comments about their purchase experience and opinions to their friends and unknown circle through social media. So that every customer review comment also plays a role in the e-commerce platform, and if the specific product receives negative comments from a few customers, it also affects sales. Therefore, the e-commerce applications incorporated a sentiment analysis phase capable of categorizing the review comments such as an object, features of the object, meaning, holder and time of expression. Generally, the sentiment analysis finalizes the customer reviews as positive, negative, and neutral comments [2].

The sentiment analysis is categorized into three categories: statistics-based, knowledge-based, and hybrid. Among them, the knowledgebase-based method helps extract the features from the customer's reviews. Then the classification is performed over the reviews by applying the different Machine Learning (ML) algorithms such as the Naïve Bayes classifier, Support Vector Machine (SVM) and Maximum Entropy algorithm. Customers may have different sentiments over the various products using different entities and emotions. In this scenario, the system must apply multi-sentiment analysis to handle the different sentiments expressed in review comments and predict customer opinions on products. This kind of analysis is done by considering customer reviews collected from e-commerce websites, blogs, Facebook, Twitter, etc. Data preprocessing is also necessary before performing the sentiment classification. The basic data preprocessing [3] on review comments include syntax analysis, semantic analysis, tokenization etc. The data preprocessing steps can enhance the classification algorithm's performance.

**Research Gaps:** People are interested in purchasing products online. Here, people need help to choose their interests like products from the vast number of products.

To help society use e-commerce websites frequently, this paper proposes a new fuzzy aware sentiment classifier incorporated product recommendation system to recommend suitable products to the customers to satisfy their requirements. The contributions of this paper are listed below:

- 1) To propose a new product recommendation system to recommend suitable products to customers.
- 2) To apply basic level data preprocessing steps such as tokenization, syntax analysis and semantic analysis to extract the raw data from reviews.
- 3) To analyze the customers' reviews by applying the proposed sentiment analysis technique to know the customers' opinions on the products.
- 4) To introduce fuzzy temporal rules for making effective decisions on product recommendation.
- 5) Proved as better than the available systems regarding the precision value, recall value, f-measure value and prediction accuracy by conducting various experiments.

The remainder of this paper is formulated below: Section II explains the available works in the direction of sentiment analysis and recommendation systems. Section III provides an overall architecture of the system for understanding the entire system. Section IV explains the proposed model by providing the necessary backgrounds, data preprocessing, fuzzy rules and classification. Section V demonstrates the effectiveness and efficiency of the proposed product recommendation system. Section VI concludes the work with future direction.

## II. RELATED WORKS

Sentiment analysis, content recommendation systems, product recommendation systems, feature selection and classification incorporated systems in the past by many researchers. Among them, Li and Feng [4] developed a new clustering algorithm using the Latent Class Regression method capable of considering product ratings and opinions for identifying the reviewer's choice. They have enhanced their method by considering the products' weighted features and proved them as better through experimental results. Jawa and Hasija [5] designed a new model that works according to the interest-aware graphs with the sentiment analysis to calculate the correlation value of different entities, and it also supplies suitable and relevant products in e-commerce.

Zhang et al. [6] built an aspect-based sentiment collaborative filtering model that combines sentiment analysis with fuzzy Kano. They have obtained the various attitudes of the customers according to the results of sentiment scores. Moreover, they have incorporated a new similarity measure technique with user choices for a collaborative filtering method. Ultimately, their model is proved better than other models by conducting experiments by applying the Amazon datasets. Karthik et al. [7] proposed a novel Feature aware Product Ranking and Recommendation Algorithm to provide suggestions for customers interested in purchasing good quality products. Their algorithm analyses the various products and their ranks based on the review comments provided by the customers who purchased and used the product. Ultimately, the algorithm suggests the products that are more suitable for the

customers. It evaluates through experimental results and is also proven superior to the classical ML algorithms, including random forest and SVM.

Irfan et al. [8] proposed a hybrid framework that uses context-aware recommendation based on product ratings and customer reviews. They have used text mining methods over large-scale user item feedback to calculate the sentiment scores. Moreover, they have proposed a greedy heuristic method for producing the item ranks according to the customers' similarities. The major advantage of their framework is the consideration of purchase similarities and the greedy search method. Dau and Salim [9] developed a new sentiment analysis incorporating deep learning technique-based recommendation system that considers the various aspects of products and the customer's sentiments that are used to improve the recommendation accuracy. They have mainly designed a semi-supervised topic modelling model for extracting product aspects associated with lexicons from customer reviews. They also have used long short-term memory (LSTM) encoder to achieve better product recommendation performance than other models.

Wang et al. [10] proposed sentiment matrix factors, sentiment scores and the reviews-based recommendation model to predict suitable content. Initially, they analyzed various topics and reviewed comments by applying the lexicon construction and Latent Dirichlet Allocation (LDA) methods. Then, they combined the user consistency computed using their review comments on products and the ratings. Next, they have integrated the reliability measurement of topics and sentiment analysis on review comments. Finally, they proved that their model is superior to other product recommendation systems. Hu et al. [11] proposed an enhanced recommendation model that considers the interests, credibility and sentiment scores. Their model consists of five different modules for performing the recommendation process, feature sentiment assignment, user interests, credibility analysis and feature extraction process. They have considered the customer's opinions on their liked products and the trust scores of the customer's review comments. Finally, they have made product decisions using weighted sentiment scores and features.

Mohammad et al. [12] developed two new lexicon generation approaches to handle aspect-based issues that use statistical methods and genetic algorithms. They have proved that their models as better than the existing approaches. Karthik and Ganapathy [13] developed a new approach called Multi scenario demographic hybrid with necessary and useful features, including users' ages and locations. Moreover, they have ranked the available products according to age group and purchase locations. Finally, their system is proven superior based on prediction accuracy.

Zarzour et al. [14] designed an architecture incorporating deep learning technique-based sentiment analysis to predict review comments. Their architecture has two major components: LSTM and Gated Recurrent Unit (GRU) methods. Finally, they evaluated their architecture by conducting experiments using the actual purchase and Amazon datasets and achieving better prediction accuracy. Munuswamy et al. [15] developed a novel rating and sentiment-aware

content prediction method to build a recommendation system to mine valuable data from customer reviews or product feedback. Their algorithm helps predict the people who liked products by considering the ratings. Their algorithm uses a dictionary to calculate the sentiment scores to recommend the exact items. In the end, their method obtained superior prediction accuracy than available methods. Karthik and Ganapathy [1] developed a fuzzy aware product recommendation system capable of predicting the suitable products for the customers based on their interests in e-commerce. They calculated the sentimental score for each product, used them to form fuzzy rules, and stored them in an ontological table for making final decisions. Finally, they have proved that their system is superior by achieving better results in the majority of experiments on various sizes of datasets.

Wenxiong et al. [16] built a novel multi-level graph-based neural classifier for performing the sentiment analysis over their review comments. They have applied node connection windows to consider local and global features. Specifically, they have integrated a message-passing system that considers the scaled dot-product attention to fuse the features. Huiliang et al. [17] proposed a new neural classifier that applies an improved Bat Algorithm and Elman Neural Network to analyze the reviews of the products. Their method consists of four important steps: data collection, feature selection and sentimental classification. In their work, they have used Web Scrapping Tool to extract customer reviews about the products from e-commerce websites. The preprocessed data is categorized as positive, negative and neutral. Finally, they have achieved superior prediction accuracy than the available systems.

Abolfazl et al. [18] designed an automated model for performing effective sentiment analysis of customer review comments. They have considered the feature extraction process by incorporating the Term frequency, Inverse document frequency. They also speed up robust and local binary patterns to extract the features from pre-processed data. Finally, they have integrated the Deep Belief Network and Whale Optimization Method to perform feature optimization and sentiment classification. They have obtained around 97% classification accuracy, which is superior to other classifiers. Antony et al. [19] proposed a novel product recommender to predict suitable customer products. Their recommendation system incorporates the bidirectional encoder and the attention-based sequential recommendation system for effective classification. They have compared their system with other models and proved it superior.

Yao et al. [20] proposed a deep product recommender that considers the sentiment analysis of review comments and the product ranking. They applied the deep learning technique to map the extracted features and the ranking-based latent factor. Many experiments have been conducted using Amazon datasets and obtained higher accuracy than the available models in this direction. Rosewelt and Renjith [21] built a new method for enhancing the product recommendation systems' performance by deeply analyzing product reviews and the customer's purchase behaviours. They have considered the product features, feedback, and not-liked product features to improve prediction accuracy.

### III. SYSTEM ARCHITECTURE

Fig. 1 demonstrates that the proposed product recommendation system's workflow consists of four important components: Amazon Dataset, User Interaction Module, Decision Manager and Product Recommendation System, which has three different phases Sentiment Analysis, Data Preprocessing and Sentiment Classification Module.

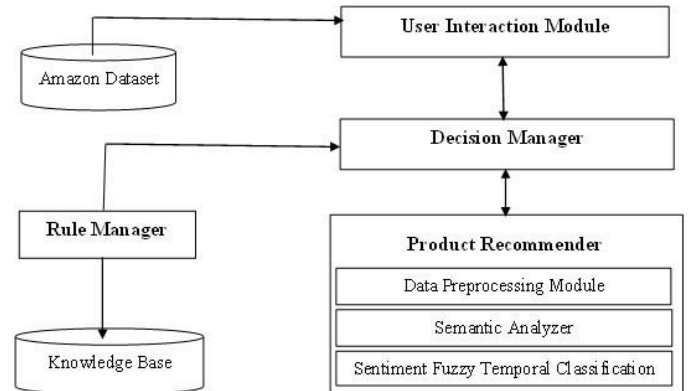


Fig. 1. System architecture.

The user interaction module extracts the necessary data from the Amazon dataset. The decision manager receives the extracted data and forwards them to the product recommender. The product recommender has three important phases: data preprocessing, sentiment analyzer and sentiment classification. The data preprocessing module performs the data preprocessing tasks, including stemming, stop word removal, tokenization and syntax analysis. Finally, the preprocessed data is to be moved to the sentiment analyzer capable of analyzing the data as per sentiments. The sentiment analyzer performs the sentiment analysis and forwards it to the sentiment classification by applying the classifier and considering fuzzy temporal rules. The decision manager makes effective decisions on the sentiment classification process by applying the fuzzy temporal rules stored in the knowledge base through the rule manager. Generally, the knowledge base contains the rules and facts. The rule manager is used to manage the rules available in the knowledge base based on the suggestions of the decision manager. The Amazon dataset contains the customers' purchase history and feedback as review comments.

### IV. PROPOSED WORK

This work proposes a new product recommendation system that incorporates the data preprocessing technique and classification. The data preprocessing technique incorporates the newly developed weighted topic-aware lexicon expansion for performing effective preprocessing. The sentiment classification is also adopted for enhancing the data preprocessing processes capable of identifying the effective features to enhance the classification accuracy. The classification adopts the newly developed Fuzzy Temporal Product Recommendation Algorithm to identify suitable liked products for customers according to their interests.



### A. Data Preprocessing

Data preprocessing consists of two important preprocessing tasks: lexicon expansion and sentiment classification. Before that, the basic data preprocessing, including tokenization, POS (Parts of Speech) tagging and parsing, are useful for performing effective data preprocessing tasks in this work. Here, a new data preprocessing method called Fuzzy Weighted Product based Lexicon Expansion Method (FWP-LPM) is finalizing the preprocessed content. First, it explains this work's fuzzy logic and rules for performing data preprocessing and classification tasks.

1) *Fuzzy logic and fuzzy rules:* The fuzzy set theory was proposed by Zadeh [22]. Many applications in the real world cannot make decisions with certainty. This is because many phenomena in this world are fuzzy in nature. The crisp sets make decisions by manipulating formulas that can hold values of 1 and 0 only. Therefore, the logic, such as propositional logic and the first order predicate logic can only manipulate the formulas to make a true or false decision. However, the world consists of facts that are probabilistic in nature. Hence, it is necessary to perform the gradation of truth values. This type of gradation can help to perform qualitative reasoning as well as quantitative reasoning. Fuzzy logic provides operators and membership functions for converting the crisp set values into fuzzy linguistic values so that it is possible to perform reasoning under uncertainty.

A fuzzy inference system is capable of performing qualitative reasoning through the effective application of fuzzy rules. The fuzzy rules are formed according to the fuzzy membership functions like triangular, trapezoidal and Gaussian membership functions. Moreover, the fuzzy rules are represented in the form of IF.... THEN rules. The other type of format used for representing rules are Event, Condition and Action rules which are also represented using ON Event, IF (Cond) THEN rules and both these types of rules can be used for making inferences. In a fuzzy inference system, there are two modules in which the first module performs the fuzzification process. Here, the quantitative values are converted into qualitative and linguistic variables. In the defuzzification process, the qualitative rules and values are converted into quantitative values. The fuzzy rules can be used to adjust weight in the neural network-based classification algorithms to increase classification accuracy. In other classifiers, fuzzy rules can aid in decision-making by handling the uncertainty in the classification process.

2) *Basic data preprocessing tasks:* This subsection explains the tokenization, POS Tagging and Parsing in detail. These preprocessing tasks help perform effective classification.

a) *Tokenization:* The feedback is categorized into various tokens or words or terms. The sequence is identified and grouped as meaningful content according to the term relevancy. The review comments contain the terms "fantastic product", "good", "liked products" and "Worthy products" to perform the processes of morphological analysis and tokenization. Here, the tokenization is done and you get the terms like good, fantastic, like, and worthy. In addition, the

stop words are also removed from the feedback or comments on products.

b) *POS tagging:* It provides the data on how the terms are applied in a sentence and also identifies the "Nouns", "Pronouns", "Adjectives" and "Verbs" are tagged on tokens. Moreover, it labels the terms over the POS tagging. Every token is identified and tagged with POS, which is used for identifying the suitable terms to predict the user's interest.

c) *Parsing:* It provides a standard grammatical structure for any input sentence. Here, the parsing model groups the words according to their relevancy. In this work, the parsing model constructs a parse tree by considering the words relevancy in terms of subject or object.

3) *Weighted topic (product) based lexicon expansion:* The lexicon analysis is used to find the difference between the input content and the common opinion or meaning of the term. This work considers the relevancy between two terms with closure sentiment scores and relevant meaning. In this work, the polarity of the expression with less emotion is also calculated as the value of Weighted Point based Mutual Information (WPMI) simply between any two input terms using the formula given in (1).

$$WPMI(t1, t2) = \log_2 \left( \frac{p(t1, t2)}{p(t1)p(t2)} \right) * WT \quad (1)$$

Where, t1 and t2 are the different input terms or words, p indicates the probability, and WT represents the weight that is the common difference between the two terms.

The term's or word's orientation value semantically is demonstrated by using (2).

$$SOT(T) = WPMI(T, Pos) - WPMI(T, Neg) \quad (2)$$

Where, Pos means positive (+ve) and Neg means negative (-ve), T represents the token.

Generally, two different assumptions are considered in this work. First, the sentiment orientation of emotions such as "(:)" and ":((" is stable relatively throughout the entire comments. Here, the positive and negative signs and comments on products are useful for knowing the two extreme statuses of the product in the market. Second, the comment on a product is not valid over the products with negations. For example, "I don't like this product". This comment is a negative comment about a product. Now, the polarity value of their opinion is measured by computing the relevancy score between the terms. The sentiment orientation on a product is calculated using (3).

$$SO(T) = \log_2 \left( \frac{H(T, Pos) \times H(Neg)}{H(T, Neg) \times H(Pos)} \right) \quad (3)$$

Where, H indicates the hits. The sentiment may not be applicable to some terms in comments. In this scenario, the POS tags of the terms can be applied for identifying the potential and useful terms that include "Adjectives", "Nouns", "Pronouns", "Verb" and "Intersections". This set of tags was identified and selected after conducting the experiments with various combinations of tag sets and applying this set to perform the classification effectively.

Fuzzy Weighted Product based Lexicon Expansion Method (FWP-LPM)

**Input:** Feedback or Review Comments and sales data

**Output:** Preprocessed Content

Step 1: Read the feedback about a specific product {FBp1, FBp2. . . .FBPn}

Step 2: Perform the tokenization process and extracts the terms as tokens.

Step 3: Perform the POS Tagging process and extracts the terms with parts of speech.

Step 4: Perform the Parsing process and construct the parse tree to provide the useful terms.

Step 5: Find the value of Weighted Point based Mutual Information (WPMI) for the two adjacent terms of the input terms using (1).

Step 6: Find the orientation of the sentiment score for the input term of a product by using (2) and (3), and also consider the sales history of the input data.

Step 7: Apply the Fuzzy Rules to finalize the terms.

Step 8: Return the preprocessed terms/contents.

The newly developed FWP-LPM is applied for performing the data preprocessing and is useful for extracting the preprocessed content.

4) *Sentiment classification:* This section describes the sentiment score calculation procedure used in this work to identify users' interest in the products through their comments/feedback. The product rating is calculated using the relevant feedback by applying the newly developed product ranking algorithm (PRA). Here, the sentiment polarity and product rank in the form of a score is summed up as a sentiment score. First, the product ranking process is explained in this section.

a) *Product ranking:* The average product score ( $PS_{p,u}$ ) is computed by applying (4). Fuzzy Weighted Product based Lexicon Expansion Method (FWP-LPM)

$$PS_{p,u} = \sum_{i=1}^{TP_{p,u}} (SSi_{p,u}) \quad (4)$$

Where,  $TP_{p,u}$  represents the number of feedbacks received and considered for the respective product. The overall ranking of the product is computed by applying (5).

$$POR_{p,u} = \frac{OR_p * NOF}{PS_{p,u}} \quad (5)$$

Where, the variable  $OR_p$  indicates the overall rank of the specific product and the variable  $NOF$  indicates the number of feedbacks considered for the specific product in this work.

In this way, the rank is to be identified for each product according to the feedback and also consider the current

purchase behaviour of the users. Moreover, the similarity between the products is also considered in this work by applying the Cosine similarity formula that is given in (6).

$$CosineSim(p_i, p_j) = \frac{p_i \cdot p_j^T}{\|p_i\| * \|p_j\|} \quad (6)$$

The cosine similarity value between the two products is useful for finalizing the specific product rank and product classification processes. This cosine similarity also plays an important role in the decision-making process in the various recommendation systems. In this work, the similarity value of each product must be below the threshold. The average cosine similarity value is considered a threshold value.

### B. Classification

The classification is performed by applying a newly developed Fuzzy Temporal and Sentiment awareness Product Recommendation Algorithm (FTS-PRA) in their work to predict the user's interests and to recommend suitable products. The fuzzy logic is applied in this work for making effective decisions over the product recommendation process. Moreover, this paper uses the standard triangular fuzzy membership function to generate the fuzzy rules. In the process of fuzzy rule generation, time is also considered an important parameter. The reason is for considering the temporal feature for enhancing the prediction accuracy. The steps of the FTS-PRA are as follows:

Fuzzy Temporal and Sentiment aware Product Recommendation Algorithm (FTS-PRA):

**Input:** Feedback or Review Comments, sales data

**Output:** Recommended product

Step 1: Read the feedback about a specific product {FBp1, FBp2. . . .FBPn}

Step 2: Apply basic preprocessing tasks

Step 3: Apply Weighted Product based Lexicon Expansion along with sentiment score.

Step 4: Check whether the specific product similarity value is below the threshold and sold out reasonable numbers.

Step 5: Calculate the product ranking score for the product by applying (3) and (4).

Step 6: Apply the Fuzzy Temporal Rules

Step 7: Perform the sentiment classification and initiate the product recommendation process

Step 8: Recommend a suitable product to the customer/user.

The newly developed FTS-PRA is used to predict the user purchase pattern and the suitable products by analyzing the feedback of the customers who purchased the product early. First, it reads the product's feedback and performs the preprocessing tasks including Tokenization process, POS Tagging process and Parsing. Moreover, this algorithm applies the newly developed weighted product-based Lexicon expansion with a semantic score method to retrieve the most useful contents from feedback. Next, the product similarity is calculated by considering the feedback analysis. Then, based

on the sentiment classification result, find the product score for the products and also recommend the product to the users. Finally, it recommends the product to the customer.

## V. RESULT AND DISCUSSION

This section demonstrates the experimental results for evaluating the proposed system and the relevant discussion. First, it explains the dataset used in this work.

### A. Dataset

The proposed system is evaluated using the famous benchmark dataset, the Amazon dataset. The Amazon dataset is considered the Kindle store items, books, magazines, CDs, Toys, Greeting Cards, Crafts and Video games, grocery, office products, pantry, home and gourmet food. All these items are categorized into different datasets according to the type of products.

Amazon Sales Dataset 2023: The Amazon sales dataset 2023 [25] has sales records. The sales records contain the details about the products, sales time and date and the frequency of sales with the number of items sold out for the specific time duration [25].

### B. Performance Metrics

The proposed system is evaluated by considering the standard evaluation metrics including Precision and Recall metrics shown in (7) and (8).

$$Precision = \frac{Relevant\ Recommended\ Products}{Total\ Recommended\ Products} \quad (7)$$

$$Recall = \frac{Relevant\ Recommended\ Products}{Total\ no.\ of\ relevanted\ products\ to\ be\ Recommended} \quad (8)$$

This work focuses on the precision value and recommends the same product repeatedly that may be different from what users liked. In this scenario, the product recommendation can be based on metrics such as Serendipity and nDCG.

a) *Serendipity*: This metric is very useful for recommending a suitable product to the user. Serendipity value is computed by applying the formula shown in (9).

$$P_x = \frac{no.-rank_x}{no.-1} \quad (9)$$

b) *nDCG*: This metric is useful for identifying the user's liked products and recommending them for purchase. The nDCG value helps check the correctness of the recommended product described in (10).

$$nDCG(L, k) = \frac{1}{|L|} \sum_{x=1}^{|L|} Z_{kx} \sum_{m=1}^k \frac{2^{R(x,m)-1}}{\log_2(1+m)^l} \quad (10)$$

### C. Experimental Results

The experiments are done with different sets of records as separate datasets such as DS1, DS2, DS3, DS4, DS5 and DS6. These datasets contain different products with various numbers of records. Fig. 2 demonstrates the precision value analysis between the proposed model and the existing models like the Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]).

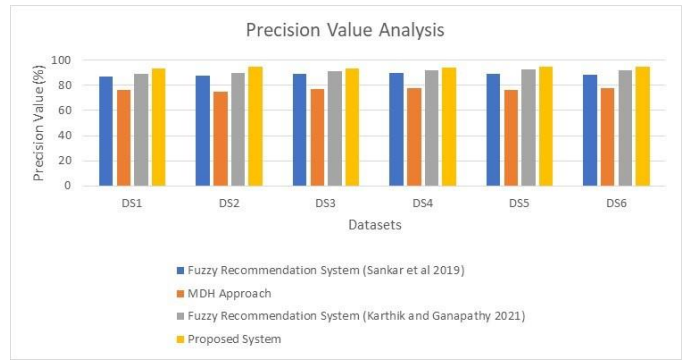


Fig. 2. Precision value analysis.

Discussion: Fig. 2 demonstrates that the performance of the proposed model is proved as better than the available models like the Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]).

Reason for the Enhancement: The performance is using a weighted topic-based lexicon expansion method, sentiment analysis and fuzzy temporal rules.

Fig. 3 shows the recall value analysis between the proposed model and the existing models like the Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]).

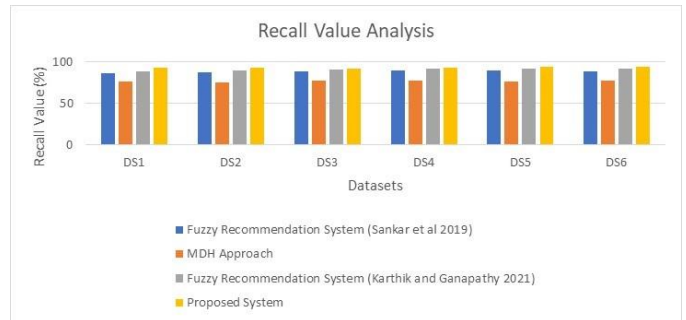


Fig. 3. Recall value analysis.

Discussion: Fig. 3 shows the performance of the proposed model that is proved as superior in terms of recall value than the available product recommendation systems such as Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]).

Reason for the Enhancement: The reason for the enhancement here is the use of weighted topic-based lexicon expansion method, sentiment analysis and fuzzy temporal rules.

Fig. 4 shows the Serendipity value analysis between the proposed model and the available recommendation systems like Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]).

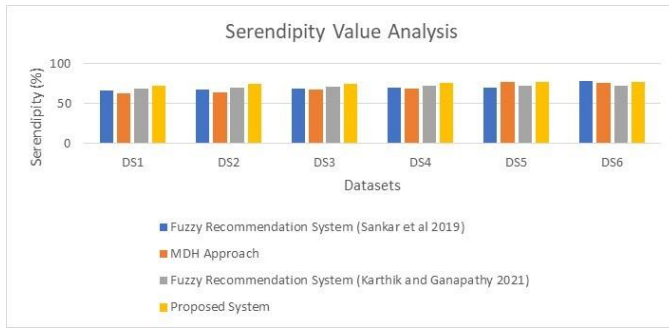


Fig. 4. Serendipity value analysis.

Discussion: Fig. 4 shows the serendipity value of the proposed model which achieves superior value than the available models like the Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]).

Reason for the Enhancement: This better enhancement is applying weighted topic-based lexicon expansion method, sentiment analysis and fuzzy temporal rules.

Fig. 5 demonstrates the nDCG value analysis between the proposed model and the available models like the Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]).

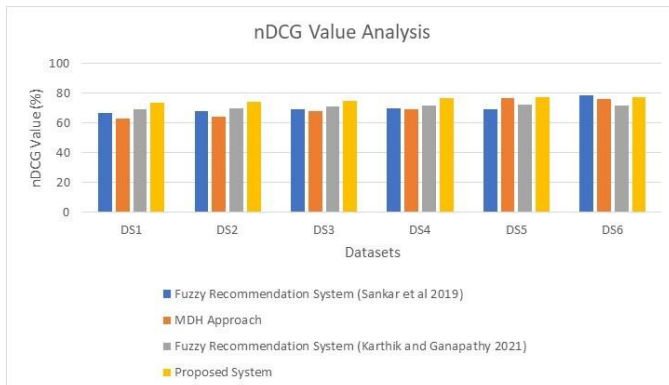


Fig. 5. nDCG value analysis.

Discussion: Fig. 5 shows the achievement of better nDCG value than the available models like the Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]).

Reason for the Enhancement: This betterment applies a weighted topic-based lexicon expansion method, sentiment analysis and fuzzy temporal rules.

Table 1 shows the comparative outcome analysis between the proposed and available product recommender models. The proposed product recommendation system considers the evaluation metrics such as precision, recall, serendipity and nDCG. It implies that a new product is recommended based on the context and relevant to current user interest. This improves user satisfaction as well. Table 1 shows the consolidated results

with the conducted results. Both recommendation-specific metrics Serendipity and nDCG are improved without impacting or compromising the precision and recall.

TABLE I. COMPARATIVE OUTCOME ANALYSIS

Recommendation system	Precision	Recall	Serendipity	nDCG
FBPRR	0.32	0.15	0.022	0.23
Fuzzy rule	0.52	0.32	0.024	0.25
MDH	0.45	0.45	0.02	0.21
Fuzzy recommendation	0.49	0.49	0.04	0.34
Product Recommendation System	0.50	0.49	0.041	0.36
Personalized Recommendation System	0.51	0.51	0.042	0.37
Proposed System	0.52	0.52	0.045	0.38

Discussion: Table 1 shows the better achievement of the proposed recommender model according to the evaluation parameters such as precision value, recall value, serendipity value and nDCG value than the available recommenders like the Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]), Product Recommendation System [23] and Personalized Product Recommendation System [24].

Reason for the Enhancement: This achievement applies a weighted topic-based lexicon expansion method, sentiment analysis and fuzzy temporal rules.

Table 2 shows the time analysis between the proposed and existing product recommendation systems. Here, the experiments have been done with randomly selected 700 records as training datasets and 300 records are given as testing datasets from the Amazon sales dataset 2023 and Amazon Product Review Dataset for this time analysis.

TABLE II. TIME ANALYSIS

Recommendation system	Training Time (sec)	Testing Time (sec)
FBPRR	0.41	0.19
Fuzzy rule	0.40	0.18
MDH	0.39	0.17
Fuzzy recommendation	0.39	0.17
Product Recommendation System	0.38	0.16
Personalized Recommendation System	0.37	0.15
Proposed System	0.34	0.14

Discussion: Table 2 shows the better achievement of the proposed recommender model with respect to the training and testing time than the available recommenders like the Fuzzy recommendation system (Sankar et al. [2]), MDH Approach (Karthik and Ganapathy [13]), Fuzzy Recommendation System (Karthik and Ganapathy [1]), Product Recommendation System [23] and Personalized Product Recommendation System [24].

Reason for the Enhancement: This efficiency betterment is considering time constraints and applying a weighted topic-based lexicon expansion method, sentiment analysis and fuzzy temporal rules.

## VI. CONCLUSION AND FUTURE WORKS

In this work, a new fuzzy logic incorporated sentiment analysis-based product recommendation system is developed to predict the customer's need and recommend suitable products successfully. The proposed system incorporates a newly developed sentiment analysis model which incorporates the classification through fuzzy temporal rules. Moreover, the basic level data preprocessing activities such as stemming, stop word removal, syntax analysis and tokenization are performed to enhance the sentiment classification accuracy. Finally, the proposed product recommendation system recommends suitable products to the customers by predicting the customer's needs and expectations. The proposed system is evaluated using the Amazon dataset and proved superior to the existing recommendation systems in terms of precision, recall, serendipity and nDCG values. This work can be further enhanced by introducing a deep learning algorithm for classification instead of a normal machine learning classifier.

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# Information Technology Technical Support Success Factors in Higher Education: Principal Component Analysis

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**Abstract**—The use of information and communication technologies at higher education institutions is no longer an option, but rather a need. Information Technology support is an essential factor that entails giving end users assistance with hardware and software components. Technical support for information technology has been recognized as a crucial element linked to student happiness because it helps students understand, access, and use technology efficiently. The successful implementation of IT technical support will be aided by identifying the essential success criteria that enable efficient and effective support for students and instructors. Hence the main aim of this study is to identify and rank the key success factors for the successful implementation of IT technical support at higher education institutes. 81 key success factors identified from 100 research papers were analyzed using principal component analysis. The findings led to the identification and ranking of 25 PCs. 95.35 percent of the observed variation was accounted for by the first 25 PCs with eigenvalues higher than 1. The percentages for the first 6 PCs were, in order, 11.87%, 22.21%, 30.64%, 38.25%, 45.12%, and 51.47%. This research provides useful information highlighting factors that can be used to examine areas in educational institutions that need to receive continuous and special care to generate high student satisfaction; ensure future success and gain a competitive advantage. These factors can assist the management of HEI to determine the success or failure of an institution in terms of the technical support provided to students and student satisfaction.

**Keywords**—Information technology; technical support services; key success factors; principal component analysis; higher education institutions

## I. INTRODUCTION

Information Technology technical support is an important part of the implementation and integration of technology in education [1]. Technical support is needed by students who are not familiar with information and communications technology and need to use online learning effectively [2]. Support from technical staff is not limited to infrastructure, hardware, and software issues; when academic staff is supported by technical staff are most likely to explore different online tools that will aid in multi-modal teaching [3]. Technical support is needed to assist and enhance the efficient delivery of academic content. [4]. To study, students depend on the technical team's constant and prompt reactions. [5].

Lack of technical support and advice leads to unsuccessful projects [6].

Higher education institutions all across the world were utilizing a range of measures to sustain their academic programs as the COVID-19 virus started to spread in early 2020. To avoid losing the academic year, the academics had to come up with creative ways to teach. To assist academic staff and students who were compelled to use technological tools like Moodle, Blackboard, email, and MS Teams and to help mitigate the problems experienced, there was an immediate and great need for IT technical support services[79]. According to [7] the pandemic made access to technical support services at all higher education institutions an even bigger problem. Email, Microsoft Teams, WhatsApp, and several other online channels were used to deliver technical support services. Students required technical support and advice to enable them to understand how this new technology will benefit them [5].

Technical support has been cited by numerous researchers [84,85,86,87] as a crucial success component that is linked to student contentment. Reference[87] cited technical support as a key element that influenced distant learners' satisfaction with their courses at Malaysian universities. According to studies [84, 85, 86], students who received technical support felt more at ease and inspired to use the e-learning systems. To create a successful IT technical support services satisfaction model and reduce the risk of failure, key success factors (KSFs) must be recognized [8, 9]. It is crucial to emphasize that KSFs will evolve as both the environment and users' perceptions of them do. To attain or sustain optimum benefit, identified KSFs will need to be continually assessed [9]. The most important success variables ought to be small, manageable, and measurable [10].

Principal component analysis (PCA), according to Hanci and Cebeci [12], is a multidimensional statistical technique that can split similar relevant variables into a cluster of fewer key determinants as principle components (PCs). It helps draw attention to differences and spot patterns that may be concealed in a dataset [11]. The PCA method, a mathematical methodology based on eigenanalysis, calculates the eigenvalues and equivalent eigenvectors of a square symmetric matrix using sums of squares and cross-products [13]. The author in [81] used PCA to reduce the number of



evaluation criteria for learner support services provided to undergraduate students at remote education centres. The PCA method was used by Reference[82] to identify the service quality indicators among Ghanaian graduates of a higher education institution. PCA was utilized in the study [83] to identify the aspects of service quality at a Kenyan university. The main objective of this study is to use the PCA method to identify the key success factors for IT technical support services in higher education institutions. The following section of this paper is organized as follows: Section 2 related works; Section 3 materials and methods; Section 4 the results and discussion and Section 5 conclusion.

## II. RELATED WORKS

Technical aid some of the services offered to students and academics to lessen the workload of the instructor and improve student performance include having the knowledge and abilities to assist students and instructors with technical issues, providing support using online tools (WhatsApp), being able to resolve issues quickly and effectively, understanding the specific needs of students, and being available 24/7. Over the years, numerous research measuring the service quality of HEIs were carried out utilizing the Service Quality (SERVQUAL) 5 dimensions technique (tangibility, reliability, responsiveness, empathy, and assurance). The author in [14] discovered that the institution in Thailand did not live up to the expectations of the 350 study participants. Perceptions received lower scores than anticipated. This suggests that significant service enhancements are required to improve service quality. Similarly, in [15], they determined that it was important to assess the level of service at a university in Ghana, particularly from the perspective of the students, given the growing demand for investment in the management and administrative areas of HEIs. Data was gathered and examined by 384 students. The study's findings indicated that most students were happy with the services provided by the institution to the point where they would suggest it to others. Contrary to the other four dimensions, the tangibility dimension was performing well in terms of its services. The author in [16] at Valley View University in Ghana surveyed 100 students to gauge their satisfaction with the services provided. The findings demonstrated that the university's assurance, tangibility, and responsiveness services were satisfied; however, the empathy dimension was only moderately satisfied. A Tanzanian university's service quality and student happiness were the subjects of the study described in [17]. The findings indicated that the reliability dimension was the most favourable aspect of the study, while the other dimensions obtained low scores, indicating that the services provided to the students were unsatisfactory.

The author in [18] sought to investigate how service quality was implemented at an Indonesian university. We conducted interviews, observations, and document analyses. The outcomes demonstrated that the university's implementation of service quality was of poor quality. The SERVQUAL instrument was used in the study [19] to compare literature reviews and assess service quality in HEIs. The outcomes of the literature review were triangulated, and they were evaluated for certain quality aspects that would be

typical of public HEIs and might need to be improved. In terms of the services being provided, the perception of the students was lower than expected. The study by [20] looked at how the five service quality factors impacted Indonesian university students' satisfaction. The sample group included 125 students. The sampling process was straightforward and random. According to the findings, tangibility, dependability, and responsiveness had a good impact, whereas empathy scored reasonably, and assurance had no impact.

The study in [21] assessed the level of services offered at Albanian HEIs. According to the study's findings, none of the services provided to students satisfied them, as evidenced by the fact that all five SERVQUAL dimensions obtained low scores. The reliability factor received the most negative evaluations from students who thought that staff members were unwilling to help them with issues, failed to notify students in advance of schedule changes, and did not give them the necessary support. A study [22] looked at the relationship between student happiness and the caliber of services provided to Sri Lankan students in private foreign HEIs. The key SERVQUAL dimensions that were most important in determining student satisfaction were looked at. The results of the study demonstrated a significant link between student happiness and service quality. In this study, the qualities of assurance and responsiveness had a substantial contribution to student happiness. This research will fill a gap since no earlier studies have concentrated especially on the technical support services offered to students at HEIs.

## III. MATERIALS AND METHODS

The techniques for data extraction and dimensionality reduction are thoroughly explained in this section. To obtain the pertinent data, this investigation used the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) technique recommended by [23]. One of the finest techniques for helping researchers do systematic reviews and meta-analyses correctly and review a structure like a road map is PRISMA. This approach is well-liked in systematics literature and has been widely applied in a variety of research [24-28, 80]. The scientific literature that can be obtained using a structured approach that is based on objectives that are set so that different authors can utilize them can be summarized and analyzed by the researcher in a systematic review, which provides significant evidence [29].

All published studies reporting on IT technical support services were found through a search of the literature. Identification of pertinent research, screening, and selection of those studies, eligibility, and inclusion stages were all completed following the PRISMA methodology.

1) *Identification*: Scientific articles are chosen relating to IT technical support service key success factors in higher education institutions published in scholarly journals listed on the SCOPUS database (368) and ScienceDirect (749). Databases were searched by using the keywords “key success factors”, “IT technical support services”, “higher education”, limited to years greater than 1985 and less than 2022, limited to “journals”, limited to “computer science” subject area and limited to the “English” language. The Next step of the

PRISMA method is to remove duplicate articles.

2) *Screening*: A review of articles relevant to IT Technical Support Service Key Success Factors in Higher Education, the articles were screened by analyzing the title and abstract. The articles were put into the Mendeley citation management software. From a total of 1,117 articles 303 duplicate articles were removed. Finally, 814 articles remain.

3) *Eligibility*: Eligible criteria are needed to select appropriate articles [30], therefore articles are filtered based on inclusion and exclusion criteria as shown in Table 1.

TABLE I. INCLUSION AND EXCLUSION CRITERIA

Criteria	
Exclusion Criteria	
EC1	Papers in which only abstract is available.
EC2	Duplicate records.
EC3	Review and survey papers.
EC4	Papers not written in the English language.
EC5	Papers not relevant to IT technical support services.
EC6	Papers not applying PCA or Factor Analysis or SERVQUAL dimensions.
EC7	Papers not reporting sample size.
Inclusion Criteria	
IC1	Articles published in English.
IC2	Papers in Computer Science subject area only.
IC3	Papers relating to IT technical support service key success factors in higher education.
IC4	Journal papers only.
IC5	Papers between 1985 to 2022

Table 1 shows that only publications that satisfy the criteria are chosen; chapter books, brief reports, articles, non-English papers, and works from before 1985 are all excluded. In this instance, 25 items were eliminated since they did not meet the requirements and 789 articles are still present. Another 749 pointless articles have been eliminated at this point.

4) *Included*: Overall, 100 articles that match the inclusion

criteria remain. The 100 papers that can contribute to this study are examined in this final step. The papers are carefully read through to extract and condense key information. The information gathered will be used for this study. The flow of a database search using PRISMA is shown in Fig. 1.

This section aims to provide the key success factors that will be used to assess the IT technical support services provided to students at HEIs.

a) *Dataset*: For this study, a total of 81 factors have been identified from 100 research studies. They have been gathered and presented in binary form to display the attribute of the factors identified for further analysis.

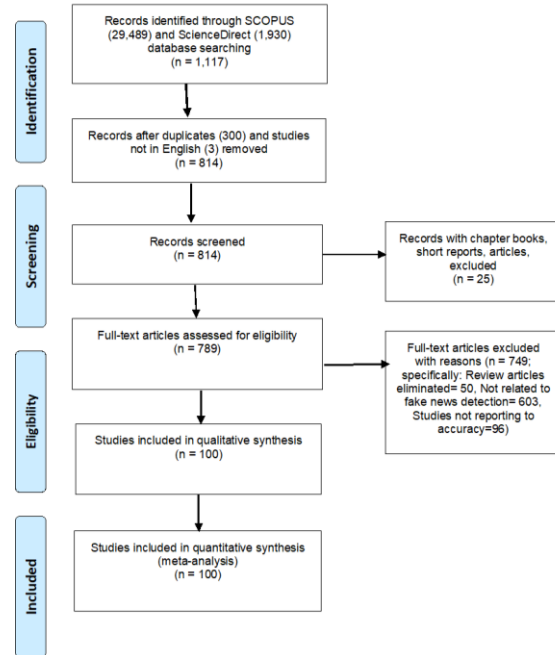


Fig. 1. Flow diagram of database search using PRISMA [31].

TABLE II. QUALITATIVE AND QUANTITATIVE IT TECHNICAL SUPPORT SERVICES (ITSS) FACTORS FOR PCA

ITSS FACTORS	NAME	DESCRIPTION	ADAPTED FROM SOURCE
F1	reliability	The student is assured that support staff to help resolve queries promptly.	[14] [32] [33] [15] [16] [18] [17] [19] [20] [21] [22]
F2	responsiveness	IT technical support staff's willingness to assist students and provide them with prompt service.	[34] [14] [32] [35] [15] [16] [18] [17] [19] [20] [21] [22]
F3	tangibility	Communication medium used to provide support services to students. Friendliness of staff.	[14] [33] [35] [15] [16] [18] [17] [19][20][21] [22]
F4	empathy	IT technical support staff gives students personal attention and understanding of the student's specific needs.	[14] [35] [15] [16] [18] [17] [19] [20] [21] [22]
F5	assurance	IT technical support staff being courteous to students as well as staff knowledge to answer students' queries.	[14] [35] [15] [16] [18] [17] [19] [20] [21] [22]
F6	trustworthy and loyalty	Loyalty requires developing a solid relationship with students.	[33]
F7	commitment	Students' likeliness to contact the same technical staff for assistance in the future.	[33]
F8	competence	IT technical staff have the appropriate knowledge and skills.	[14]
F9	reputation	IT technical staff are consistent in terms of	[34] [33]

		service delivery.	
F10	technical support staff	Timeliness and effectiveness of solution provided.	[34] [36] [37] [38] [39]
F11	communication material	Documents provided to students are easy to follow and are easily accessible and accurate.	[40] [32] [33]
F12	communication method	Effective use of modern online tools and services. WhatsApp service is reliable and easy to use. Technical staff is easily accessible by this service.	[40] [36] [33]
F13	location	Remote technical support provided is very convenient. Remote technical support is available 24/7.	[40]
F14	customer orientation	The student is very satisfied with the service provided.	[41]
F15	competitor orientation	IT technical staff has a competitive advantage over others in terms of providing excellent service to students and knowledge of the technical staff.	[41]
F16	inter-functional orientation	Inter IT technical department communication.	[41]
F17	performance orientation	IT technical staff's commitment to service.	[41]
F18	employee orientation	IT technical staff choose to provide service excellence.	[41]
F19	long term orientation	IT staff continuously improving student services.	[41]
F20	academic aspects	IT staff assist students with queries thereby increasing student academic performance.	[42] [43] [44] [45] [40] [46] [47]
F21	non-academic aspects	Support services, financial aid, security, etc. are considered non-academic aspects.	[42] [43] [44] [45] [40] [46]
F22	dependability	Students rely on IT technical staff to assist with technical queries.	[48]
F23	effectiveness	Effective use of modern online tools and services.	[48]
F24	capability	The technical staff has the knowledge, skills, and experience to assist promptly with student queries.	[48]
F25	efficiency	Promptness of delivery.	[48] [49] [50]
F26	assurance	Courtesy of technical staff; ability to encourage confidence and trust.	[48] [51]
F27	unusual situation management	unusual situation management.	[48]
F28	semester	Usually, six months.	[48]
F29	syllabus	Course content.	[48] [49] [50]
F30	teaching methodology	The method used to conduct lecturers e.g., using blackboard.	[52] [49] [51] [53] [54]
F31	disciplinary action	Reprimand in response to rule violation or misconduct.	[52]
F32	environmental change in study factor	Universities' involvement in reducing their carbon footprint.	[52]
F33	mediating self-actualization placement	Fulfillment of one's talents and potential.	[52]
F34	NSE as a service quality measure	NSE dimensions of service quality include but are not limited to content and structure of the study, acquired general skills, acquired scientific skills, testing, and assessment, program schedules, etc.	[55]
F35	customer focus and need-based	The customer is driven by a specific need.	[56]
F36	channels of communication	Examples: university website, WhatsApp communication, Facebook, Twitter, alerts, and reminders.	[56,57]
F37	instructional competence	Important practices that lecturers must grasp for effective instruction to students to maximize knowledge and skills.	[56] [50] [57] [58]
F38	specific policies and procedures	Guidelines for development, implementation, monitoring, and evaluation of HEIs.	[56]

F39	evaluation and control system	Implemented through the preparation of emergency policies and a crisis management team.	[56]
F40	curriculum design	Relevance of materials to students. Enthusiasm and methodology used by lecturers.	[40] [47] [51]
F41	effective leadership	Efficient guidance.	[56]
F42	periodic review	Assessing regularly.	[56]
F43	resource allocation	Equipment provision.	[56]
F44	operational planning	Department goals, capabilities, and budgets.	[56]
F45	competence	Theoretical knowledge, practical knowledge, up-to-date, teaching expertise, and communication.	[59] [54]
F46	attitude	Understanding the needs of students.	[59] [43] [58] [53] [54]
F47	content	Documents given to students are easily obtainable and accurate. Adherence to course objectives.	[59] [43] [58] [53] [54]
F48	delivery	Easy access to IT technical support staff.	[59] [43] [58] [53] [54]
F49	academic services	Includes admissions, financial aid, disability services, etc.	[60] [58] [61] [54]
F50	leisure	Relaxation.	[60]
F51	industry links	HEIs in contact with outside companies	[60]
F52	cost	Cost of facilities.	[62, 60]
F53	facilities	Tangibles, ease of access, support services, recreational facilities, library services, staff availability	[63] [49] [64] [65] [62] [66]
F54	flexibility	Ability to assist out of normal hours.	[67] [62] [68]
F55	availability	Reachable.	[50] [57] [62] [65] [69] [68]
F56	personnel quality	Ability and skills of staff.	[50] [57] [62] [65] [70]
F57	sufficiency of resources	Adequate facilities available for students to use, e.g., computer laboratories, and libraries.	[50] [57] [62] [71]
F58	quality of faculty	Value of faculty.	[50] [66] [62] [71]
F59	access	Right to use.	[61] [53] [42] [70] [72] [43] [44] [40]
F60	courtesy	The staff is courteous with students.	[70] [72] [53]
F61	communication	Between lecturer and student.	[70] [72] [53]
F62	credibility	Trustworthiness.	[70] [72] [53]
F63	security	Campus facilities are safe.	[70] [72] [53]
F64	understanding	Both students and lecturer appreciate each other.	[70] [72] [53]
F65	standards of organizations	Each organization has its policies and guidelines.	[70]
F66	assessment	Evaluation methods.	[70]
F67	feedback	Opinions from staff and students.	[70]
F68	human resources quality	Capability and promptness of staff.	[46]
F69	privacy	Any information given by students (e.g., passwords) to technical staff is kept confidential.	[69]
F70	contact	Communication method.	[69]
F71	administrative services	Student support services.	[49] [64] [53] [61]
F72	campus infrastructure	Setup of HEI.	[49] [53] [73]
F73	leadership	Authority.	[74] [73]
F74	perishability	A service that cannot be made in advance	[75]

		and stored.	
F75	intangibility	A service has no physical substance.	[75]
F76	variability	Service may vary in quality from one provider to the next.	[75]
F77	lack of ownership	Shortage or absence of something required.	[75]
F78	inseparability	Makes customer-provider collaboration compulsory.	[75]
F79	infrastructure	Setup of an organization.	[76]
F80	teamwork	Colleagues working together.	[76]
F81	institutions management	Process of planning and organizing resources to run a successful organization.	[77]

a) *Principal Component Analysis:* Principle component analysis (PCA) is a multivariate statistical technique that summarizes the data by breaking it down into principle components (PCs), which are smaller elements that may be used to assess the construct more precisely without sacrificing any of the data's information [12]. Using built-in R stats package functions, PCA was applied to R-Studio.

b) *Data Standardization:* In PCA, data normalization is referred to as scaling. Here, the dataset is altered using an equation (1). This indicates that the attribute's mean is zero and that the resulting distribution has a unit standard deviation. The dataset was standardized as follows:

$$X_{ij} = (X_{ij} - X_m) / \sigma \quad (1)$$

where  $i = 1, 2, 3, \dots, 100$  (research no.) and  $j = 1, 2, 3, \dots, 81$  (factor no.),  $X_{ij}$  represents the original value of the  $i$ th research rating of the  $j$ th factor,  $X_m$  is the mean, and  $\sigma$  represents the standard deviation of the series formed by values of the  $i$ th research for all 81 factors. To standardize the data the R-Studio function `scale()` was used. The numeric matrix is entered as input and then the scaling on the columns is performed [78].

Table 2 displays the study dataset, which includes 100 quantitative examples and 81 qualitative cases for each element, and describes them all. To show the factors and determine the weights of each element, PCA was used to analyze the dataset. The dataset was standardized into items of classes and attributes using the PCA approach known as scaling in R-Studio to ascertain the transformation of the factors. The Kaiser criteria, which uses a minimal eigenvalue of unity, was used to calculate the number of PCS. Factors 1 through 81 were included in the dataset as @ ATTRIBUTE F1–F81 and their extraction was coded as @ ATTRIBUTE class PC 1–PC 100. R-Studio 2022.07.01 Build 554 and WEKA 3.8.6 were used to obtain the statistical methods for analyzing the transformed dataset. By using these two statistical approaches, we were able to assess the contributions of multiple factors and uncover transformations among the factors with increased validation. WEKA's PCA was employed to order the attributes.

As can be seen in Table 3 there are now 25 factors from the original 81 factors that have been identified as the key

success factors to determine students' satisfaction in terms of the IT technical support services that are provided at HEIs.

TABLE III. A 5-FACTOR LOADING RANKING OF THE QUALITIES

Rank	Attribute	Contribution
0.8813	1	-0.224F4-0.22F5-0.203F2+0.193F30+0.192F57...
0.7779	2	-0.292F41-0.292F42-0.292F39-0.292F38-0.292F43...
0.6936	3	-0.23F24-0.23F26-0.228F23-0.228F27-0.228F28...
0.6175	4	0.371F16+0.371F15+0.371F18+0.371F19+0.371F14...
0.5488	5	0.247F22+0.247F28+0.247F27+0.247F23+0.206F67...
0.4853	6	-0.402F77-0.402F76-0.402F75-0.402F74-0.402F78...
0.4329	7	0.372F20+0.36 F21+0.33 F9+0.217F6-0.207F5...
0.3905	8	0.389F31+0.389F33+0.389F32-0.246F46-0.246F48...
0.3515	9	0.304F33+0.304F31+0.304F32-0.259F52-0.248F51...
0.3145	10	-0.276F69-0.276F70-0.267F55-0.257F11-0.231F25...
0.2809	11	0.48 F50+0.48 F51+0.28 F49+0.253F52-0.208F72...
0.2507	12	-0.482F80-0.482F79-0.347F54+0.25 F11+0.23 F12...
0.2215	13	-0.446F69-0.446F70+0.286F11+0.253F80+0.253F79...
0.1933	14	0.271F10-0.258F20-0.255F21+0.241F67+0.241F65...
0.1695	15	0.338F12+0.324F7+0.323F6-0.243F10+0.219F13...
0.1506	16	0.626F73+0.322F7-0.288F13+0.288F58-0.253F10...
0.1333	17	-0.631F68-0.438F6+0.225F9+0.178F59+0.154F40...
0.1184	18	-0.339F34+0.318F72+0.3 F71-0.289F10+0.272F49...
0.105	19	0.584F34+0.514F81-0.364F10-0.185F12-0.185F29...
0.092	20	0.796F81-0.493F34+0.126F10-0.111F4-0.105F5...
0.0804	21	-0.376F8+0.271F13+0.256F58+0.217F56-0.21F6...
0.0694	22	-0.402F53+0.327F68+0.318F58-0.303F56+0.262F57...
0.0597	23	0.409F34+0.326F58+0.31 F29+0.281F57+0.266F3...
0.0511	24	0.504F7-0.368F53+0.312F49-0.292F58+0.24 F29...
0.0433	25	-0.536F45+0.288F8+0.278F10+0.273F49-0.261F40...

#### IV. RESULTS AND DISCUSSION

Table 4 shows the eigenvalue, variance, and cumulative percentage values for the 25 PCs and 81 PCs that WEKA and R Studio, respectively, were identified.

TABLE IV. COMPARATIVE RESULTS PCs OF THE FACTORS FOR WEKA AND RSTUDIO

25 Principal Components: WEKA Initial Eigenvalue				81 Principal Components: RStudio Initial Eigenvalue			
principal component	eigenvalue	proportion	cumulative	principal component	eigenvalue	% of variance	cumulative % of the variance
PC1	9.615	0.119	0.119	PC1	9.615	1.187	11.871
PC2	8.376	0.103	0.222	PC2	8.376	1.034	22.211
PC3	6.827	0.084	0.306	PC3	6.827	8.428	30.639
PC4	6.165	0.076	0.383	PC4	6.165	7.611	38.250
PC5	5.567	0.069	0.451	PC5	5.567	6.873	45.123
PC6	5.144	0.064	0.515	PC6	5.144	6.351	51.474
PC7	4.245	0.052	0.567	PC7	4.245	5.241	56.715
PC8	3.429	0.042	0.609	PC8	3.429	4.234	60.949
PC9	3.161	0.039	0.649	PC9	3.161	3.902	64.851
PC10	2.998	0.037	0.686	PC10	2.998	3.701	68.552
PC11	2.722	0.034	0.719	PC11	2.722	3.360	71.912
PC12	2.448	0.030	0.749	PC12	2.448	3.022	74.935
PC13	2.358	0.029	0.778	PC13	2.358	2.911	77.845
PC14	2.286	0.028	0.807	PC14	2.286	2.822	80.667
PC15	1.929	0.024	0.830	PC15	1.929	2.382	83.049
PC16	1.533	0.019	0.849	PC16	1.533	1.892	84.941
PC17	1.397	0.017	0.867	PC17	1.397	1.725	86.666
PC18	1.209	0.015	0.882	PC18	1.209	1.493	88.159
PC19	1.089	0.013	0.895	PC19	1.089	1.344	89.503
PC20	1.054	0.013	0.908	PC20	1.054	1.302	90.805
PC21	0.936	0.012	0.920	PC21	0.936	1.155	91.960
PC22	0.893	0.011	0.931	PC22	0.893	1.102	93.062
PC23	0.786	0.010	0.940	PC23	0.786	0.970	94.032
PC24	0.693	0.009	0.949	PC24	0.693	0.856	94.888
PC25	0.630	0.008	0.957	PC25	0.630	0.777	95.665
-	-	-	-	PC26	0.552	0.681	96.346
-	-	-	-	PC27	0.488	0.603	96.949
-	-	-	-	PC28	0.425	0.525	97.474
-	-	-	-	PC29	0.404	0.498	97.972
-	-	-	-	PC30	0.327	0.404	98.376
-	-	-	-	PC31	0.261	0.322	98.698
-	-	-	-	PC32	0.229	0.283	98.981
-	-	-	-	PC33	0.192	0.237	99.219
-	-	-	-	PC34	0.142	0.176	99.394
-	-	-	-	PC35	0.125	0.154	99.549
-	-	-	-	PC36	0.098	0.121	99.669
-	-	-	-	PC37	0.076	0.094	99.763
-	-	-	-	PC38	0.061	0.075	99.838
-	-	-	-	PC39	0.047	0.057	99.896
-	-	-	-	PC40	0.036	0.044	99.940



-	-	-	-	PC41	0.028	0.034	99.974
-	-	-	-	PC42	0.017	0.021	99.995
-	-	-	-	PC43	0.003	0.003	99.998
-	-	-	-	PC44	0.001	0.002	100.000
-	-	-	-	PC45	0.000	0.000	100.000
-	-	-	-	PC46	0.000	0.000	100.000
-	-	-	-	PC47	0.000	0.000	100.000
-	-	-	-	PC48	0.000	0.000	100.000
-	-	-	-	PC49	0.000	0.000	100.000
-	-	-	-	PC50	0.000	0.000	100.000
-	-	-	-	PC51	0.000	0.000	100.000
-	-	-	-	PC52	0.000	0.000	100.000
-	-	-	-	PC53	0.000	0.000	100.000
-	-	-	-	PC54	0.000	0.000	100.000
-	-	-	-	PC55	0.000	0.000	100.000
-	-	-	-	PC56	0.000	0.000	100.000
-	-	-	-	PC57	0.000	0.000	100.000
-	-	-	-	PC58	0.000	0.000	100.000
-	-	-	-	PC59	0.000	0.000	100.000
-	-	-	-	PC60	0.000	0.000	100.000
-	-	-	-	PC61	0.000	0.000	100.000
-	-	-	-	PC62	0.000	0.000	100.000
-	-	-	-	PC63	0.000	0.000	100.000
-	-	-	-	PC64	0.000	0.000	100.000
-	-	-	-	PC65	0.000	0.000	100.000
-	-	-	-	PC66	0.000	0.000	100.000
-	-	-	-	PC67	0.000	0.000	100.000
-	-	-	-	PC68	0.000	0.000	100.000
-	-	-	-	PC69	0.000	0.000	100.000
-	-	-	-	PC70	0.000	0.000	100.000
-	-	-	-	PC71	0.000	0.000	100.000
-	-	-	-	PC72	0.000	0.000	100.000
-	-	-	-	PC73	0.000	0.000	100.000
-	-	-	-	PC74	0.000	0.000	100.000
-	-	-	-	PC75	0.000	0.000	100.000
-	-	-	-	PC76	0.000	0.000	100.000
-	-	-	-	PC77	0.000	0.000	100.000
-	-	-	-	PC78	0.000	0.000	100.000
-	-	-	-	PC79	0.000	0.000	100.000
-	-	-	-	PC80	0.000	0.000	100.000
-	-	-	-	PC81	0.000	0.000	100.000

The WEKA statistical software identified 25 PCs with eigenvalues of 9.615 to 0.630, a variance of 0.119 to 0.008, and a cumulative variance of 0.119 to 0.957. The percentage ranges for each of the 81 PCs found by R Studio were as

follows: eigenvalue 9.615 to 0.001, variance 1.187 to 0.002, and cumulative variance 11.871 to 100. The 81 components, like other research that have used PCA to address various real-world issues, only take into account eigenvalues bigger than unity. The 81 PCs' eigenvalues, on the other hand, ranged

from 9.615 for the first component to 0.001 for the last. Moreover, for PCs 81 and 25, respectively, the 56 consecutive PCs had eigenvalues that ranged from 9.615 to 0.630, which is less than unity. A cumulative variance of 11.871 and an eigenvalue of 9.615 for PC1 explain the same total variance of 11.871.

The Institutions Management (F81) extraction value for PC represents 0.001, while the maximum 0.997 extracted values are for F14 – Customer Orientation, F15 – Competitor Orientation, F16 - Inter Functional Orientation, F17 – Performance Orientation, F18 – Employee Orientation, F19 – Long term Orientation. These factor loadings were integrated to account for the high eigenvalue, as seen in the first component.

According to Table 4, the cumulative variances for the first six PCs are 11.87%, 22.21%, 30.64%, 38.25%, 45.12%, and 51.47%.

TABLE VI. COMMUNALITY

Factors	Initial (I)	Extraction			
F1	1.000	0.782	F42	1.000	0.984
F2	1.000	0.861	F43	1.000	0.984
F3	1.000	0.726	F44	1.000	0.984
F4	1.000	0.828	F45	1.000	0.554
F5	1.000	0.829	F46	1.000	0.865
F6	1.000	0.283	F47	1.000	0.865
F7	1.000	0.089	F48	1.000	0.865
F8	1.000	0.545	F49	1.000	0.419
F9	1.000	0.611	F50	1.000	0.297
F10	1.000	0.114	F51	1.000	0.297
F11	1.000	0.291	F52	1.000	0.577
F12	1.000	0.108	F53	1.000	0.388
F13	1.000	0.369	F54	1.000	0.345
F14	1.000	0.997	F55	1.000	0.757
F15	1.000	0.997	F56	1.000	0.673
F16	1.000	0.997	F57	1.000	0.681
F17	1.000	0.997	F58	1.000	0.471
F18	1.000	0.997	F59	1.000	0.656
F19	1.000	0.997	F60	1.000	0.933
F20	1.000	0.715	F61	1.000	0.933
F21	1.000	0.678	F62	1.000	0.933
F22	1.000	0.953	F63	1.000	0.933
F23	1.000	0.953	F64	1.000	0.768
F24	1.000	0.864	F65	1.000	0.663
F25	1.000	0.846	F66	1.000	0.663
F26	1.000	0.864	F67	1.000	0.663
F27	1.000	0.953	F68	1.000	0.123
F28	1.000	0.953	F69	1.000	0.257
F29	1.000	0.567	F70	1.000	0.257
F30	1.000	0.794	F71	1.000	0.463
F31	1.000	0.960	F72	1.000	0.507
F32	1.000	0.960	F73	1.000	0.093
F33	1.000	0.960	F74	1.000	0.995
F34	1.000	0.012	F75	1.000	0.995
F35	1.000	0.984	F76	1.000	0.995
F36	1.000	0.831	F77	1.000	0.995
F37	1.000	0.754	F78	1.000	0.995
F38	1.000	0.984	F79	1.000	0.092
F39	1.000	0.984	F80	1.000	0.092
F40	1.000	0.540	F81	1.000	0.001
F41	1.000	0.984			

TABLE V. DEPICTS THE CONTRIBUTION OF 10 FACTORS IDENTIFYING THE DIFFERENT GROUPS FOR THE 6 PCs

PC1	-0.224F4-0.22F5-0.203F2+0.193F30+0.192F57-0.19F3 +0.183F63+0.183F61+0.183F62+0.183F60...
PC2	-0.292F41-0.292F42-0.292F39-0.292F38-0.292F43 -0.292F44-0.292F35-0.245F36-0.182F40+0.168F63...
PC3	-0.23F24-0.23F26-0.228F23-0.228F27-0.228F28 -0.228F22-0.212F25-0.194F29+0.18 F61+0.18 F62...
PC4	0.371F16+0.371F15+0.371F18+0.371F19+0.371F14 +0.371F17-0.131F26-0.131F24-0.127F23-0.127F22...
PC5	0.247F22+0.247F28+0.247F27+0.247F23+0.206F67 +0.206F65+0.206F66+0.205F24+0.205F26+0.177F25...
PC6	-0.402F77-0.402F76-0.402F75-0.402F74-0.402F78 +0.093F46+0.093F47+0.093F48-0.092F66-0.092F67...

As depicted in Table 5, Empathy has an eigenvector value of -0.224 and is one of the KSFs in the first group of PC1. Compared to subsequent components, this one describes the dataset's largest irregularity. In PC2, F41(effective leadership), F42(periodic review), F39(evaluation and control system), F38(specific policies and procedures), F43(resource allocation), F44(operational planning) and F35(customer focus and need based) have an eigenvector value of -0.292. F36(channels of communication) has -0.245; F40(curriculum design): -0.182 and F63(security): 0.168. The highest eigenvector value of +0.18 for PC3 is F61(communication) and F62(credibility). The highest eigenvector value of 0.371 for PC4 is F16(inter functional orientation), F15(competitor orientation), F18(employee orientation), F19(long term orientation), F14(customer orientation) and F17(performance orientation). For PC5, F22(dependability), F28(semester), F27(unusualsituation management), F23(effectiveness): 0.247. For PC6, F46(attitude), F47(content), F48(delivery): 0.093. The contribution of 10 factors identifying the different groups for the 6 PCs can be seen in Table 5.

The individually weighted factor values contribute to the PC from the factors in Table 6 that are shown there. The communalities shown in Table 6 show each factor loading that was employed for extraction, as observed between the extracted component's minimum and highest ranges of 0.089 and 0.997. Table 6 also displays the outcomes of each factor's presentation of its contribution to the communality.

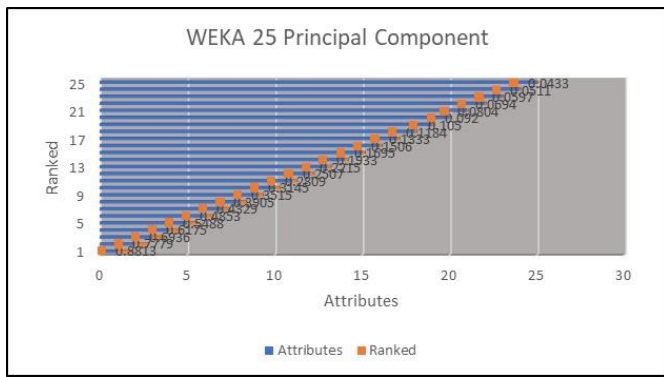


Fig. 2. Ranking of 25 PCs.

The 25 PCs are ranked in Fig. 2, with the top six components scoring, respectively, 88.13%, 77.79%, 69.36%, 61.75%, 54.88%, and 48.53%.

A scree plot is a diagnostic tool that determines whether or not PCA performs properly on the data. The most variety is captured by PC1, followed by PC2, and so on. Although there are as many primary components in PCA as there are qualities, each one gives some information about the data. Information is lost if PCs are not present. The number of PCs is on the x-axis, while the eigenvalues are on the y-axis. The screen plot in Fig. 3 illustrates these PCs.

The graphic depiction of PCA is shown in Fig. 4. The graphic illustrates the correlation between the variables in the dataset; it indicates that if two variables point in the same direction, they are correlated; if they create a 90-degree angle, there is no connection; and if they point in the opposite directions, there is a negative correlation. For instance, variables F49, F55, and F56 are correlated because they all point in the same direction; variables F4 and F30 are negatively linked because they point oppositely; and variables F36 and F64 are uncorrelated since they form a 90-degree angle.

'Rotated' loading score is where each PC has its loading score, creating a matrix of eigenvectors. From this, it can be determined which factor has a positive or negative loading score. Fig. 5 depicts the 10-factor loading scores for the first 5 ranked attributes.

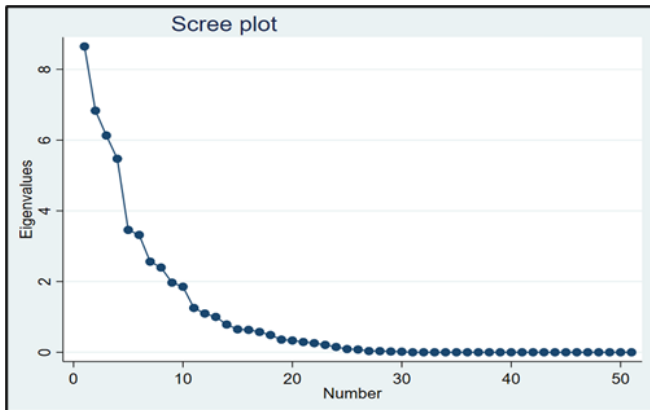


Fig. 3. Scree plot of the PCs.

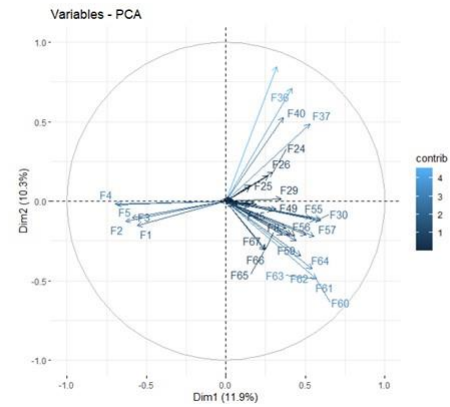


Fig. 4. Contribution of each variable.

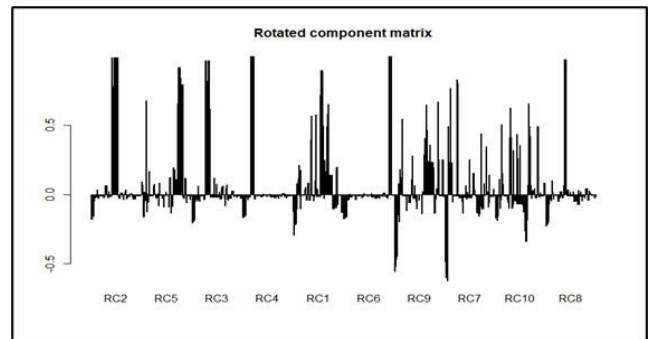


Fig. 5. Bar plot of the rotated component matrix for the 10-factor loadings.

According to these results, several KSFs that are used to specify the KSF diversity of the IT technical support satisfaction model based on the taxonomy of the groups that may have been discovered by the selection of these KSFs exhibit significant morphological variance. In this study, we attempted to explain the morphological diversity and map the KSFs to numerous relevant IT technical support satisfaction model components. These findings indicate that taxonomic groups could have been created by selecting certain characteristics. PCA was used in studies [81,82,83] to locate KSFs. According to different identity categories, the current study shows how KSF diversity differs. Several KSF studies have selected particular KSFs to contextualize their results. However, to offer a thorough nature of KSFs with varied morphologies, the results from this research were achieved by including all the KSFs that were found. A hybrid PCA and factor analysis technique was used in this study to identify, validate, rank, and categorize a dataset of 25 inputs as critical, leading to the discovery and description of all KSFs. The results of this study demonstrate that tangibility, reliability, responsiveness, empathy, and assurance are the KSFs that are most frequently used to categorize IT technical support services.

## V. CONCLUSION

By examining the physical traits that serve as a crucial preliminary method for evaluating various KSFs and simultaneously clarifying their effectiveness when utilized successfully, diversity was computed using many KSF markers. The range of KSFs that may be used for diverse IT technical support service satisfaction model implementations

is the important information offered by the study's findings. From the 81 factors for evaluating student IT technical support services provided to students at HEIs, only 25 of the most substantial have been uncovered. The first six primary components' low variances demonstrate unequivocally that the highest KSFs considerably increased the pool's diversity having eigenvectors not limited to values 0.23, 0.224, 0.247, 0.292, 0.371, and 0.402. The results of this study significantly advance our understanding of KSFs for IT technical support. With a special emphasis on the morphological traits of a divergent model that was created from a variety of distinct morphological taxonomies of the KSFs that were found. The study's conclusions can help practitioners avoid neglecting any KSF and help them consider their roles in creating a successful technical support service model. To date, no study has concentrated on studying the key success factors of

student IT technical support services in HEIs. It is recommended that the identified key success factors be used to evaluate IT technical support services that are being rendered to students at HEIs so that services can be improved and/or maintained. HEIs will be able to attract and retain more students. Future studies will focus on providing IT technical support services to staff and students and secondary schools (public and private).

Finally, The findings of this study make an essential contribution to the body of knowledge, with special emphasis on the identified CSFs of IT technical support services provided to students at HEIs. The study findings can assist HEI policymakers and IT practitioners in HEIs in not overlooking any essential success factors, therefore attaching a substantial consideration to providing the effective delivery of IT support services provided to students.

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# Effect of Distance and Direction on Distress Keyword Recognition using Ensembled Bagged Trees with a Ceiling-Mounted Omnidirectional Microphone

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**Abstract**—Audio surveillance can provide an effective alternative to video surveillance in situations where the latter is impractical. Nevertheless, it is essential to note that audio recording raises privacy and legal concerns that require unambiguous consent from all parties involved. By utilizing keyword recognition, audio recordings can be filtered, allowing for the creation of a surveillance system that is activated by distress keywords. This paper investigates the performance of the Ensemble Bagged Trees (EBT) classifier in recognizing the distress keyword "Please" captured by a ceiling-mounted omnidirectional microphone in a room measuring 4.064m (length) x 2.54m (width) x 2.794m (height). The study analyzes the impact of different distances (0m, 1m, and 2m) and two directions (facing towards and away from the microphone) on recognition performance. Results indicate that the system is more sensitive and better able to identify targeted signals when they are farther away and facing toward the microphone. The validation process demonstrates excellent accuracy, precision, and recall values exceeding 98%. In testing, the EBT achieved a satisfactory recall rate of 86.7%, indicating moderate sensitivity, and a precision of 97.7%, implying less susceptibility to false alarms, a crucial feature of any reliable surveillance system. Overall, the findings suggest that a single omnidirectional microphone equipped with an EBT classifier is capable of detecting distress keywords in a low-noise enclosed room measuring up to 4.0 meters in length, 4.0 meters in width, and 2.794 meters in height. This study highlights the potential of employing an omnidirectional microphone and EBT classifier as an edge audio surveillance system for indoor environments.

**Keywords**—Distress speech; ensemble bagged trees; audio surveillance; machine learning; distance; directions

## I. INTRODUCTION

Screaming, yelling, or shouting is a natural way to express agony. They are particularly useful for detecting distress events in audio-based surveillance and monitoring applications that use the pitch and intensity of voice. The audio key-event detection system using Gaussian Mixture Model (GMM) presented in [1] uses acoustic references to detect and examine abnormal events based on a binary classification technique of shot and normal classes. In [2], a monitoring service technology was developed to determine the stress level from the voice tone changes. An anomalous audio event detection using GMM in [3] discriminates screams and gunshot sounds from noises. Another study in [4] utilizes the personal computer equipped with a sound card and microphone to detect distress sounds like a cry for help or glass breaking. Real-time

sound analysis was developed using eight mic channels to distinguish stress from normal situations [5]. Audio data are advantageous in assistive awareness systems for emergency recognition of falls and distressed speech expression in elder or patient care [6-7]. In [8], a two-stage learning-based method was proposed to detect screams and cry in urban environments. Indoor context based on Receiver Operating Characteristic (ROC) result gives the least false alarm rate compared to the other five contexts; Gathering, conversation, outdoors, machinery, and multimedia. Detection of speech distress was also conducted through remote monitoring [9]. According to the results obtained in [10], it can be concluded that in various interaction scenarios, voice pitch may serve as an accurate biosocial and individual identifier. The distress call is useful in emergencies, especially tracking a person by detecting cries for help in an enclosed environment [11].

However, people might also talk, laugh or scream loudly and high-pitched when they get excited. Surveillance systems triggered by the voice's pitch and intensity will create false alarms in those circumstances. Moreover, the existing surveillance system may also intrude on an individual's privacy and invasion of civil rights [12]. For example, always-listening devices like smartphones may accidentally wiretap the information of the surroundings [13]. Hence, the privacy-aware architecture was proposed to prevent privacy violations and potential recordings [14, 15]. The risks are apparent due to the availability of technology that can access sensitive data such as audio [16]. Overcoming these issues requires a simplified surveillance system that intelligently recognizes distress keywords apart from the voice's pitch and intensity. Such a system will enable a crime detection automation system that recognizes targeted distress speech and non-distress (high-toned) speech. This idea has been explored for outdoor surveillance [8] and should be extended to indoor environments when video surveillance is not viable [17-19]. Places like shared bathrooms and nursery rooms should be equipped with audio surveillance to reassure safety [20-21].

Having indoor audio surveillance that is always recording in the cloud is not well accepted by many due to privacy and security concerns. Edge Artificial Intelligence (AI) could be employed as a solution. Audio surveillance with edge AI will be able to detect specific keywords and trigger the system at the device level (locally). Among the AI algorithms, the Ensemble Bagged Trees (EBT) is one of the supervised machine learnings explored in audio data classification for safety-related applications. EBT has been applied to non-

speech data to investigate false speakers via spoofing sounds [22], classify non-speech audio data [23], monitor babies [24], and classify sounds [25-26]. EBT has also recently been employed to differentiate multiple emotions; anger, disgust, fear, joy, neutral, surprise, and sad from speech audio signals [27-29].

These studies show that EBT performs considerably better than other classifiers, such as Boosted Trees, Bagged Trees, Subspace K-Nearest Neighbor (KNN), Support Vector Machine (SVM), Quadratic SVM, and Quadratic Discriminant [24,29]. EBT can be a good option for real-time distress keyword recognition due to its ability to handle noise and variability in speech data. In speech recognition, there can be significant variation in speech patterns due to individual differences, accents, and other factors. Bagged trees can capture this variability by creating multiple decision trees and combining their outputs. Thus, it can improve accuracy and robustness in recognizing spoken keywords. EBT is computationally efficient and can be easily parallelized, making it a good option for real-time speech recognition applications. It can also be trained using small amounts of data, which is beneficial for scenarios where large amounts of labeled data may not be available.

Employing EBT in the edge audio surveillance system requires careful evaluation to get robust performance. To the best of our knowledge, there is still a shortage of work on distress speech detection using EBT because most studies focus on non-speech and non-distress signals. Moreover, the effectiveness of EBT on distances and directions of the sound sources from the microphone is still undiscovered. This paper investigates the effect of speech distance and direction on the EBT recognition performance, which was proven superior in a previous analysis [30]. For that, two experiments were conducted in a room that resembled a typical nursing room size. Experiment 1 studies the performance of EBT to detect a distress keyword from three different distances: 0m, 1m, and 2m. Experiment 2 analyzes the effect of different directions, facing toward and away from the microphone.

This paper is arranged as follows. Section II covers the materials and research methodology. Section III presents and discusses the results. Finally, Section IV concludes the findings, research's limitations, and future recommendations.

## II. MATERIALS AND METHODS

### A. Experimental Setup

The experiment was conducted in a low-noise room with a dimension of 4.064m (Length) x 2.54m (Width) x 2.794m (Height). An omnidirectional microphone was installed at the center of the room's ceiling to capture audio signals from various angles at equal coverage and in a short range. However, omnidirectional microphones collect more noise than directional microphones [31]. Thus, it was suggested to place the omnidirectional away from the reflecting areas [32-33]. Speeches were uttered from horizontal distances of 0 m, 1 m, and 2 m by speakers in sitting condition, facing toward the microphone and away from it, as shown in Fig. 1 to 3. The microphone was connected to a Vivo V17 smartphone

(Android 9.0 Pie & Octa-core processor) that performed as a speech recording device.

Guidelines:

- ✗ - Position of the audio sources
- - Microphone

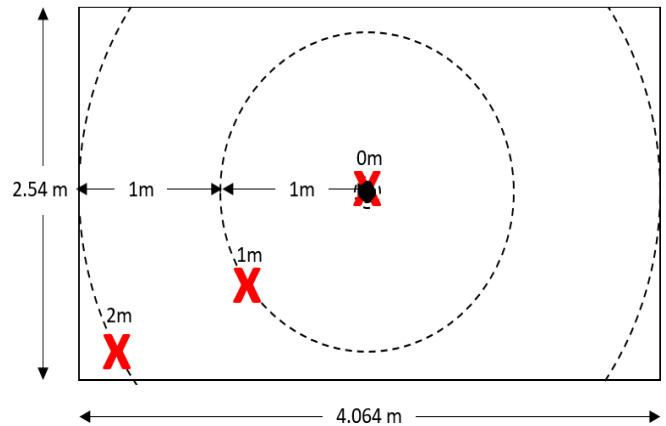


Fig. 1. Distance between speaker and microphone in a closed room.

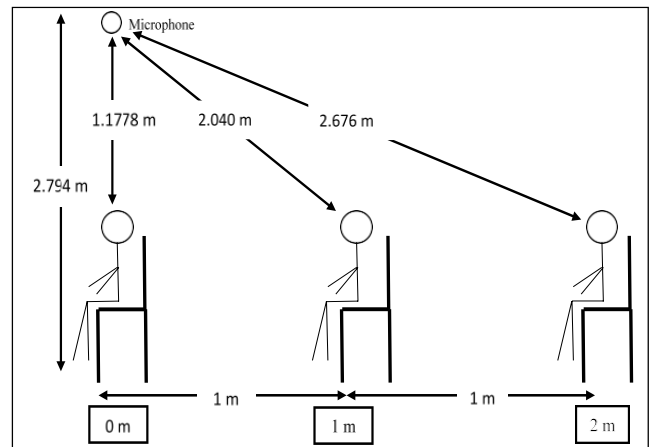


Fig. 2. Position of the speaker during data collection facing toward the microphone.

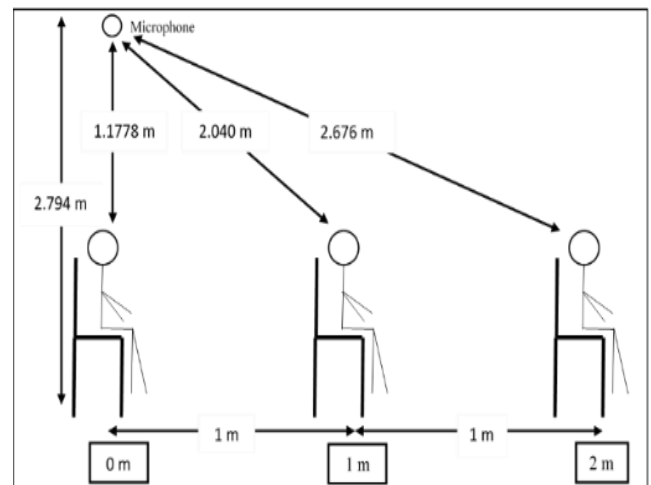


Fig. 3. Position of the speaker during data collection facing away from the microphone.

### B. Signal Preprocessing – Audio Filtering

The recorded audio signal was initially stereo with MP4a format, 44100 Hz sampling rate, and 32-bit rate. The audio signal was then exported in WAV format with 44100 Hz for further processing. WAV format audio files are stored in a large space because the signals are uncompressed, maintaining strong sound quality [34]. Due to the differences in time-frequency representation, both left and right channels were calculated to find their average to produce only a mono data channel instead of separating the channels into two parts [35-36].

### C. Feature Extraction and Feature Reduction

Each preprocessed audio signal was divided into smaller frames using a Hamming window of 1024 ms and an overlap length of 512 ms [37-39]. For every frame, thirteen Mel-Frequency Cepstral Coefficients (MFCCs) were extracted and organized into an  $f \times c$  matrix, where  $f$  is the number of frames and  $c$  is the thirteen MFCCs. The total number of frames was set to 120 by adding or deleting frames at regular intervals, resulting in a matrix of  $120 \times 13$  MFCCs representing the audio signal features [30]. Principal Component Analysis (PCA) was used to reduce the features to  $13 \times 13$  [40]. The pseudocode for feature extraction is given in Fig. 4.

```
Obtain a speech signal of 1.5s length, and do the following:
  Detect Endpoints, obtain the voiced part
  Divides into f frames (Hamming window: 1024ms, overlap 512ms)
  For n = 1 to f
    Extract 13-MFCCs
    Construct an  $f \times 13$  matrix
  End For loop
  If  $f > 120$ , do the following,
    Obtain number of rows to be removed, r
    Determine the interval, d
    For i = 1 to f
      Delete the 13-MFCCs at every d
    End for loop
  Else
    Obtain number of rows to be added, r
    Determine the interval, d
    For i = 1 to 120
      For every d, compute new MFCCs using the average
        of MFCCs(d-1) and MFCCs(d+1)
      Add the new MFCCs at row d
    End For loop
  End if-else
```

Fig. 4. Pseudocode for feature extraction.

### D. Data Collection

The distress keyword "Please" was chosen for analysis, as it was found to be the most distinct compared to other distress keywords such as "Oi", "Help", "Tolong", and "No [30]. A total of 3600 speeches containing the targeted distress keyword "Please" and non-targeted speeches were collected and divided

into four datasets: Dataset 1, Dataset 2, Dataset 3, and Dataset 4. Dataset 1 comprises 100 samples for each distance and 300 for each direction of distressed "Please" speeches, recorded by five female speakers, with each speaker producing 20 samples for each distance and direction.

Dataset 2 includes 600 samples of recorded distressed "Please" speeches played at three different distances and directions. Dataset 3 has the same design as Dataset 1, except the speakers uttered "Please" in a non-distressed tone. Dataset 4 contains 20 samples of each of the five words "One", "Two", "Three", "Okay", and "Yes", spoken in a distressed or high tone captured from three female speakers at each position. Each dataset was labeled '1' for the targeted "Please" and '0' for the non-targeted speeches. The datasets were then divided into training and testing data in an 80 to 20 ratio, as shown in Table I. The EBT was trained using a combined training data of 2880 speeches and tested on various groups of unseen speeches.

TABLE I. DATA COLLECTION OF DISTRESS KEYWORD "PLEASE"

Dataset	Characteristic	Label	Sample	Data Partition	
				Training (80%)	Testing (20%)
1	Distress "Please"	1	600	480	120
2	Distress "Please"	1	600	480	120
3	Non-distress "Please"	0	600	480	120
4	Distress/High-tone Words	0	1800	1440	360

### E. EBT Classifier

Z Breiman presented the ensemble technique in 1996, intending to improve the Decision Trees (DT) classification performance [41]. The word 'Bagging' itself is a Bootstrap Aggregation that reduces the decision tree variance.

The bootstrap method randomly creates minor groups of data with replacements from the overall dataset from the training dataset. Each set created with equal probability will undergo a parallel training of DT classifiers. It produces a robust performance compared to an individual DT model [42]. Each DT model will independently produce different features. Then, the aggregation process was applied by accumulating the predictions of all different DT groups and taking the mean of the outcomes to get the final bagging result. Likewise, this machine learning classifier is a highly precise model combining various decision trees [43]. For this study, 30 DT classifiers were used for the parallel ensemble technique, as illustrated in Fig. 5.

Equation (1) defines its principle where DT learners,  $f_d(x)$  are trained based on the architecture in Fig. 5 with the bootstrapped dataset. The mean of the total predictions from every DT learner is taken as the result.

$$f(x) = \frac{1}{D} \sum_{d=1}^D f_d(x) \quad (1)$$

Where; D = sets of bootstrapped data, d = DT learners.

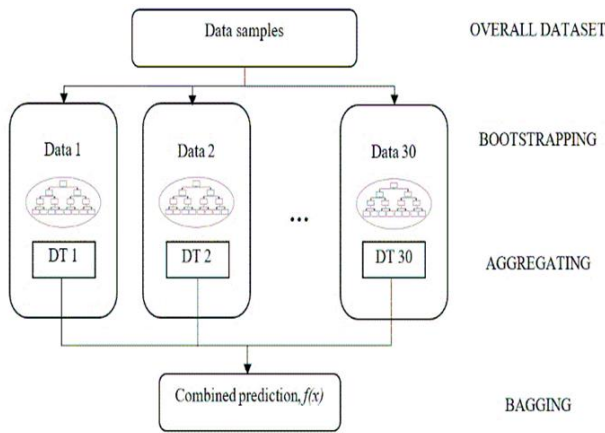


Fig. 5. The ensemble bagged trees.

F. Evaluation Metrics

The efficiency of the EBT as a distress keyword recognizer is measured based on the following metrics: accuracy, precision, recall, and F1 score, as stated by equations (2) until (5). In an audio-based surveillance application, all metrics are important, but precision and recall are two indicators defining performance. Precision and recall values will determine whether such an audio-based surveillance system would have minimal false alarms or unidentified incidents.

1) *Accuracy*: It measures the overall correctness of the EBT's output. The calculation of accuracy is based on the following formula:

$$Accuracy = \frac{No.of\ samples\ predicted\ correctly}{Total\ number\ of\ samples} \times 100\% \quad (2)$$

2) *Precision and recall*: These metrics provide information on how effectively the EBT performs when categorizing specific classes. Precision measures the proportion of true positives among all the positive results. In other words, precision measures the percentage of correctly identified events out of all the events detected by the EBT. The recall measures the percentage of true positives that were accurately detected.

In an audio-based surveillance system, precision is important to avoid false alarms, which can be a nuisance and result in unnecessary responses by security personnel. On the other hand, recall is important to identify all critical events, even if they are rare or infrequent. The precision and recall are given by equations 3 and 4, respectively:

$$Precision = \frac{True\ Positive\ (TP)}{True\ Positive\ (TP)+False\ Positive\ (FP)} \times 100\% \quad (3)$$

$$Recall = \frac{True\ Positive\ (TP)}{True\ Positive\ (TP)+False\ Negative\ (FN)} \times 100\% \quad (4)$$

3) *F1 Score*: It is considered a weighted average based on precision and recall and is calculated with the following:

$$F1\ Score = \frac{2(Precision*Recall)}{(Precision+Recall)} \quad (5)$$

In an audio-based surveillance system, the F1 score can be a useful metric to optimize a balance between precision and recall, especially when there is a trade-off between the two.

III. RESULTS AND DISCUSSION

All four datasets described in Table I were merged to form a training data set of 2880 samples. This combined data set was used for EBT training and validated with a 20-fold technique. To evaluate the performance of the trained EBT, 720 unseen samples were tested based on the distances and directions as defined in the subsequent subsections. Table II presents the results that were deduced from the confusion matrices in Fig. 6. Excellent accuracy, precision, and recall values exceeding 98% were observed during validation.

Of the testing data, the EBT has a satisfactory recall rate of 86.7%. It means the system has moderate sensitivity to every possible incident, adequate but not achieving the desired characteristic of a surveillance system. Nevertheless, a precision of 97.7% was observed, indicating the system is less susceptible to generating a false alarm, a feature of a trusted surveillance system.

TABLE II. PERFORMANCE ON DIFFERENT DISTANCES AND DIRECTIONS

Validation Performance (%)					
Metric	Accuracy	Precision	Recall	F1-Score	
	99.4	99.2	99.9	99.5	
Testing Performance (%)					
Metric	Accuracy	Precision	Recall	F1-Score	
Distance: 0m	Facing Toward	97.5	95.1	97.5	96.3
	Facing Away	87.5	96.3	65.0	77.6
Distance: 1m	Facing Toward	95.0	97.2	87.5	92.1
	Facing Away	93.3	100.0	80.0	88.9
Distance: 2m	Facing Toward	99.2	97.6	100.0	98.8
	Facing Away	96.7	100.0	90.0	94.7
Average					
Testing data	94.9	97.7	86.7	91.9	

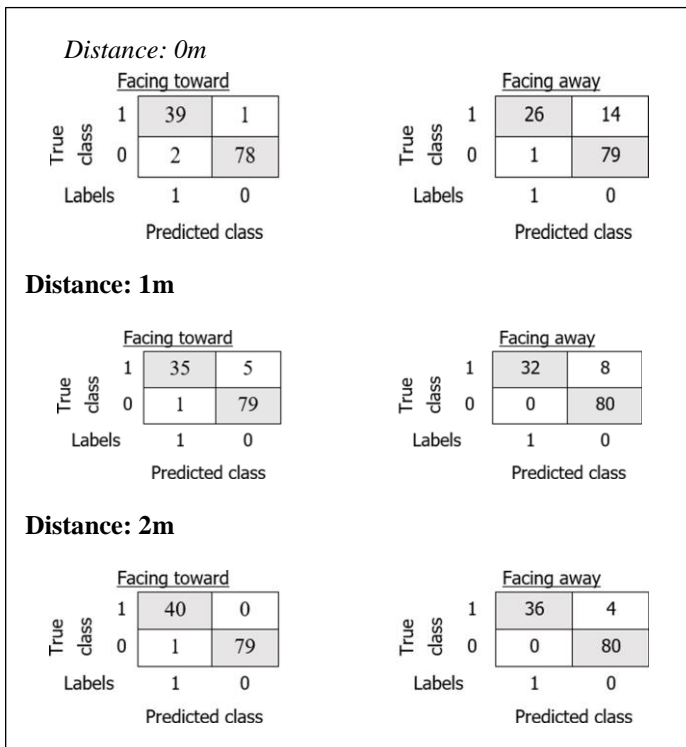


Fig. 6. The confusion matrices for different distances and directions.

#### A. Effect of Sound Distance

Fig. 7 shows the evaluation metrics versus distances of the testing results in Table II. Overall, EBT demonstrated high recognition accuracy with excellent precision for all distances examined. The lowest accuracy was observed at a 0 m distance, right under the microphone, possibly due to sound energy spreading from the speaker. When moving a little farther, the recognition performance improved. It is interesting to note that recall values are lowest at 0 m, slightly increased at 1 m, and highest at 2 m from the microphone.

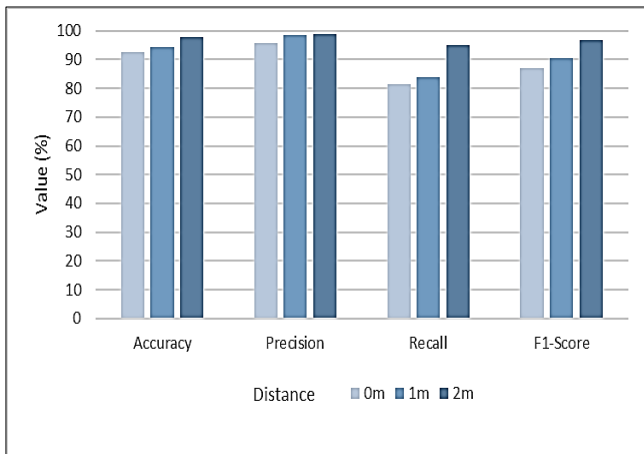


Fig. 7. Evaluation metrics versus distance.

This observation indicates that the system is more sensitive and could better recognize the targeted signals when the signals are a little farther, at one or 2-meter from the microphone. The findings corroborate that the omnidirectional microphone can capture signals from a wider distance, contributing to EBT's recognition performance in this study.

#### B. Effect of Sound Direction

Fig. 8 displays the evaluation metrics values for the facing toward and facing away directions. Based on the chart, it can be observed that facing toward the microphone will produce a better recognition rate. This is expected as the coverage area of the signals emitted toward the microphone is much wider. Sounds emitted from sources facing toward the microphone contain higher intensity than the sounds emitted from sources facing away.

Facing away from the microphone apparently affects the sensitivity of the system to recognize the targeted keyword. The overall recall value falls under 80%, in which a distance of 0 m scores the lowest. However, the recall value is gradually improving as the distance increases. At closer distances, facing away from the microphone can result in a weaker signal-to-noise ratio, which can make it more difficult to distinguish speech from background noise or interference. This can result in a lower recall of speech and a lower overall quality of the recording. However, at farther distances, the reduction in speech intensity due to facing away may be less pronounced, and the ambient noise level may also be lower, resulting in a clearer and more intelligible recording.

#### C. Proposed Edge Audio Surveillance

From the results, it can be inferred that a single omnidirectional microphone equipped with an EBT classifier is adequate for capturing audio in a low-noise enclosed room measuring up to 4.0 meters in length, 4.0 meters in width, and 2.794 meters in height. An audio surveillance system with an omnidirectional microphone and a processing unit that contains algorithms for signal preprocessing, feature extraction, feature reduction, and a pre-trained EBT can be developed. Fig. 9 presents the proposed edge audio surveillance.

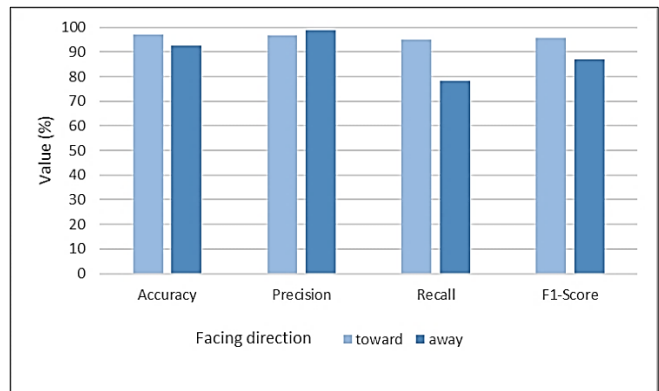


Fig. 8. Evaluation metrics versus direction.



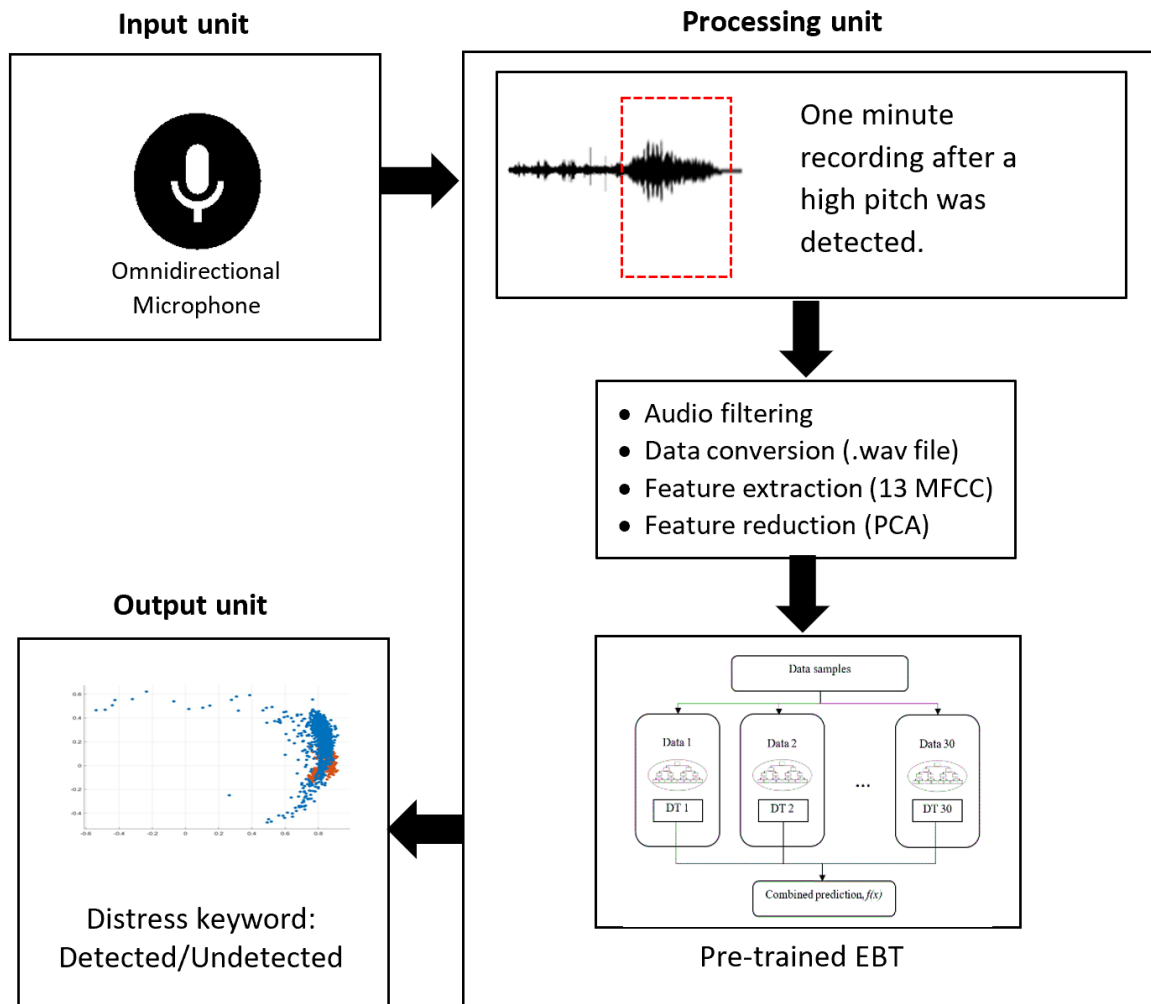


Fig. 9. Block diagram of the proposed audio surveillance system.

The processing unit can be assembled into several devices to form an edge surveillance system. A potential device would be the Raspberry Pi 4. Raspberry Pi 4 is a low-cost, small-sized computer that can run various operating systems and programming languages. The Raspberry Pi 4 has up to 8GB SDRAM and is clocked at 1.5GHz, enough processing power and memory to run simple speech preprocessing and pre-trained EBT, and can be easily connected to microphones and other output devices. The efficiency of the pre-trained EBT on the Raspberry Pi 4 will depend on factors such as the size of the EBT, the complexity of the individual trees, and the available resources on the Raspberry Pi. However, with proper optimization and tuning, it is possible to achieve efficient and accurate inference on the Raspberry Pi 4 with a pre-trained EBT model.

#### IV. CONCLUSION

This paper presents audio-based surveillance based on distress keyword recognition using an EBT classifier and an omnidirectional microphone. The experiments were conducted in a setting similar to a typical nursing room, enclosed and low-noise. The recognition performance of EBT was evaluated

under different conditions, explicitly varying distances and directions of the sound sources from the microphone. Results show that the system is more sensitive and could better recognize the targeted signals when the signals were a little farther, at a one or 2-meter distance, and facing toward the microphone. It can be inferred that a single omnidirectional microphone equipped with an EBT classifier is adequate for capturing the distress keyword "Please" in a small, low-noise enclosed room.

To further enhance the sensitivity of the developed audio surveillance, expanding the dataset by incorporating various sources of both targeted and non-targeted signals is recommended. This approach will help to mitigate the occurrence of false alarms. Additionally, it is advised to increase the number of samples with background noise to address common issues related to high-pitched vocalizations, such as screaming in joy or surprise, that may trigger the distress event detector. Furthermore, implementing an adaptive noise filtering mechanism can facilitate the system's learning about the surrounding noises associated with the threshold of the distress signal speeches, thereby enhancing recognition accuracy.



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# A Feature-based Transfer Learning to Improve the Image Classification with Support Vector Machine

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**Abstract**—In the big data era there are some issues regarding real-world classification problems. Some of the important challenges that still need to be overcome to produce an accurate classification model are the data imbalance, difficulties in labeling process, and differences on data distribution. Most classification problems are related to the differences in the data distribution and the lack of labels on some datasets while other datasets have abundant labels. To address the problem, this paper proposes a weighted-based feature-transfer learning (WbFTL) method to transfer knowledge between different but related domains, called cross-domain. The knowledge transfer is done through making a new feature representations in order to reduce the cross-domain's distribution differences while maintaining the local structure of the domain. To make the new feature representation we implement a feature selection and inter-cluster class distance. We propose two stages of the feature selection process to capture the knowledge of the feature and its relation to the label. The first stage uses a threshold to select the feature. The second stage uses ANOVA (Analysis of Variance) to select features that are significant to the label. To enhance the accuracy, the selected features are weighted before being used for the training process using SVM. The proposed WbFTL are compared to 1-NN and PCA as baseline 1 and baseline 2. Both baseline models represent the traditional machine learning and dimensionality reduction method, without implementing transfer learning. It is also compared with TCA, the first feature-transfer learning work on this same task, as baseline 3. The experiment results of 12 cross-domain tasks on Office and Caltech dataset show that the proposed WbFTL can increase the average accuracy by 15.25%, 6.83%, and 3.59% compared to baseline 1, baseline 2, and baseline 3, respectively.

**Keywords**—Feature-transfer learning; image; feature selection; weight; distance

## I. INTRODUCTION

In this big data era, the use of machine learning is growing and expanding into various purposes and uses, including image classification. The success rate of machine learning in image classification is generally determined by the accuracy value. Although nowadays there are already many public datasets [1], some challenges associated with image classification still exist. The first challenge arises because there are some unlabeled or limited labels of datasets [2] [3] [4]. Meanwhile, on the other side there are many other datasets with a very abundant labels. The second challenge is related with the labeling process which needs much effort to make a label for the dataset [3] [4] [5] [6]. Whereas the availability of the labeled data training determines the success of the classification model [7]. The third challenge is

associated with the limited ability of the traditional machine learning method, which requires the training and inference data come from the same dataset that has the same distribution. Even though this ability is needed to produce an accurate classification model [2] [3] [8]. Unfortunately, traditional machine learning methods such as: NN (Nearest Neighbor) and PCA (Principal Component Analysis) do not show good results on the third challenge [9].

To overcome the challenges, we can make a classification model by using knowledge from different but related datasets (domain) [4] [10] [11] [12]. The method is called transfer learning, which is an extension of traditional machine learning. The different but related dataset (domain) used in transfer learning is often called cross-domain. The use of cross-domain terms indicates the existence of the source domain ( $D_S$ ) and the target domain ( $D_T$ ). The original idea of transfer learning is to utilize the knowledge from the labeled domain often called the source domain, to predict the correct label for an unlabeled domain often called the target domain. Before transferring the knowledge, we need to conduct the similarity measurement between the cross-domain to avoid negative transfer. Negative transfer is when the classification model trained using a combination of the cross-domain gives poorer performance than the one trained using the source domain only. Generally, the similarity measurement in the cross-domain is performed using Maximum Mean Discrepancy (MMD).

There are many transfer learning approaches, such as feature-based, instance-based, parameter-based, and relational-based transfer learnings [3] [10] [11]. Our work focuses on feature-transfer learning, considering this approach is mostly used for image domain [12] [13] [14] [15] [16] [17]. Research on the feature-transfer learning began with the discovery of the Transfer Component Analysis (TCA) method which only focuses on overcoming marginal distribution differences in cross-domains [13]. After TCA, several other feature-transfer learning methods were found, such as Geodesic Flow Kernel (GFK) [16], Joint Distribution Adaptation (JDA) [14], Subspace Alignment (SA) [17], Transfer Joint Matching (TJM) [15], and Balanced Distribution Adaptation (BDA) [9]. Moreover, the success key for knowledge transfer in the cross-domain can be done by focusing on the instances in  $D_T$  and conducting the features matching to minimize data distribution difference [18]. Feature-based also can be improved the classification accuracy when it is used with the classifier like SVM [19] [20] [21]. However, one of the weakness of SVM is restricted the

data precision and requires computational cost, so it needs an additional step, such as features reduction to minimize cost [22] [23]. Many techniques can be applied in feature-transfer learning, for example, the use of the Grassman manifold as the geometric property[16], adding balance unit parameter to overcome the data imbalance problem[9], or the formation of subspace features to minimize the distribution difference[17]. In general, the previous feature-transfer learning method works by adapting the dimensional reduction approach and generating an adaptation matrix which is a projection of the cross-domain's features. These techniques need an iteration process to get the best result and add some parameters in the model, where the parameters have to be tuned up to give optimal results. These previous feature-transfer learning methods need large computational requirements due to the complex process and the use of many parameters. CORAL [24] proposed simpler feature-transfer learning without using many parameters. It used the second-order statistical approach to overcome the distribution differences in the cross-domain. However, this method did not consider the label information contained in the source domain. Though some important information can also be obtained from the label.

Therefore, in this paper we propose a simple feature-transfer learning method without using many parameters while still adopting a dimension-reduction approach and utilize the label information from the source domain. We name this proposed approach as Weighted-based Feature-Transfer Learning (WbFTL). The dimension reduction in the method is more towards the formation of new features subsets through the implementation of features selection techniques. Implementing the features selection has several benefits. First, it can reduce the search space and generate significant features for the classification [25]. Second, the features selection also has a simpler way of working without the need to do features projection of the cross-domain, thus retaining the original form of the features and maintaining the explicit meaning of the selected features [26]. Lastly, the features selection method in the classification problem also can enhance the classification results [27] [28] [29] [30]. To optimize the model, the proposed feature-transfer learning adds some weight to the selected features and also use the closest distance between instances to the center of the class label. These combination techniques allow the proposed method to make a new features representation that can minimize the distribution differences between cross-domain while still maintaining the local structure of each domain to get an efficient and accurate classification model.

The experiment showed WbFTL increasing the accuracy by 15.25%, 6.83%, and 3.59%, respectively, against the 1NN, PCA, and TCA baseline models. WbFTL is also superior to the previous feature transfer method and provides a higher average accuracy than those of GFK, JDA, SA, and TJM. Compared to BDA, WbFTL has a competitive accuracy. However, our proposed WbFTL is more superior in the parameters used than BDA. Unlike BDA, WbFTL supports minimal use of parameters that can be run on limited machine resources.

Overall, the contribution of our work can be summarized as follows:

1) WbFTL is an easy feature-transfer learning approach that can overcome the distribution difference in the cross-domain without using many parameters in the training and inferring process.

2) WbFTL is a novel feature-transfer learning method that uses feature selection as the strategy to make transformation of the features. Combined with the feature weighting, the experiment results show that the proposed method get better results compared to other feature-transfer learning methods.

3) WbFTL also the first feature-transfer learning method that utilize the label information in the source domains in the transformation process.

## II. METHODS

Machine learning has two important components: domain and task. In transfer learning we have source domain, source task, target domain, and target task. The source domain or  $D_S$  contains source features space ( $\mathcal{X}_S$ ) and marginal probability ( $P(x_S)$ ), written as  $D_S = \{\mathcal{X}_S, P(x_S)\}$ , where  $x_S \in \mathcal{X}_S$ . The source task or  $\mathcal{T}_S$ , consists label space  $\mathcal{Y}_S$  and classification function  $f(\cdot)$  to determine the label for instances in  $D_T$  based on the knowledge from  $D_S$  and  $D_T$ . The source task can be written as  $\mathcal{T}_S = \{\mathcal{Y}_S, f(\cdot)\}$ . Same as the source domain and task, the target domain, and target task can be written as  $D_T = \{\mathcal{X}_T, P(x_T)\}$  and  $\mathcal{T}_T = \{\mathcal{Y}_T, f(\cdot)\}$ .

The WbFTL method is included in the category of transductive transfer learning. In this category, only instances in  $D_S$  have the label, meanwhile  $D_T$  are unlabeled. There are 800 features in each  $D_S$  and  $D_T$ , and the number of instances on  $D_S$  and  $D_T$  can be different. The goal of the WbFTL is to do feature transformation and make a new feature representation that represents the cross-domain,  $D_S$  and  $D_T$ . The overview of WbFTL in carrying out the transformation can be seen in Fig. 1.

From Fig. 1 it can be seen that the WbFTL method emphasizes the problem of distribution equalization in the cross-domains. Distribution equalization is conducted by making a new features representation that reflects both domains. The process of equalizing this domain begins by measuring the similarity between domains, followed by features selection and features weighting to create a method that is cost effective while still being able to produce a good accuracy. WbFTL also overcomes the conditional distribution differences by utilizing the label information in the features transformation process.

As depicted in Fig. 1 below, the new features representation should minimize the distribution difference between  $D_S$  and  $D_T$ , while still preserving the local structure of the domain itself. The new features representation formed will be used for the training and inference process with SVM, as depicted in Fig. 2. Before being processed by SVM, the data used will be converted into a features vector using statistical calculations [31].

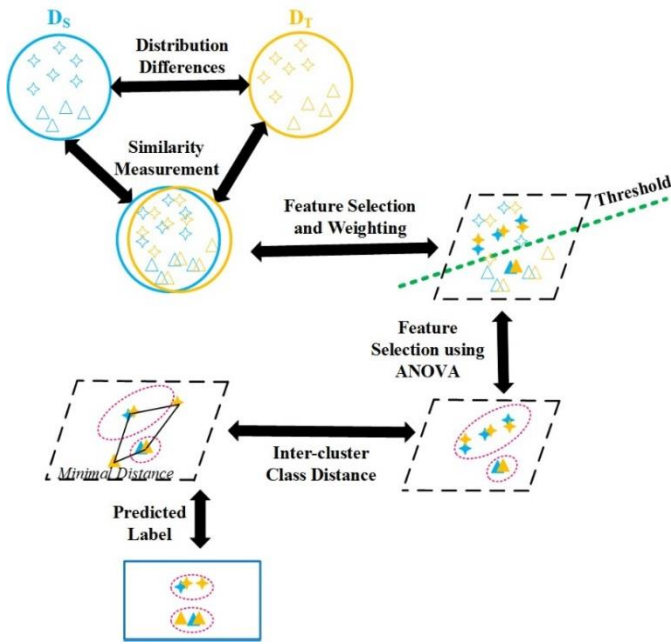


Fig. 1. The overview of WbFTL

There are three steps of features transformation in WbFTL as shown in Fig. 3. The first step is features selection using a threshold to select the features. The second transformation step is the features selection using ANOVA. The third step is only transforming the features in  $D_T$ , by calculating the minimum distance between instances in  $D_T$  to the class label of  $D_S$ .

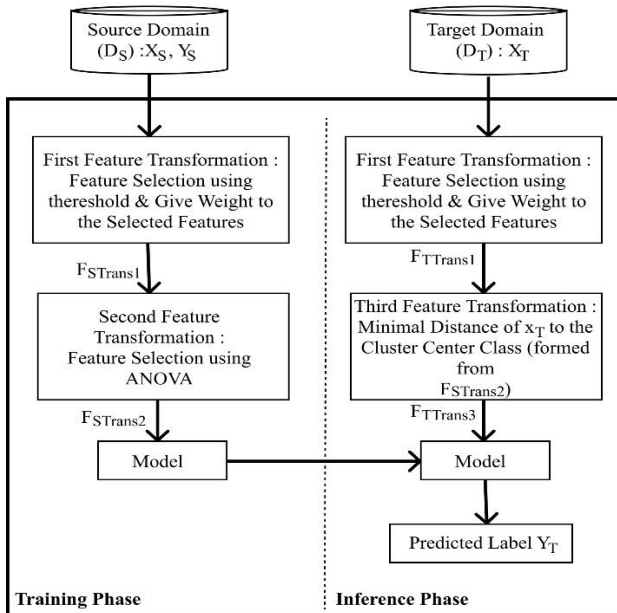


Fig. 2. The training and inference process in the WbFTL.

The features selection method is one of the strategies to form a new features representation besides features mapping, features clustering, features encoding, features alignment, and features augmentation [32]. This strategy can preserve the

local and important structure of the domain, besides, also reducing the distribution difference of the cross-domain.

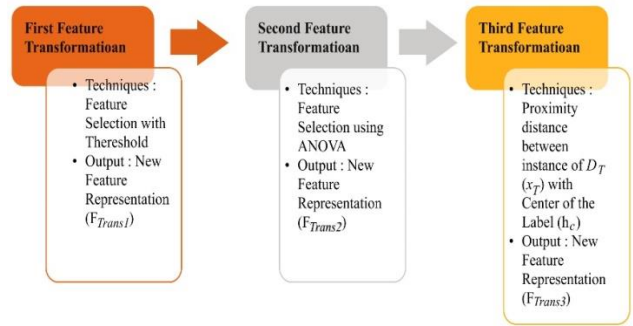


Fig. 3. Feature transformation steps in WbFTL.

Before doing the features transformation, there is a similarity measurement process between  $D_S$  and  $D_T$  using MMD, as a non-parametric method [9] [13] [14] [15] [16] [18] [32]. In the non-parametric method, the measurement is done using approximation distribution value, because it is difficult to get the real distribution value. In the proposed feature-transfer learning, MMD is used in conjunction with the kernel which will map the original value of the features space of each domain to a new features representation using a mapping function. Our proposed method uses a distance function as the mapping function, that is the Euclidean Distance and Reproducing Kernel Hilbert Space (RKHS) [13] [14] [15] [16] [18] [32]. The use of MMD and kernel makes it sufficient to calculate the similarity of the cross-domain using density estimation. The density estimation is done using average features values in the features space  $X_S, X_T$ . The formulation of the mapping function on feature-transfer learning can be seen in (1).

$$Sim(D_S, D_T) = \|F_{S_i} - F_{T_i}\|_{\mathcal{H}}, \quad (1)$$

where  $Sim(D_S, D_T)$  is the similarity measurement result using MMD and RKHS in the cross-domain,  $F_{S_i}, F_{T_i}$  is the vector of the mean value of the  $i$ -features in  $D_S$  and  $D_T$ , sequentially.

The new features space formed from MMD and kernel will be the input for the first step of features transformation. The shape of the features space resulting from the application of MMD and the kernel can be seen in (2).

$$F = \{f_1, f_2, \dots, f_n\} \in R^n, \quad (2)$$

where  $F$ , is the new features space which is the result of  $D_S$  and  $D_T$  features mapping,  $n$  is the amount of the original features, that is 800 features.

### A. Features Selection and Weighting

Feature selection is the process of generating a feature subset based on its relevance and redundancy [33]. The purpose of feature selection is to select the right features in order to get a better understanding of the characteristics of the data. Therefore, selecting significant features will assist the model in studying the data and producing the right label [23]. Feature selection can also enhance classification accuracy [29] [30]. Moreover, feature selection can also be used to reduce

the dimensionality while maintaining the local structure of the dataset and reducing the model complexity.

WbFTL applies the feature selection technique in the first and second steps of the feature transformation process. The two steps of feature selection in WbFTL use a statistical-based approach, i.e., average and varians.

1) *Feature selection using thresholds and feature weighting*: The first step in feature transformation is adopting the filter method. The filter method can work faster and simpler in the implementation and does not depend on the classifier used [34] [35]. The average value will be used as the threshold value, which serves as a stopping criteria. Features with a value under the threshold will be selected because they are considered similar or significant features between  $D_S$  and  $D_T$ . The feature subset that is formed can be written as in (3)

$$A = \{a_1, a_2, \dots, a_k\} \in R^k \quad (3)$$

where  $A$  is the feature subset and  $k$  is the amount of the selected features, with  $k < n$ .

Previous feature-transfer learning also reveals that feature weighting can enhance classification accuracy [27] [36]. Feature weighting is the generalization of feature selection [37] [38]. Therefore, the selected features in the feature subset will be weighted according to their degree of similarity. The smaller the feature value, the greater the weight given. The weight value describes the level of similarity. The formula for the feature weight can be seen in (4). This weighting method is similar to Fisher's criteria, which are used in various cases.

$$w(a_i) = \frac{\frac{1}{k} \sum_{i=1}^k a_i}{a_i}, \quad (4)$$

where  $w(a_i)$  is the weight for the  $i$  –features.

The first feature transformation is generated as a dot product between the selected features in (3) and the weight according to formula (4). The dot product can be written as in formula (5) and the representation of the first feature transformation can be written in (6).

$$b_i = w(a_i) \times f_i, \quad (5)$$

$$F_{Trans1} = \{b_1, b_2, \dots, b_k\} \in R^k \quad (6)$$

where  $b_i$  is the first features transformation for the  $i$  –feature,  $w(a_i)$  is the weight for the  $i$  –feature,  $f_i$  is the original value for the  $i$  –feature, and  $F_{Trans1}$  is the first feature transformation.

2) *Feature selection using ANOVA*: The disadvantage of the first-step feature transformation above is that it does not involve label information. Therefore, to select the features that are significant to the label, the second feature transformation is carried out using ANOVA. The ANOVA technique uses variants, a statistical property, to select the features. Previous research shows that the use of ANOVA with SVM gives good accuracy in image classification [28] [39] [40].

The second step of feature transformation in WbFTL applies ANOVA to select features. The first feature

transformation ( $F_{Trans1}$ ) above became the input for the second feature transformation ( $F_{Trans2}$ ), which is used for the training process. The second feature transformation has the same value as the first feature transformation, only different in the number of features. The representation of the second feature transformation can be seen in (7).

$$F_{Trans2} = \{b_1, b_2, \dots, b_a\} \in R^a \quad (7)$$

where  $F_{Trans2}$  is the second feature transformation that uses ANOVA, and  $a$  is the selected features from the implementation of ANOVA with  $a < k$ .

### B. Inter-Cluster Class Distance

The third feature transformation is done by calculating the distance from instances of  $D_T$  to the center of the class label. The Euclidean distance will be used for the distance calculation. The third feature transformation adopts the gravity law, which is also similar to the general works of classification [41]. The use of distance has also been widely used in feature-transfer learning, such as for determining the weight proportion [8], determining the similarity between cross-domain [13] [14] [15], and the implementation of metric learning [32].

The input for the third feature transformation ( $F_{Trans3}$ ) comes from the first feature transformation ( $F_{Trans1}$ ). The formula to calculate the distance of each instances in  $D_T$  is written in (8). While the formula to get the third feature transformation can be seen in (9). The representation of the the third feature transformation written on (10).

$$d_i = \frac{x_T \times h_C}{Dist(x_T, h_C)^2} \quad (8)$$

$$z_i = d_i \times F_{Trans1}, \quad (9)$$

$$F_{Trans3} = \{z_1, z_2, \dots, z_k\} \in R^k \quad (10)$$

where  $d_i$  is the distance between the  $i$  –instance of  $x_T$  and the cluster center  $h_C$ .  $z_i$  is the third feature transformation for the  $i$  – feature of  $x_T$ .  $F_{Trans3}$  is the third feature transformation which is only applied to  $D_T$ ,  $h_C$  is the center of the cluster class label calculated by average formula.  $Dist(x_T, h_C)$  is the euclidean distance between  $x_T$  (instances in  $D_T$ ) and  $h_C$ .

### C. Dataset and Experimental Setup

The dataset for the proposed feature-transfer learning was taken from the image domain, which is the real-world object category. There are 10 class labels in each dataset: calculator, laptop, keyboard, mouse, monitor, video projector, headphones, backpack, mug, and bike [13] [14] [15] [16]. We use four datasets in the experiment. A detailed description of each dataset is shown in Table I. All the datasets used already implemented SURF as the feature descriptor. The features descriptor algorithm will extract the superior degree of the pixels in the original image so that it can capture stable features from each image [39]. Fig. 4 is an example of some images from the class label monitor, backpack, mug, and mouse in each dataset.



TABLE I. DESCRIPTION OF THE DATASET USED

Dataset	Instances #	Features #	Class #	Domain
Office-Amazon	958	800	10	A
Office-Webcam	295	800	10	W
Office-DSLR	157	800	10	D
Caltech-256	1123	800	10	C



Fig. 4. Example of dataset used.

Different from previous research on feature-transfer learning, which uses many parameters in its classification model, this proposed method does not use parameters. The only parameter needed in the proposed feature-transfer learning is the C parameter in the classifier SVM. The C value is set to 0.001 with a linear kernel. This value setting follows previous feature-transfer learning research [17]. Moreover, the proposed feature-transfer learning in this paper has a simpler feature transformation process. By using feature selection and feature weighting approaches and employing statistic properties like average and variance, the proposed method can be done with limited resources while still providing good accuracy results.

### III. RESULT

The experiment result of the WbFTL will be compared with three baselines and five previous feature-transfer learning methods, namely: Geodesic Flow Kernel (GFK) [16], Joint Distribution Analysis (JDA) [14], Transfer Joint Matching (TJM) [15], Balanced Distribution Adaptation (BDA) [9], and Subspace Alignment (SA) [17]. All the datasets used in WbFTL were also used in the comparison methods, including the use of SURF as the feature descriptor.

#### A. Comparison with the Baselines and Previous Feature-Transfer Learning Methods

The difference between WbFTL and previous feature-transfer learning methods mainly lies in the feature transformation process performed, the optimization process, and the use of pseudolabels, as shown in Fig. 5. The red box indicates the feature transformation steps. Fig. 5(a) is the

previous feature-transfer learning method. Meanwhile, Fig. 5(b) shows the steps of WbFTL. Even though both of the methods use a dimensionality reduction approach, WbFTL chooses feature selection rather than forming a projection matrix as used in previous methods. WbFTL also uses feature selection and feature weighting as optimization processes. This approach makes WbFTL simpler and more cost-effective. Moreover, WbFTL does not need to go through an iterative process to find a stable pseudolabel that will be considered the predicted label.

All the methods will be compared based on their accuracy values. The accuracy values from the baselines and the previous feature-transfer learning methods will be taken from the original paper for each method. The comparison results for the accuracy of each pair of datasets can be seen in Table II. Meanwhile, Fig. 6 shows the comparison graph between WbFTL and the baselines model.

This research used three baselines, and the results of the baselines gained from the original paper [9]:

- Baseline 1: INN as the representation of the traditional machine learning method
- Baseline 2: PCA as the representation of the dimensional reduction method
- Baseline 3: TCA as the first feature-transfer learning method

There is no feature transfer or knowledge transfer in the implementation of baseline 1 and baseline 2.

In addition, the experiments also compare the average accuracy from 12 pairs of datasets between the WbFTL method, the baselines, and the comparison methods. The comparison results of the average accuracy are shown in Table III, and the visualization will be shown in graphical form in Fig. 7 and Fig. 8. From the experiment results in Table III, it can be seen that the WbFTL gets 46.62% for the average accuracy. This value overcomes the baselines and previous feature transfer learning methods, except for BDA. Although the average accuracy value of the WbFTL is comparable with the average accuracy of the BDA, the WbFTL uses fewer parameters, as shown in Table IV. So, it is possible to use it with limited resources.

Table II shows 12 pairs of datasets formed from four datasets: A, W, D, and C. These twelve pairs of datasets are formed by swapping the positions of the datasets that will become  $D_S$  and  $D_T$ . For example, the  $A \rightarrow W$  means dataset A becomes  $D_S$  and dataset W becomes  $D_T$ . Another example is  $W \rightarrow A$  which means dataset W becomes  $D_S$  and dataset A becomes  $D_T$ . Because the principle of transfer learning is that there are no definite rules on which datasets must become  $D_S$  or  $D_T$ . The best value for each dataset pair is written in bold, and the second best value is written in underline. From the value yield, we can see that WbFTL gives a better accuracy value on  $A \rightarrow C$ ,  $C \rightarrow A$ , and  $C \rightarrow W$ , where dataset C becomes one of the processed domains.

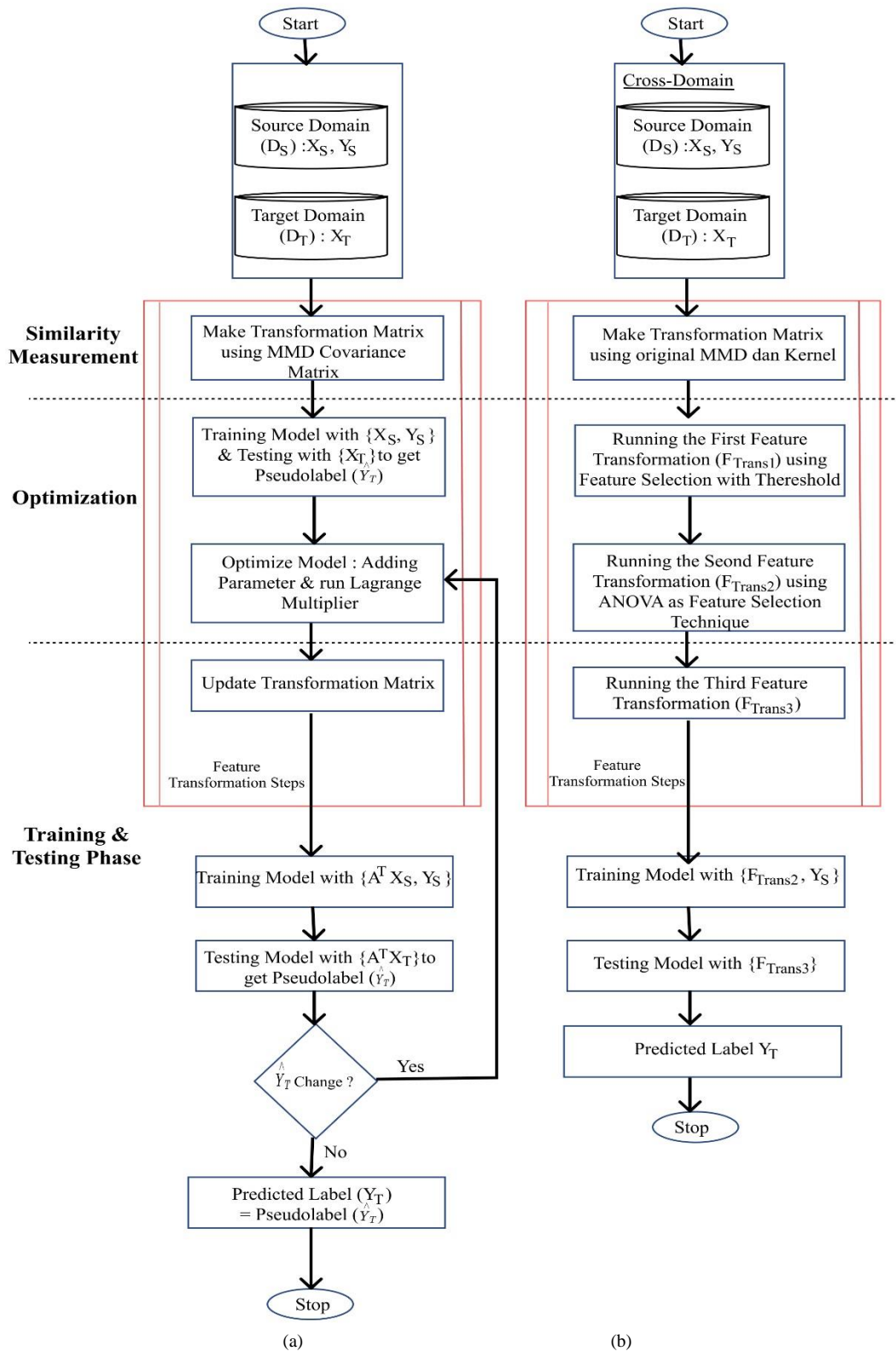


Fig. 5. Comparison method between previous feature-transfer learning and WbFTL.

### Accuracy Comparison for Dataset Pair

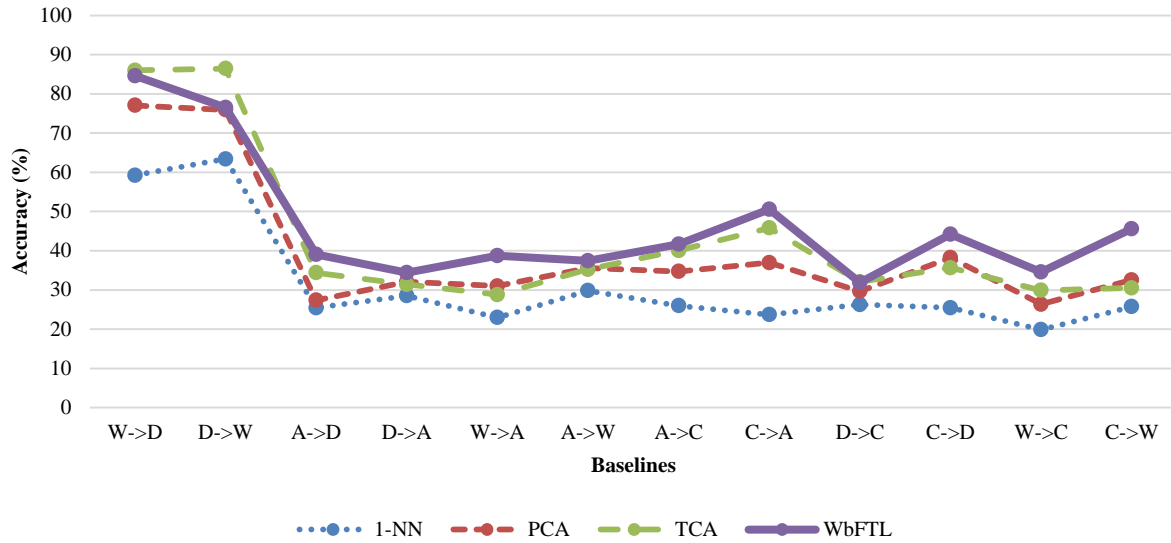


Fig. 6. Accuracy comparison between baselines and WbFTL for dataset pair.

TABLE II. ACCURACY COMPARISON PER DATASET PAIR

Dataset	Baselines			Previous Feature-Transfer Learning Methods					Proposed Method
	<i>INN</i>	<i>PCA</i>	<i>TCA</i>	<i>GFK</i>	<i>SA</i>	<i>JDA</i>	<i>TJM</i>	<i>BDA</i>	<i>WbFTL</i>
W→D	59.24	77.07	85.99	80.89	75.16	89.17	89.17	91.72	84.62
D→W	63.39	75.93	86.44	75.59	76.95	89.49	85.42	91.86	76.53
A→D	25.48	27.39	34.39	36.31	33.76	39.49	45.22	43.31	39.1
D→A	28.50	32.05	31.42	32.05	39.87	33.09	32.78	33.09	34.38
W→A	22.96	31	28.81	29.75	39.25	32.78	29.96	32.99	38.77
A→W	29.83	35.59	35.25	38.98	33.22	37.97	42.03	32.99	37.41
A→C	26	34.73	40.07	40.25	39.98	39.36	39.45	40.78	41.71
C→A	23.7	36.95	45.82	41.02	49.27	44.78	46.76	44.89	50.57
D→C	26.27	29.65	32.06	30.28	34.55	31.52	31.43	32.5	31.91
C→D	25.48	38.22	35.67	38.85	39.49	45.22	44.59	47.77	44.23
W→C	19.86	26.36	29.92	30.72	37.17	31.17	30.19	28.94	34.58
C→W	25.76	32.54	30.51	40.68	40	41.69	39.98	38.64	45.58

TABLE III. AVERAGE ACCURACY COMPARISON FOR EACH METHOD

Methods	Baselines			Previous Feature-Transfer Learning Methods					Proposed Method
	<i>INN</i>	<i>PCA</i>	<i>TCA</i>	<i>GFK</i>	<i>SA</i>	<i>JDA</i>	<i>TJM</i>	<i>BDA</i>	<i>WbFTL</i>
Average Accuracy	31.37	39.79	43.03	42.95	44.89	46.31	46.4	46.62	46.62

TABLE IV. PARAMETER COMPARISON

Methods	<i>TCA</i>	<i>GFK</i>	<i>SA</i>	<i>JDA</i>	<i>TJM</i>	<i>BDA</i>	<i>WbFTL</i>
Parameters	$\mu$	$d$	$\beta_1, \beta_2$	$\lambda$	$\lambda$	$\lambda, \mu$	None

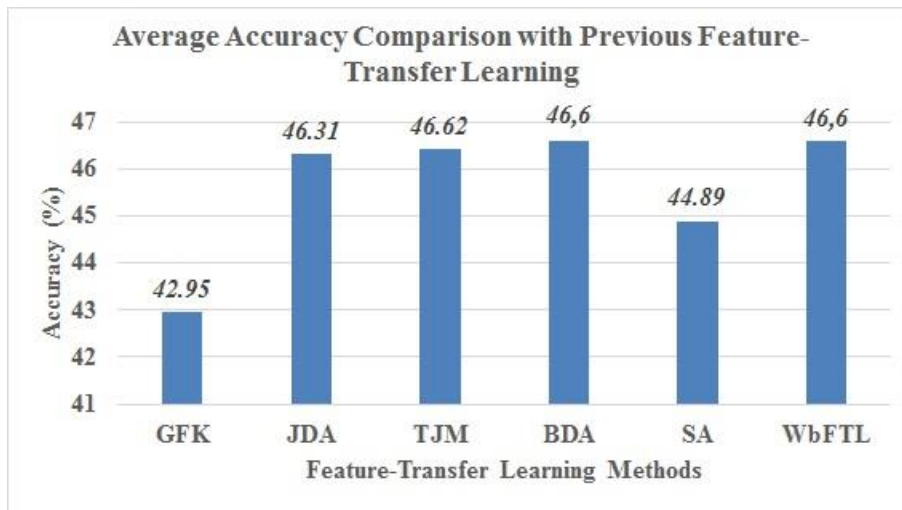


Fig. 7. Average accuracy comparison between WbFTL and previous feature-transfer learning.

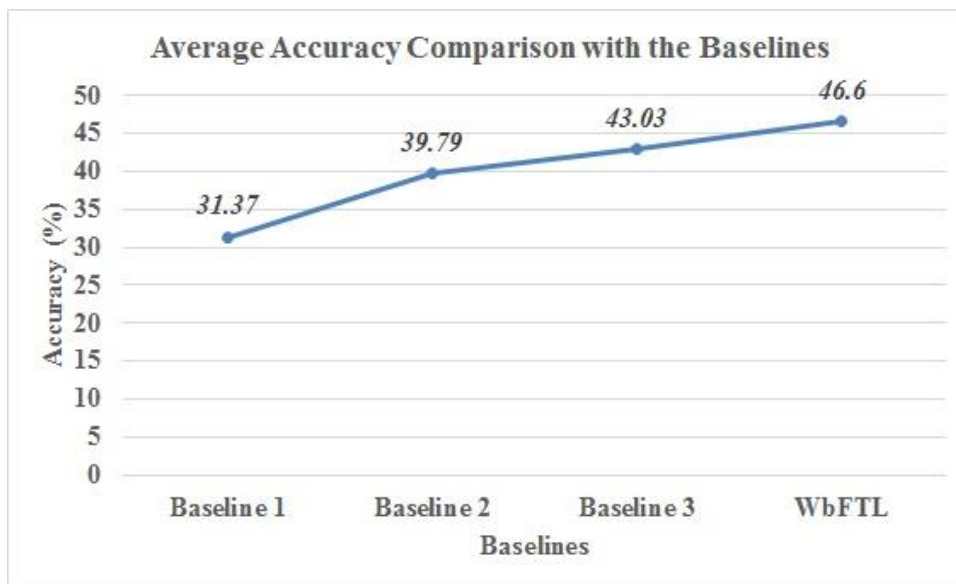


Fig. 8. Average accuracy comparison between WbFTL and the baselines.

Based on the accuracy value in Table III, we can see that the average accuracy of WbFTL exceeds the average value of all baselines. This value also shows an increase in accuracy of 15.25%, 6.83%, and 3.59% when compared to baseline 1, baseline 2, and baseline 3. This result also shows that the implementation of feature-transfer learning has proven to improve image classification accuracy across domains. Even when compared to using a simple classification model such as 1NN, which is baseline 1, WbFTL is far better at generating predictive labels. Compared to PCA, the commonly used dimensionality reduction method, WbFTL also provides better accuracy results. Although WbFTL also uses a dimensionality reduction approach, the process used in WbFTL is simpler than PCA. WbFTL does not take iterative steps to generate a stable transformation matrix, as can be seen in Fig. 5. This result also indicates that feature selection can be applied to form new feature representations to produce a better classification model without applying dimension reduction as in baseline 1. Feature selection as a form of dimensionality

reduction has also proven to be applicable to transform features and produce good classification models at a cost-effective rate.

When compared with the previous transfer learning methods, such as TCA, which is baseline 3, it is also seen that WbFTL provides an increase in yield of 3.59%. This result indicates that the feature transformation process in WbFTL is able to minimize more differences in data distribution compared to that carried out in baseline 3. This is because TCA works to reduce marginal distribution differences without considering label information. While WbFTL reduces the difference distributions between cross-domains by utilizing label information through the second and third transformations.

The experiment results prove that the distribution difference in the cross-domain can be reduced by making a new feature representation that reflects both domains. The formation of this new feature representation can be done by

using a dimensionality reduction approach to reduce the searching space. Concerning the implementation of dimensional reduction techniques, the feature selection method is proven to be implemented and gives good results for transfer learning cases.

The use of the feature selection method makes the WbFTL simpler compared to other feature-transfer learning methods, which have to make a projection matrix. Other than being complex, the use of the projection matrix in the previous feature-transfer learning method also requires optimization, which involves many parameters to be tuned, requiring more resources. A comparison of the number of parameters used in the previous feature-transfer learning method with the WbFTL can be seen in Table IV.

### B. Ablation Study

The ablation study will show accuracy for each step of feature transformation, which is conducted in WbFTL. In this research, the ablation study will compare the accuracy of the second feature transformation with the third feature transformation. The first feature transformation will not be seen in particular because it uses the same approach as the second feature transformation, namely feature selection. By looking at the accuracy of the second feature transformation, it already includes the first transformation. The result of the ablation study can be seen in Table V. Where  $F_{Trans2}$  is the accuracy using only feature selection to transform features, and  $F_{Trans3}$  is the final accuracy value after carrying out all stages of feature transformation.

TABLE V. ABLATION STUDY FOR DATASET PAIR

Dataset	$F_{Trans2}$	$F_{Trans3}$
W→D	84.62	84.62
D→W	76.53	76.53
A→D	39.10	39.10
D→A	33.86	34.38
W→A	38.87	38.77
A→W	36.73	37.41
A→C	41.44	41.71
C→A	50.68	50.57
D→C	31.91	31.91
C→D	44.23	44.23
W→C	34.49	34.58
C→W	46.26	45.58

Based on the ablation study result in Table V above, we can see that the third feature transformation has a better result than the second feature transformation, although it is not showing a significant difference. When viewed from the 12 pairs of the existing datasets, the increase in accuracy values occurs in pairs D→A, A→W, A→C, and W→C. While several dataset pairs experience a very small decrease in accuracy after doing the third feature transformation, namely at W→A, C→A, and C→W.

By looking at these results, it can be seen that the majority of degradation was found when the Amazon dataset became  $D_T$ . Accuracy values also tend to decrease when the Caltech dataset becomes  $D_S$ . The biggest decrease was in C→W, which decreased by 0.68.

Meanwhile, when the Amazon became  $D_S$ , the accuracy value tended to improve at each step of the feature transformation performed, as shown in A→W and A→C. The increase in accuracy is also seen when the dataset that becomes  $D_T$  has more instances than the number of  $D_S$ , as shown in D→A, A→C, and W→C. The biggest increase in A→W was 0.68.

### C. Discussion

The experimental results in Table V above show that the classification results are better when using large datasets as  $D_S$ . This can be seen from the accuracy value, which tends to be high when Amazon becomes  $D_S$ . Similar results are also shown in Table II. In Table II, the accuracy value of A→D is 39.1%; this value is greater than the accuracy of D→A, which is only 34.38%. As mentioned in Table I, the Office-Amazon dataset is larger than the Office-DSLR. Other dataset pairs, such as C→A, also have 9% higher accuracy than A→C because the Caltech-256 dataset is larger than Office-Amazon.

In addition, the imbalance of instances between  $D_S$  and  $D_T$  also affects the accuracy value of each pair of datasets. Better accuracy is obtained on pairs of datasets with an almost equal number of instances. As shown in Table II, where the highest accuracy is D→W and W→D of 76.53% and 84.62%, respectively. The pair with the next highest accuracy is C→A at 41.71% and A→C at 50.57%. In this case, the number of instances between the Office-DSLR and Office-Webcam datasets is more evenly matched than the number of instances between Office-Amazon and Caltech-256. Conversely, when the number of instances of the two domains is very different, the accuracy value will deteriorate, as shown by the D→C pair, which only has an accuracy of 31.91%.

The condition of the original image in the dataset pair used also affects the accuracy value. In Fig. 4 above, it can be seen that the original images between the Office-Amazon and Caltech-256 datasets are quite different in terms of background color, objects in the image (original and cartoon objects), and lighting. This background color difference will affect the value of the resulting feature extraction results, so it can affect the level of image similarity. So the accuracy value between the Office-Amazon and Caltech-256 dataset pairs tends to be small, only in the range of 40%–50%. Meanwhile, the Office-DSLR and Office-Webcam datasets have more similar original image conditions, resulting in higher accuracy in the range of 75%–85%. Given that the original image conditions are almost the same, the feature extraction values will be more similar, so the resulting accuracy will also be better.

## IV. CONCLUSION

In summary, we have proposed a simple feature-transfer learning method called WbFTL. The proposed method is more efficient than the previously reported feature-transfer learning methods because it employs a feature selection strategy for

making a new feature representation. In addition, the WbFTL involved weighting on the selected features to improve the accuracy. The proposed method is also simple since it utilizes statistical properties such as averages and variance to transform the features. There are three steps of feature transformation in the proposed feature-transfer learning method. The first step was feature selection which used a threshold obtained from the feature averaging value as the stopping criteria. The second step was feature selection using the ANOVA technique. Finally, the third step was calculation of the distance between the target domain and the center of the class label employing the Euclidean distance.

This experiment was carried out using only one type of classifier, namely SVM, with SURF as a feature extraction technique. There are still many other types of classifiers that can be used. Another limitation in the experiment is the category of dataset used, which is limited to real-world objects only.

From the experiment result using 12 pairs of the dataset, we have shown that the WbFTL provides a better result than the previous method, except for the BDA. Although the WbFTL gives a comparable result to the BDA, it is superior in terms of simplicity because it does not use any parameters to run the model. Allowing it to use in the conditions of limited resources. We also showed that WbFTL get higher accuracy of 15.25%, 6.83%, and 3.59% when compared to 1-NN, PCA, and TCA model baselines.

We can improve the results and accuracy of the WbFTL in the future by combining it with CORAL as one of the feature transformation steps in WbFTL. Furthermore, the accuracy can also be increased by optimizing the feature transformation steps, such as optimizing the feature weighting process or applying the weighting to the distance.

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# Distributed Training of Deep Autoencoder for Network Intrusion Detection

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**Abstract**—The amount of data being exchanged over the internet is enormous. Attackers are finding novel ways to evade rules, investigate network defenses, and launch successful attacks. Intrusion detection is one of the effective means to counter attacks. As the network traffic continues to grow, it can be challenging for network administrators to detect intrusions. In huge networks connected with millions of computers Terabytes/Zettabytes of data is generated every second. Deep Learning is an effective means for analyzing network traffic and detecting intrusions. In this article, distributed autoencoder on the CSE-CIC-IDS2018 dataset is implemented by considering all the classes of the dataset. The proposed work is implemented on Azure Cloud using distributed training as it helps in speeding up the training process, thereby detecting intrusions faster. An overall accuracy of 98.96 % is achieved. By leveraging such parallel computing into the security process, organizations may accomplish operations more quickly and respond to risks and remediate them at a rate that would not be possible with manual human capabilities alone.

**Keywords**—Network intrusion detection systems; deep learning; autoencoders; cloud computing; distributed training; parallel computing

## I. INTRODUCTION

Organizations must prioritize cybersecurity as they begin their digital transformation initiatives. The availability, confidentiality and integrity of the data has to be maintained irrespective of whether the deployment was on the premises or on the cloud. Therefore, while organizations want to ensure that they keep up with technological changes, they also need to prioritize security. In a matter of seconds, the amount of exchanged data can multiply dramatically, increasing the risk to sensitive data. And as the Internet of Things (IoT) expands beyond consumer electronics and into industrial machinery, there is concern over both the number of attacks and how sophisticated they are becoming. Human welfare is at risk as attackers are targeting hospitals, cars, and power plants. Given the stakes, it is crucial that IT directors put the practical approach in place to protect this valuable data. Security managers are implementing significant changes as they embrace new technology and security measures. Rather than making systems secure, the emphasis is on ensuring that the data they contain is secure. As a result of digital transformation, attackers are exploring vulnerabilities to launch attacks. Today, any vulnerability in the supply chain has a catastrophic effect that costs millions of dollars thus, immediately destroying the credibility.

Digitalization, connected cars, connected homes and IoT has enhanced the digital footprint. The world is transitioning from a physical to a digital experience. The ever increasing threat landscape brings in more challenges in the security domain. This led to the integration of Artificial Intelligence (AI) and Machine Learning (ML) in cyber security. To protect their organizations from novel attacks, companies are increasing their investments in cyber security automation. Few decades ago, companies used to invest very less on security. With the increase in the incidents and breaches post the covid pandemic period, the world has transitioned into a remote network which operates without geographical boundaries. Attackers are finding new ways to breach the security, posing significant threat to organizations. Deep Learning (DL) models can leverage cloud computing services. This paradigm shift helps train DL algorithms on distributed hardware more easily.

DL has been quite a game-changer for several companies and organizations during the recent years. As a result, it is not surprising that many specialized, cloud-based solutions have developed to aid data scientists in their work multiple ways. The global ML market is projected to grow from \$7.3 billion in 2020 to \$30.6 billion in 2024. This would lead to a substantial growth of 43% according to Forbes. To continue with the constantly changing business requirements of consumers, data scientists and ML engineers have to create more sophisticated models. ML experts have found MLaaS to be extremely useful and powerful in designing more sophisticated models.

Organizations have to leverage DL techniques to quickly identify, evaluate and treat risks to evade major attacks on their networks. The consequences after a network attack are devastating. Attacks might be one or more of the following;

- Loss to government, private and public parties
- Legal and regulatory impact
- Financial implications
- Impact to essential services
- Loss of trust
- Socio-psychological impact.

Decades ago, computing was completely self-managed with respect to hardware, software and configuration. The location of the data center was dedicated to a physical location and customization was based on requirements. Ring fence security was used to block or control external access. These

techniques are no longer suited in the present digital era as they are expensive because of the capital and operational costs. Also, the complexity with customization has increased. Another major disadvantage of traditional computing is their inability to scale. Thus, there is a complete paradigm shift towards cloud computing.

Traditional methods of storage are no longer suitable because of the following requirements.

- Exponentially growing data.
- Very expensive, not scalable and slow
- Loss of data.

Compared to traditional storage methods, there are numerous advantages of storing data on the cloud.

- Ease of use and access
- Easy sharing
- Disaster recovery
- Scalability and elasticity
- Cost efficient
- Security

There are numerous advantages of cloud computing over traditional computing

- Shared infrastructure that are logically separated.
- No access to the underlying hardware.
- Optional customization of software and configuration.
- Geographically dispersed points of presence
- Suited for performance and scalability.
- As-a-service (aaS) subscription model.

MLaaS refers to a group of different cloud-based systems that combine ML tools with solutions to assist ML team in various tasks such as deploying and running orchestration models, data pre-processing, model training and tuning predictive analysis for a variety of problem statements. It leverages cloud computing's flexibility to provide ML services on the go. The MLaaS industry is pretty substantial. Valued at \$1.0 billion in 2019, it is anticipated to grow to \$8.48 billion by 2025. Azure Machine Learning Studio offers a development environment. It helps create ML models both for entry-level and professional data scientists. Most actions in Azure ML Studio may be accomplished using a GUI interface, just like with Microsoft Windows.

The key contribution of this research is to perform distributed training. This research article emphasizes on the fact that training time can be drastically reduced when distributed training is used. As the size of the dataset increases, the traditional methods of training DL models using single machine are no longer suitable. In the context of NIDS, the main aim is to help the network administrators to detect intrusions at a faster rate. In terms of training time, the proposed distributed autoencoder model improves the

performance by reducing the training time. This helps the network administrators to take necessary steps before the attacker is successfully able to launch an attack on the network.

The manuscript is organized as follows. Section II gives a detailed description of the literature review carried in the area of Network Intrusion Detection (NIDS). Section III gives the details of the proposed methodology. Section IV gives the details about the experimental setup. Section V gives the details on the results. Finally, Section VI discusses about conclusion, limitations and future enhancements.

## II. RELATED WORK

Ketulkumar et al. implemented 'Multiclass Decision Forest' on the UNSW-NB15 dataset using. The ML algorithm was run on Azure ML platform. The author has achieved an average overall accuracy of 96.33% [1]. Youngrok et al. carried out their research on three datasets namely NSL-KDD, N-BaTot and IoTID20 datasets by using auto encoders. The authors opined that stacked encoders work better when their model size is increased [2]. Pooja Rana et al. implemented their FCM-ANN and SVM-ANN and FCM-SVM, SVM-ANN algorithms. The authors concluded that FCM-SVM methodology outperforms other classifiers on the UNSW\_NB15 dataset. SVM-ANN methodology outperforms other classifiers on the NSL-KDD dataset [3]. Kanimozhi et al. implemented various ML algorithms and ANN (MLP) on the CSE-CIC 2018 dataset. The authors concluded that ANN (MLP) outperforms other ML Classifiers. Using ANN (MLP) the authors achieved an accuracy of 99.97% along with other metrics. The authors also used a Calibration curve [4]. Smitha Smitha Rajagopal et al. proposed a meta-classification approach. The authors tested their proposed model on UNSW NB-15, CICIDS 2017 and CICDDOS 2019 datasets [5]. Jan Lasky et al. carried out an extensive literature review on NIDS and concluded that DL techniques outperform shallow ML techniques [6].

Kanimozhi et al. used the combination of Random Forest and Decision Tree classifiers. The authors used ANN algorithm on the UNSW-NB15 dataset with an accuracy of 89% [7]. Zeeshan Ahmed et al. carried out an extensive literature survey on ML and DL approaches used in NIDS. The authors conclude that a majority of the researchers detested their models on outdated datasets like KDD cup'99 and NSL-KDD. Another important finding from their work is most of the researchers have not addressed the class imbalance problem in their datasets. This affects the accuracy and detection rate of the minority attack classes [8]. Satish et al. carried out a detailed review of research trends in NIDS. The authors conclude that KDD Cup'99 is the most used dataset for NIDS. However, KDD Cup'99 does not reflect the current attacks. The authors encourage researchers to carry out their research using datasets that reflect the current day attacks [9]. Narayana et al. implemented the Stacked Auto encoded- Deep Neural network (SAE-DNN) on KDD, NSL-KDD and UNSW-NB15 datasets. Their hybrid model on UNSW-NB 15 achieved an accuracy of 99.5% [10]. Sultan Zavrak et al. used Variational Auto Encoder (VAE). The metrics used by authors were Receiver Operating Characteristics (ROC) and Area Under ROC curve [11]. Sydney Mambwe et al. used Simple RNN,

LSTM and GRU on NSL-KDD and UNSW-NB15 datasets [12].

Zichan Ruan et al. used visualization algorithm to gain insights into the KDD99 cup dataset [13]. Matthias Langer et al give a taxonomy of Distributed Deep Learning Systems (DDLs) [14]. Asif et al. in their research paper detailed about the strategic importance of NIDS [15]. Abhishek Divekar et al. in their research work conclude that UNSW-NB 15 dataset is an alternative to KDDCup 99. The authors also highlighted that class imbalance of KDD-99 and NSL-KDD. Class imbalance hampers the efficacy of the classifiers on the minority class [16]. Mahdi Soltani et al. proposed model on Deep Intrusion Detection (DID) system. The authors evaluated their work on CIC-IDS2017 and CSE-CIC-IDS2018 datasets [17]. Joffrey L Leevy et al. carried out a detailed survey of IDS models on CSE-CIC-IDS2018 dataset. The authors opined that most of the researchers who carried out their work on CSE-CIC-2018 dataset did not address the class imbalance [18]. Sukhpreet et al. used eXtreme Gradient Boosting (XGBoost) on the NSL-KDD dataset. Jiyeon Kim et al used Convolutional Neural Network (CNN) and focussed only on DoS (Denial of Service) attacks. They used the KDD and CSE-CIC-IDS 2018 datasets [20]. Said Ouiazzane et al proposed snort signature based NIDS on the CICIDS2017 dataset. They implemented their proposed model using ML algorithms [21]. Haripriya et al carried out a literature review on NIDS datasets. They implemented Deep Autoencoder by including all the files of CSE-CIC-IDS2018 dataset. An overall accuracy of 97.79% was achieved [22-23].

Attackers are finding novel ways to launch sophisticated attacks. Studies from literature review show that there is an increasing necessity to not only detect intrusions accurately but also more quickly. Once intrusions on the network are detected, necessary steps should be taken so that the attacker is not successfully able to launch the attack. Considering the enormous amount of data generated on the network, training the DL algorithm on a single machine is no longer suitable. This research work mainly focuses on distributed training of deep autoencoder model to speed up the training.

### III. PROPOSED METHODOLOGY

There are two means to achieve parallelism namely model parallelism and data parallelism. Model parallelism is when the same data is used for each thread but the model is split among them. In data parallelism, same model is used for each thread but operating on different portions of the data.

This research article focuses on data parallelism. Fig. 1 illustrates data parallelism [24]. Initially, a compute cluster with two nodes is created. Each node contains a replica of the model. However, each node processes a different portion of the data. The errors between each node's predictions for its training samples and the labeled outputs are individually calculated. Each node then modifies its model in response to the errors. This information is communicated to all the other nodes to update their related models. The worker nodes need to synchronize model parameters on every batch computation. This ensures the consistency of the training model.

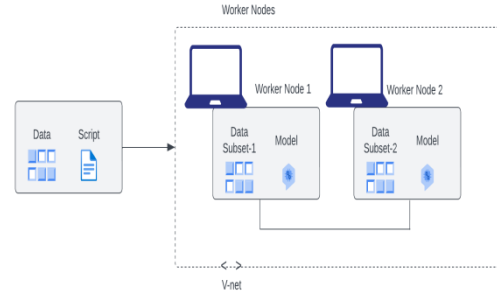


Fig. 1. Data parallelism.

#### A. Autoencoders

The proposed work uses autoencoders. An autoencoder is a special type of neural network architecture, used for unsupervised learning. The main idea of using an autoencoder is to learn a lower-dimensional representation for a higher-dimensional data.

#### B. CSE-CIC-IDS2018 Dataset

CSE-CIC-IDS 2018 dataset is used on the proposed autoencoder model [25]. The dataset is obtained from AWS S3 bucket. It consists of seven types of attack scenarios along with 80 features. The dataset was created as joint venture between the Communications Security Establishment (CSE) and Canadian Institute of Cybersecurity (CIC).

#### C. Preprocessing

Preprocessing helps network traffic data to be easily processable by the DL algorithm. It also helps speeding up the training process. Rows containing NAN and infinite values were dropped. Label encoding and one-hot encoding were used. The CSE-CIC-IDS2018 dataset suffers from class imbalance. The classifier tends to be more biased towards the majority class leading to inaccurate results. This has a major negative impact on the performance. The class imbalance was addressed Synthetic Minority Oversampling Technique (SMOTE). It is an augmentation technique for the minority class.

#### D. Configuration in Azure Machine Learning Studio

Fig. 2 illustrates the Azure ML Resource group. The following steps were carried out.

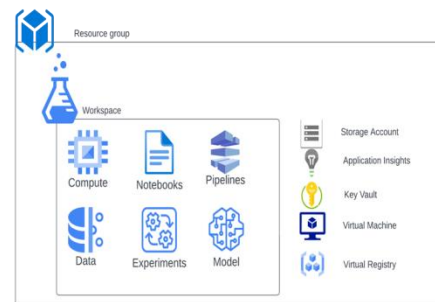


Fig. 2. Azure ML resource group.

- Sign in to Azure Machine Learning Studio and select create workspace. Give the workspace name. In addition to this provide subscription type, resource group and the region. After providing all the details a workspace is created.
- Microsoft Azure Blob (Binary Large Objects) was employed to store CSECICIDS 2018 dataset. Blob storage is best suited for large scale unstructured data.

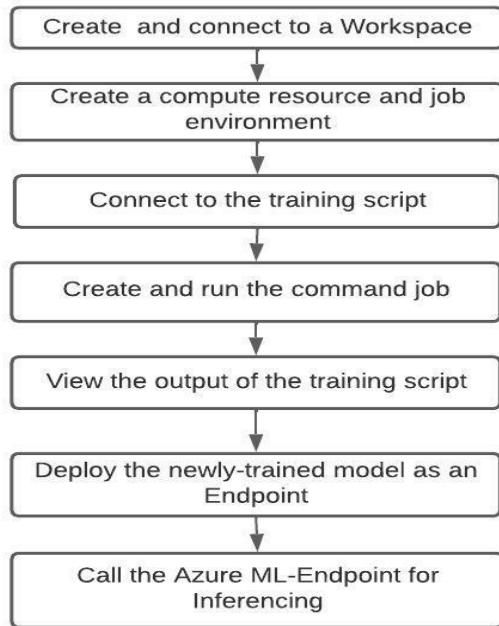


Fig. 3. Flowchart depicting model deployment on Azure cloud.

Fig. 3 clearly illustrates the different steps to be followed while deploying the DL model on the cloud.

#### IV. EXPERIMENTAL SETUP

##### A. Details on the Implementation

Fig. 4 illustrates accelerated networking. The configured Virtual Machines (VMs) supports accelerated networking. It greatly improves network performance by reducing latency,

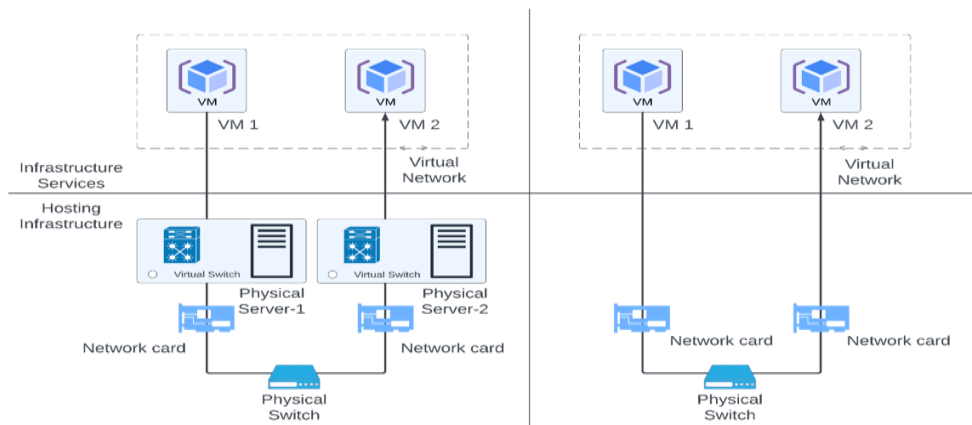


Fig. 4. Accelerated networking.

jitter and CPU utilization. This is suitable in scenarios with most demanding network workloads.

Premium Solid State Drive (SSD) disks were used for storage. The main advantage of using SSD is that they have access speeds of 35 to 100 microseconds. Compared to Hard Disk Drives (HDD) they are 25 to 100 times faster. SSDs are more suitable in I/O intensive workloads and deliver high-performance and low-latency disk support for VMs.

Locally Redundant Storage (LRS) was used as illustrated in Fig. 5. The key advantage of using LRS is, it replicates the storage account three times within a single data center located in the primary region. Thus, the application is restricted to replicate data only within a country/ region. This is more suitable in scenarios where data governance requirements are being imposed. Table I illustrates the configuration of the VMs used in the training model.

Synchronous distributed training is implemented across the worker nodes, each having two CPUs. All variables and computations are replicated to every local device. In order to enable collaboration of multiple workers, it utilizes a distributed collective implementation (such as all-reduce).

First the ScriptRunConfig is created. This is used to specify the training script arguments, the environment and the cluster to run on. The training script in this experiment uses a Multi-Worker Distributed training of the Keras model. This can be done using the `tf.distribute.Strategy` API. `tf.distribute.Experimental.MultiWorkerMirroredStrategy()` is used to leverage distributed training. The tensor flow configuration is used to run a multi-worker tensor flow job. The number of nodes in the training job is specified by setting the worker count variable. In tensor flow, to enable the training on multiple machines, the `TF_CONFIG` environment variable is used. This allows the training code on each Virtual Machine (VM) instance used in the training job, to gain access to information about the training job and the VM's operation. Thus, to comply with the requirements set forth by Tensor Flow for distributed training and to enable communication between VMs, `TF_CONFIG` environment variable must be present on all the VMs configured for the training job. Next, a distributed config is created by specifying the number of worker count. The number of worker nodes is set to two. The train - test split is set is to 70 % and 30 % respectively.

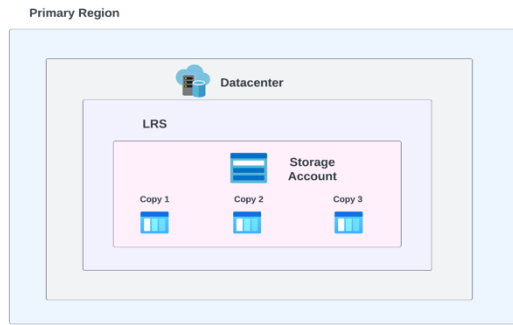


Fig. 5. Replication of storage account using LRS.

TABLE I. VM CONFIGURATION - DV2 11SERIES

VM Configuration	VM 1	VM 2
Size	Standard_D11_v2	Standard_D11_v2
vCPU	2	2
Memory GiB	14	14
Temporary Storage(SSD)GiB	100	100
Max temp storage throughput:IOPS/ ReadMBps / Write MBps	6000/93/46	6000/93/46
Maxdatadisks/ throughput IOPS	8/8*500	8/8*500
Max NICs	2	2
Expected network bandwidth (MBps)	1500	1500

TABLE II. HYPERPARAMETERS USED IN THE PROPOSED DISTRIBUTED DEEP AUTOENCODER

Sl. No.	Hyper Parameters	Value
1	Activation Function: Hidden layer	ReLU
	Output layer	Softmax
2	Batch Size	128
3	Number of Epochs	15
4	Loss function: Multi Classification	Categorical Cross Entropy
5	Optimizer	Adam
6	Learning Rate	0.01

Table II gives the details of hyper tuning parameters in training the proposed distributed autoencoder model.

## V. RESULTS AND DISCUSSION

In our experimentation two scenarios are considered. In the first scenario, single VM is used for training. In the second scenario, two VMs are used to train the model.

Fig. 6 illustrates the time taken when the autoencoder model is run on a single VM without distributed training. Fig. 7 illustrates the time taken when the autoencoder model is run on two VMs by leveraging distributed training. Time taken to

train is plotted on the X-axis and CPU Utilization is plotted on the Y-axis. In this research work, by using data parallelism, Deep Auto-encoder algorithm is trained on two VMs (distributed training), which speeds up the training process. An overall accuracy of 98.96% is achieved.

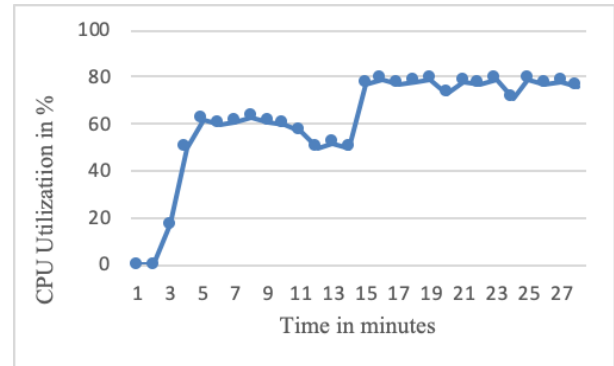


Fig. 6. CPU utilization and Time taken when a single node is used.

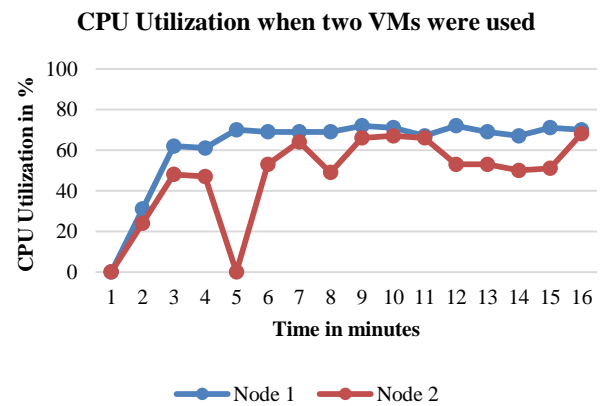


Fig. 7. CPU utilization and time taken when multiple nodes are used.

Fig. 8 depicts the training time when single node and distributed training is used. Time taken to train when single VM is used is 67 minutes while the time taken to train when two VMs (Distributed Training) is 43 minutes. 24 minutes reduction in terms of training time was observed when distributed training was used. Table III gives the comparative analysis of the proposed work with other techniques.

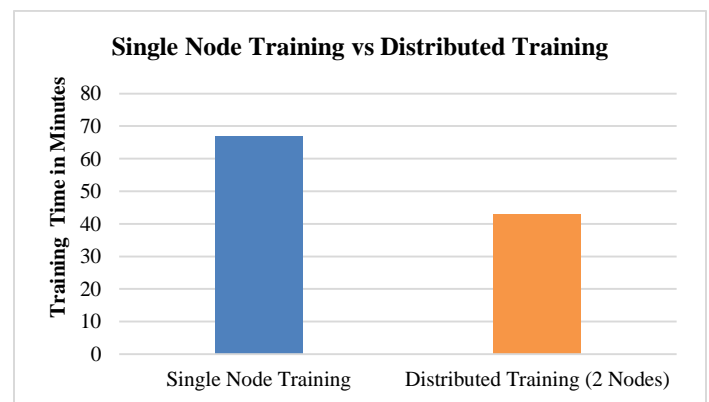


Fig. 8. Single node training vs. distributed training.



TABLE III. COMPARATIVE ANALYSIS

Sl.No	Authors	Algorithm Used	Dataset Used	Accuracy	Year	Attacks detected	Whether Distributed training was used?
1	V. Kanimozhi et al [4]	Artificial Neural Network and Multi-Layer Perceptron	CSE-CIC-IDS 2018	99.97%.	2019	Only Botnet attack	No
2	Alzughabi et al [26]	Multi-Layer Perceptron with Back Propagation	CSE-CIC-IDS 2018	98.41 %	2023	All the attacks of the dataset	No
3	Farhan et al [27]	Deep Neural Network	CSE-CIC-IDS 2018	90 %	2020	All the attacks of the dataset	No
4	Proposed Work	Deep Auto Encoder	CSE-CIC-IDS 2018	98.96 %	2023	All the attacks of the dataset	Yes

## VI. CONCLUSION

With the pace at which internet is growing, the amount of data exchanged over it is increasing, paving way for novel network attacks. Detecting intrusions early to avoid network attacks is the need of the hour. Considering the huge size of dataset, classifying all the attacks is a compute-intensive task. The main contribution of this research work, is to perform distributed training on the autoencoder model using the latest benchmark dataset by classifying all the classes of the dataset. Performance on the model proved to more efficient when distributed training was used. For compute and data intensive tasks, DL combined with distributed training is the most appropriate solution. Promising results were achieved with an overall accuracy of 98.96% and 24 minutes reduction in training time when distributed training was used. To the best of our knowledge, this is indeed the first research work done in this area. As a future work, other DL algorithms suitable for distributed training for NIDS can be explored. The training time can further be reduced by using high configuration VMs. Also, services from various cloud service providers can be leveraged for distributing training. A comparative study of various ensemble methods for DL algorithms suitable for NIDS can also be carried out.

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# An Arabic Intelligent Diagnosis Assistant for Psychologists using Deep Learning

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**Abstract**—Mental illnesses have increased in recent years, especially after Covid-19 pandemic. In Saudi Arabia, the number of psychiatric clinics is small compared to the population density. As a result, psychologists encounter a variety of difficulties at work. The main goal of the current research is to develop a system that assists psychologists in the diagnosis process, which will be based on the DSM-5 (Diagnosis and Statistical Manual of Mental Disorders). The work on this research started with collecting the requirements and identifying users' needs. In this matter, several interviews have been conducted with Saudi Psychologist and then a questionnaire was developed and distributed to psychologists in Saudi Arabia. Following an analysis of the needs and requirements, the system was designed. A deep learning technique was applied during the diagnosing process to address the issues mentioned by psychologists. Additionally, the proposed system helps psychologists by quickly calculating the results of psychological tests. The system was built as a website. The Convolutional Neural Network (CNN) algorithm was used with 96% accuracy to automatically predict the appropriate diagnosis and suggest the most suitable psychological test for the patient to take. System testing and usability testing were also conducted by involving patients and Saudi psychologists to test the usability of the system and the accuracy of the CNN model. The results indicate that the diagnosis prediction was accurate, and that each activity was completed faster. This demonstrated the model's high degree of accuracy and the system's interfaces' clarity. Additionally, psychologists' comments were encouraging and positive.

**Keywords**—Mental health; psychologist; mental illness diagnosis; psychological test; deep learning; CNN algorithm

## I. INTRODUCTION

Health care is an important aspect of human life, such as eating and drinking. Mental disorders are one of the most important health problems that are beginning to increase recently. According to the latest Saudi National Mental Health Survey report published by King Salman Center for Disability Research [1], two out of five young Saudi nationals have been diagnosed with mental disorders at a certain time in their lives. Around 80% of Saudi nationals have been diagnosed with severe mental disorders. However, they do not seek to receive any type of mental health treatment. Moreover, the number of mental health clinics in Saudi Arabia does not exceed 100 [1], which is a very small number compared to the population density in the country.

As noticed in [1], the number of patients is large compared to the number of clinics which would put more pressure on

psychologists. Limited number of patients would be seen daily due to the time each session takes. Sometimes, psychologists need more time to diagnose the patient's condition, either due to the lack of experience or because the patient complains of rare or similar symptoms that require careful consideration to be diagnosed appropriately. Additionally, the psych-diagnostic may differ from one psychologist to another due to the difference in their references and method of diagnosis. The psychologist's human nature would also affect the final diagnosis.

During an interview with an experienced Saudi psychologist [2], he pointed out that there is a problem faced by psychologists, which is most people in our society do not prefer to visit a psychiatric clinic, either due to the unavailability of clinics close to the area in which they live or for personal reasons. Instead, they prefer attending counseling sessions online. However, it is difficult to complete all stages of diagnosis from a distance since there is another stage after the initial diagnosis, which is taking psychological tests. These tests are usually done manually, so the patient has to visit the clinic to take them, which makes the diagnosis go back to the starting point. The calculation of the tests results takes a long time to analyze and reach complete and correct diagnosis results. A number of these tests would take more than a day to analyze and understand the results. Moreover, the calculation and analysis process are prone to human mistakes since the tests have many questions and the way of calculating the results is complicated.

The main goal of the current research is to help psychologists in Saudi Arabia to overcome these problems, and hence facilitate their work. The contribution of this paper is twofold:

First, it proposed a new machine learning model to assist Arabic psychologists in diagnosing three prevalent mental disorders, namely Anxiety, Depression and OCD, based on DSM-5 [3].

Second, it automates the Arabic psychological tests based on APA [4].

This paper is structured as follows: Section II sheds light on the research background. Section III describes related work. Section IV clarifies the adopted research methodology including the results. Section V discusses the results. Section VI concludes the paper.

## II. RESEARCH BACKGROUND

The purpose of the research is to develop a diagnosis assistant for Arabic psychologists. Psychological tests are considered essential elements in this diagnosis process. Therefore, a brief background is provided to clarify what mental illness and psychological test are. In addition, the three most important prevalent psychological disorders that are covered in this research will be briefly explained.

### A. Psychological Test

Psychological testing (psychometrics) is the systematic use of tests to quantify psychophysical behavior by allowing the person to answer some questions about a particular test. The test is determined by a psychologist, to make predictions about psychological performance. It is one of the tools that helps psychologists to measure how much of a specific psychological construct a patient has. Although psychological tests are available on some websites, they are tools like any other tools, if they are not in the hands of a trained professional, they might not achieve their intended goals [5].

### B. Mental Illness

The term "mental illness" or "mental disorder" refers to a health condition that results in emotional, behavioral, or thinking changes it also can be combination of them. Mental illnesses are often accompanied by distress and/or problems functioning at home, work, or in social settings. It can affect anyone regardless of age, gender, social status, or any other aspect. Developing a mental health treatment plan requires collaboration between a mental health clinician (psychologists and psychiatrist) and the patient (and family members if desired). There are many types of treatment available, including psychotherapy (talk therapy), medication, and others. Medication and therapy are often most effective when combined. In this work, the focus is on three mental illnesses, namely Anxiety, Depression, and Obsessive-Compulsive Disorder (OCD)

Anxiety is considered one of the most common mental disorders. According to the Saudi National Survey [1], anxiety is the most prevalent disorder among individuals in Saudi Arabia. Around 12% were diagnosed with separation anxiety disorder, which is the largest percentage compared to the rest of the disorders. In the current project, Taylor Manifest Anxiety Scale[6] will be used. This scale is a test of anxiety as a personality trait to measure the severity of anxiety.

Depression is the second prevalent mental disorder in the world. The latest national survey indicates that 6% of people suffer from depression in Saudi Arabia [1]. It is a serious mental disorder that may lead to a suicide thought. Therefore, discovering the problem and knowing the severity of depression may help in creating a treatment plan that would help people to recover and get rid of this disorder. In the current work, the Beck Depression Inventory [7] will be used to measure characteristic attitudes and symptoms of depression.

Obsessive-Compulsive Disorder (OCD) is considered one of the most common mental disorders in the world [8]. It was rarely diagnosed in the past, but nowadays it is seen as a neuropsychiatric disorder mediated by specific neural circuits

and closely related to neurological conditions such as Tourette's syndrome and Sydenham's chorea [8]. OCD could be observable behavior or mental rituals. The obsessions and compulsions of obsessive-compulsive disorder are qualitatively different from obsessive-compulsive personality traits such as perfectionism and excessive conscientiousness. The psychologist can professionally diagnose the patient to determine the type of disorder. In the project, Brown Obsessive Compulsive Scale will be used [5].

## III. RELATED WORK

In this section, the systems and web applications that serve the field of mental health and offer services to assist psychologists in the diagnoses process are discussed.

Labayh [9] is a Saudi mobile app approved by the Saudi Ministry of Health. It is considered as a virtual clinic that provides immediate or scheduled consultation with many different psychologists and psychiatrics allow the patient to choose any of them. Because it is not charitable or free platform, the patient must pay for each session. The app also provides two uncertified psychological tests for depression and anxiety, offered to all people who want to try.

Shezlong [10] is an Arabic website that gathers a group of therapists and presents their information in a clear manner with the cost and duration of the counseling session. This gives the users the opportunity to choose the therapist appropriate to their psychological status and budget. The website offers six psychological tests that initially diagnose the patient's condition and make recommendations for the best psychologist to follow up with. However, the patient takes a test based on what he thinks about his situation, not according to specialized advice from a therapist.

Mentalines [11] is a profit-based Arabic website that provides several psychological tests. The user can choose any of them to purchase and take online under the supervision of a psychologist. The website also provides many services related to the mental health like articles, training sessions, therapy trips, and group therapy sessions.

In [12], assistance was provided to psychologists to diagnose Anorexia using natural language processing to assess the expressed emotions by the patient through body description according to DSM criteria [3]. The diagnosis is made by processing the patients notes about their body. To achieve it, researchers used a dataset from a collection of opinions from the Stanford Amazon Dataset service and trained the model using the RNN (Recurrent Neural Network) algorithm. According to [12], the results showed the relationship between psychologists and patients had improved; writing notes made them feel safe, less resistant, and more credible. Although the good results, the model did not recognize some words, which influenced the diagnosis.

In [13], a machine learning model was built to assess five levels of three disorders, namely, anxiety, depression, and stress, without the need for a psychologist's intervention. The dataset was collected through online questionnaires filled out by different participants. The researchers applied eight algorithms that belong to four different categories: bayes, neural networks, lazy, and tree. The results of this research

showed the neural networks RBFN (Radial Basis Function Network) model was the best with depression disorders, while random forest was the best with anxiety disorders. It had a 100% accuracy rate, this occurred due to an imbalanced dataset.

A Machine Learning Approach to detect Depression and Anxiety using Supervised Learning was proposed in [14]. This paper suggested completing the diagnosis process without the need for a psychologist's intervention. It can be done by the patient choosing the disorder, answering the questionnaire, and then the system shows the result to the patient. The dataset was collected through a standard, structured questionnaire. The researchers used four algorithms to develop the model, which are: linear regression, LDA (Linear Discriminant Analysis), CNN (Convolutional Neural Networks), SVM (Support Vector Machine), and KNN (K-Nearest Neighbor). The results of this research showed that the CNN model was the best for depression with 96% accuracy and anxiety with 96.8% accuracy. However, there were limitations in its work. The questionnaire was too long, and there was a potential that the patient would not complete it. Also, according to [14] without a psychologist's help, patients will be less honest.

In [15], a predictive model was built to predict two disorders: Major depressive disorder (MDD) and generalized anxiety disorder (GAD). The researchers used an existing EHR dataset containing biometric and demographic data collected from 4184 undergraduate students. The model was trained using varied non-psychiatric input features such as blood pressure, heart rate, housing, status, and public insurance. The participants were assessed for full Diagnostic and Statistical Manual of Mental Disorders Fourth Edition (DSM IV). For the prediction accuracy, the sensitivity and specificity for MDD were 55% and 70%, and for GAD were 70% and 66% respectively. Additionally, the positive predictive value for MDD was 20% and for GAD it was 16% and the negative predictive value for MDD was 92% and for GAD it was 96%.

From the reviewed literature, it is clear that many different approaches have been proposed to automate the process of diagnosis in the field of mental health. However, they mainly focus on one part of the process, and sometimes without supervision from specialized personnel. In the next sections, our proposed approach is explained. It aims to help psychologists in the whole diagnosis process including the initial diagnosis phase using deep learning, and final diagnosis phase involving automated Arabic psychological testing. Table I compares the reviewed systems and proposed system.

According Table I, there are several systems and research have been created and developed to improve the diagnostic process in the field of mental health. Three of them [6] [7] [8] are actual real system platforms that connect psychologists with patients. They provide a number of psychological tests without any utilization of artificial intelligence algorithms to facilitate the initial diagnosis process. Moreover, they do not have a standard reference for the diagnosis process, but they depend only on the Psychologist's experience.

TABLE I. COMPARING THE REVIEWED SYSTEMS AND THE PROPOSED SYSTEM

System	Analyze the symptoms based on DSM-5	Using AI in the diagnosis process	Provide psychological test	Software system	Digital diagnosis assistant for psychologist
[9]			*	*	
[10]			*	*	
[11]			*	*	
[12]	*	*			*
[13]		*			
[14]		*		*	
[15]		*			
Proposed System	*	*	*	*	*

Four of the reviewed papers, [9], [10], [11], [12] were conducted with the aim of using different algorithms in the diagnosis process. However, they did not rely on DSM-5 [3] on the symptoms analysis process. All of these four researches have not been deployed as an actual system yet.

As noticed, each of the related work focused on a specific side and ignoring others. For example, helping psychologists reach beneficiaries and offering psychological tests without using any new techniques. Other systems [12], [13], [14], [15] adopted artificial intelligence algorithms on the initial diagnosis, but they did not offer any other services, such as offering and calculating psychological tests which can help psychologists to expedite and facilitate the diagnosis process.

The proposed system aims to leverage these limitations. It uses deep learning algorithm (CNN) in the diagnosis process based on a standard reference which is DSM-5 [3]. Additionally, it offers appropriate physiological tests according to the result of the diagnosis.

#### IV. RESEARCH METHODOLOGY

The research methodology comprises several steps as summarized in Fig. 1 and clarified in the following subsections.

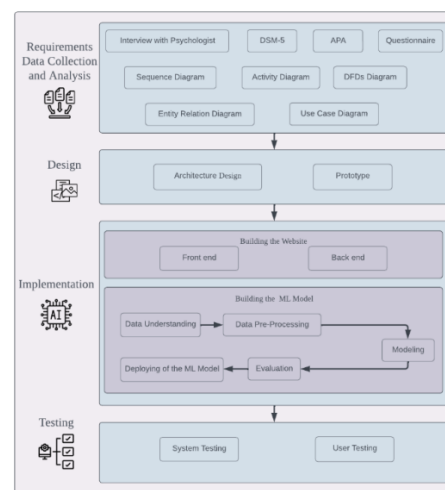


Fig. 1. Research methodology.



A. Requirements Collection and Analysis

In the process of collecting the requirements, we had several online and face-to-face interviews with psychologists from Saudi Arabia in the period between August 27, 2022 and October 18, 2022. Through these interviews, the most important needs of psychologists were identified, and the diagnostic mechanism was fully understood. Additionally, to investigate the significance of this system, an online questionnaire was designed for the experts in the field of mental health [2], and distributed to the psychologists in the Saudi Arabia in the period between 28 Sep 2022 and 8 Oct 2022. Since the target user group was precisely defined in terms of the field, country and specialization, there has been a struggle to reach them in the given timeframe. A total of 70 responses were received. They pointed out that they suffered in terms of time and accuracy to diagnose each patient. They agreed that they are in need of an Arabic system to assist them by automating the process, but at the same time not excluding them.

After full familiarity with the diagnosis process, the functional requirements, including user and system requirements, for the proposed system were identified. The requirements of three main actors namely, Admin, Psychologist, and Patient were analyzed thoroughly using data flow diagrams, use cases and scenarios, activity diagrams, sequence diagrams and Entity Relationship Diagram (ERD) [16] to clarify different aspects of the requirements. Fig. 2 illustrates scenario for the actors including psychologists and patients.

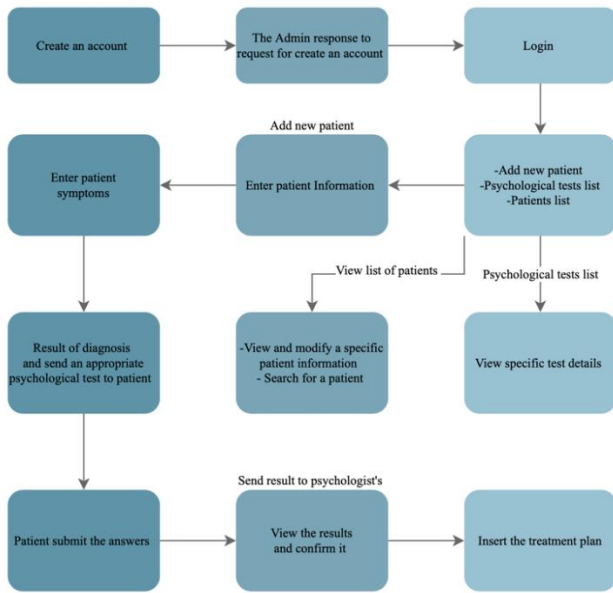


Fig. 2. System scenario to clarify the steps and the main functions of the system.

B. System Design

In this step, the system architecture was designed as illustrated in Fig. 3. Client-server architectural pattern was used to represent the architectural design of the system. Each client was considered as an end-user of the system. The functionality of the system was organized into services, with each service

delivered from a separate server. Each client can access the services through the Internet; therefore, the most suitable architectural pattern is the Client-server [16].

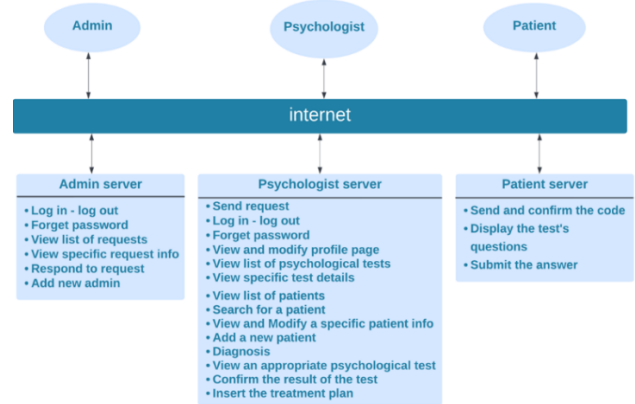


Fig. 3. Client-Server architecture for the proposed system displayed all functions for each actor.

The interfaces of the website were designed as well. Fig. 4 shows the homepage and how it looks on different devices. Fig. 5 and Fig. 6 show two pages that would assist the psychologists during the diagnosis process.

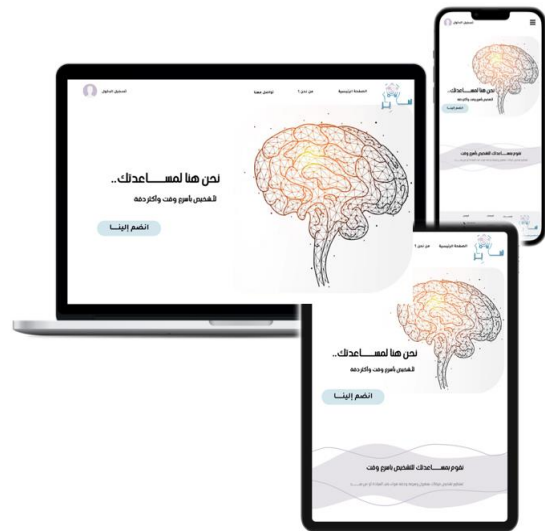


Fig. 4. The proposed website applies responsive design to work properly on different devices.



Fig. 5. This page is displayed to psychologists allowing them to enter patient's symptoms.





Fig. 6. Result of diagnosis and suggested psychological test for patient to take.

### C. Implementation

This section clarifies the implementation step and its details. This step constitutes three main activities, building the website, building of machine learning model, and deployment.

1) *Building the Website:* To build the website, the frontend and backend were implemented. Frontend implementation involved,

- Writing the content of the website by using HTML.
- Styling the interface by using CSS.
- Making the website interactive by using JavaScript.
- Backend implementation involved,
- Creating website's database in Amazon cloud (AWS).
- Connecting the database to Django.
- Creating tables of the website's database.
- Writing functions of CRUD (Create, Read, Update, and Delete) operations. These operations are implemented in Python. Example of such operations include, calculating the test score and saving the result to be displayed to the psychologist.

2) *Building the machine learning model:* To build the ML model, the following steps were followed:

- Collecting dataset.

For this research, the dataset was provided by psychologists from Saudi Arabia. There were 305 observations with 13 symptoms. The symptoms were food problems, sleep problems, conscience, communication, face features, speech, mood, behavior, fears, thoughts, focus, attention, and duration. The psychologists provided balanced observations, where around 62 observations were collected for each disorder: anxiety, obsessive-compulsive disorder, and depression. Fig. 7 shows a sample of the collected dataset.

Disorder	Eating Problems	Sleeping Problems	Conscience	Communication expression	Facial expression	Speech	Mood	Behavior	Fears?	Thoughts	Focus	Attention	Duration
الخوف	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع

Fig. 7. Sample of the collected dataset showing the symptoms being analyzed.

Pre-processing the data. The first step was to ensure that the dataset did not have missing data. This can be done by using the Python function `data.isnull().sum()`. A total of 38 missing cells were found as illustrated in Fig. 8.

```
path = 'withmissing.xlsx'
DF = pd.read_excel(path)
print("Number of Missing Data:", DF.isnull().sum().sum())
print("Dataset Shape: ", DF.shape)
```

Number of Missing Data: 38  
Dataset Shape: (305, 14)

Fig. 8. The dataset before solving the missing data problem.

To fix this problem using Python method `fillna(method="bfill")` from pandas' library and the way of filling missing data was (backward) method that uses next data point to fill the gap [17], as depicted in Fig. 9.

```
new_df = DF.fillna(method="bfill")
new_df.to_excel('dataset.xlsx')
print("Number of Missing Data:", new_df.isnull().sum().sum())
```

Number of Missing Data: 0

Fig. 9. The dataset after solving the missing data problem.

Since the dataset was categorical, the pre-processing was done by using one hot encoding technique. One hot encoding is a common approach for transforming categorical features into suitable binary vectors to be used as input in machine learning models [18]. This can be achieved by writing `get_dummies` Python method from Pandas' library. The dataset was converted into binary vectors and the features increased from 13 to 35 as shown in Fig.10.

الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع	الوجع
0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0

Fig. 10. The result of One Hot Encoding shows that all dataset converted into binary vectors.

The dataset was checked again to make sure that there was not any missing data, using Python Pandas `data.isnull().sum()` and the result was printed as shown in Fig. 11.

```
data = pd.read_excel('dataset_encoded.xlsx')
print("Number of Missing Data:", data.isnull().sum().sum())
X = data.drop(["اوساس فكري", "القلق", "اكتئاب"], axis=1)
y = data[["اوساس فكري", "القلق", "اكتئاب"]]
print("X shape:", X.shape)
print("Y shape:", y.shape)
```

Number of Missing Data: 0  
X shape: (305, 35)  
Y shape: (305, 3)

Fig. 11. The result of data preprocessing.

- Training the model.

Two machine learning algorithms were chosen namely, SVM and KNN and one deep learning algorithm was chosen which is CNN.

Support Vector Machine (SVM) is a supervised machine learning algorithm. The goal of the SVM algorithm is to create the best line or decision boundary that can segregate n-dimensional space into classes so that putting the new data point in the correct category in the prediction will be easy [19]. This best decision boundary is called a hyperplane [19]. SVM has multiple kernels: linear, polynomial, and RBF. Kernels are different in making hyperplanes. Linear works with linearly separable data, and polynomial and RBF work with non-linearly separable data [20]. The SVM algorithm was implemented in the current work using the Python Scikit-Learn package.

K-Nearest Neighbor (KNN) is a supervised machine learning algorithm. It is one of the simplest machine learning algorithms, it assumes the similarity between the new case/data and available cases and put the new case into the category that is most like the available categories [13]. This means when new data appears then it can be easily classified into a well suited category by using KNN. The KNN algorithm was implemented in the current work using the Python Scikit-Learn package.

Convolutional Neural Networks (CNN) is a type of artificial neural network. CNN contains multilayer convolutional, and each layer's output feeding into the next layer's input until out layer [21]. Keras model was used, which is a high-level, deep learning API developed by Google for implementing neural networks. It is written in Python and is used to make the implementation of neural networks easy. Keras is an open-source software library that provides a Python interface for artificial neural networks [22]. Keras also supports multiple backend neural network computation. Keras was chosen to implement CNN adopted 20 layers, the rectified linear unit (ReLU) as the activation function and optimized with a learning rate of 0.5.

The training process started by splitting the dataset into 70% for training data and 30% for testing data to ensure the same data is trained and evaluated in each model.

The SVM and KNN models were trained by fitting the training data to the model using fit() Python method as shown in Fig. 12 and Fig. 13.

```
model = OneVsRestClassifier(SVC(kernel="linear"))
model.fit(X_train,y_train)
```

Fig. 12. Training the SVM model.

```
knn = KNeighborsClassifier(n_neighbors=5)
knn.fit(X_train, y_train)
```

Fig. 13. Training the KNN model.

In training KNN, the neighbor that was chosen after more than one attempt which was five neighbors showed the best accuracy.

The CNN model was built with 20 layers, activation function (softmax,relu), and a learning rate of 0.5, and the dataset was trained 20 times using 20 epochs as shown in Fig. 14.

```
# Build The structure of Model
model = keras.Sequential()
# here we define 20 nodes with input shape 35 and activation function called relu
model.add(keras.layers.Dense(20, input_shape=(input_shape,), activation='relu'))
#then the output 3 node because we have multiclassifiaction (anxiety/ desperation /OCD)
#and the activation function called softmax
model.add(keras.layers.Dense(3, activation='softmax'))

#compile the model
optimizer = keras.optimizers.Adam(lr=0.5)
model.compile(loss='categorical_crossentropy', optimizer='adam', metrics=['accuracy'])
```

Train model

```
history = model.fit(X_train, y_train, epochs=20,
                    validation_data=(X_test, y_test),
                    verbose=1)
history_df = pd.DataFrame(history.history)
history_df.loc[:, ['loss', 'val_loss']].plot();
```

Fig. 14. Building and training the CNN model.

- Evaluating the models

To measure the quality of predictions for each model, accuracy, precision, recall, and F1 score were calculated using the confusion matrix, as clarified in Eq. (1) to (4). The confusion matrix represents the true positives (TF), false positives (FP), true negatives (TN), and false negatives (FN) from predicted and actual values [23].

$$Accuracy = \frac{TP+TN}{(TP+TN+ FP+ FN)} \quad (1)$$

$$Precision = \frac{TP}{(TP+ FP)} \quad (2)$$

$$Recall = \frac{TP}{(TP+ FN)} \quad (3)$$

$$F1\ Score = 2 \times \frac{Precision*Recall}{Precision+Recall} \quad (4)$$

Table II presents accuracy, precision, recall, and F1 score results of the SVM, KNN and CNN models.

TABLE II. COMPARISON OF THE MODELS' PERFORMANCE

Models	Accuracy	Precision	Recall	F1-score
SVM (Linear)	92.48%	96.8%	97.2%	97%
SVM (poly)	92.48%	96.8%	97.2%	97%
SVM (RBF)	94.48%	96.8%	97.2%	97%
KNN	89.48%	96.9%	96.9%	96.9%
CNN	96.74%	96.8%	97.2%	97%

The results are discussed in Section V below.

- Model Deployment.

Since the results were similar in terms of precision, recall, and F1 score, the CNN model was chosen as the best model to deploy it the website taking into consideration its accuracy result which was 96.74%.

The CNN model was deployed to the website by importing all the required Python libraries, the three target disorders were specified. The user-defined Python function inidiag() is used to connect the input data to the model and makes the prediction of specific diagnosis process then saves the result. After that, the input data was processed by converting it to the binary vector.

**D. Testing**

The proposed system was evaluated using system testing and usability testing.

1) *System testing*: System testing is the level of testing that validates a complete and integrated software product. To check how the components interact with each other and with the system as a whole and check the comprehensive test for each input in the system to verify the required output [15]. Four different scenarios were used to conduct the system testing. The results indicate that all errors were minor, and they were related to the front-end part. Upon completing the system testing, the errors were resolved.

2) *Usability testing*: A total of nine users participated in the testing, five of them represented the role of patients and the other four were psychologists. Each participant was given a number of tasks to perform on the system, and they were observed during the testing. The total time to complete each task for each participant was recorded along with the number of errors per task. After the testing session, the participants were interviewed and asked about the system and their experience in using it. The feedback was positive, and they pointed out the usefulness and ease of use of the system.

**V. DISCUSSION**

Table II indicates that the results of the three models were almost similar in precision, recall, and F1 score, however, accuracy differences were noticed. SVM performed better than the KNN model, with accuracy of 92.48%. SVM with kernel RBF has performed better than poly and linear models, with accuracy of 94.48%. Among all models, the CNN model performance was the best, with accuracy of 96.74%. CNN uses epoch, and the higher the epoch, the greater the accuracy. When an epoch is executed, it compares the earlier validation result to the original result. As a result, if an issue is discovered, it attempts to minimize the problem by upgrading the layer function.

Fig. 15, 16, and 17 illustrate the curve of training loss and validation loss in the three models. They show that CNN has a better fit compared to SVM and KNN.

In the confusion matrices illustrated in Fig. 18 to 22, 0 refers to Depression, 1 to Anxiety, and 2 to OCD.

The accuracy results were averaged after 20 epochs for CNN and averaged cross-validation [24] with 10 Kfold to avoid overfitting for SVM and KNN. Overfitting is the term for a model that does not generalize properly from observed data to unobserved data and defeating its purpose [25].

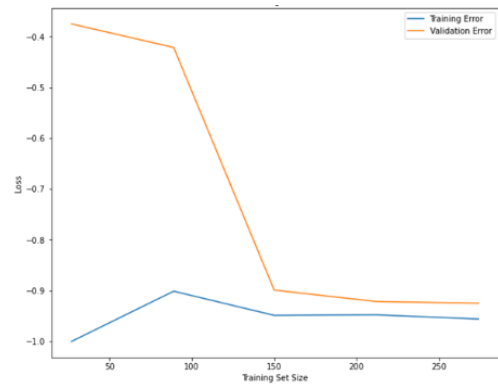


Fig. 15. Plot loss curve for the SVM model.

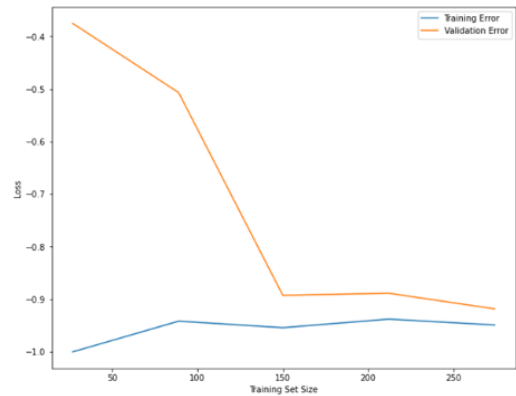


Fig. 16. Plot loss curve for the KNN model.

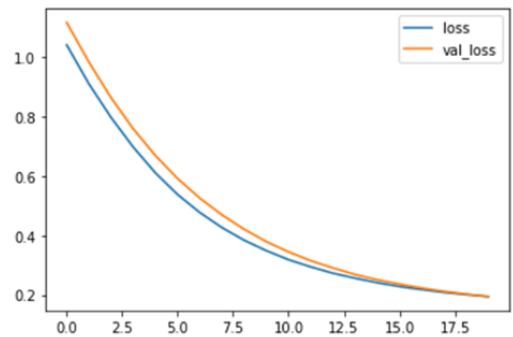


Fig. 17. Plot loss curve for the CNN model.

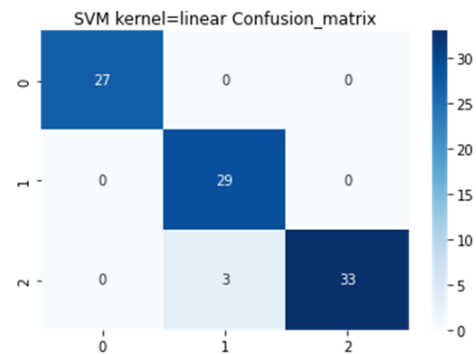


Fig. 18. The confusion matrix for SVM model with linear kernel.

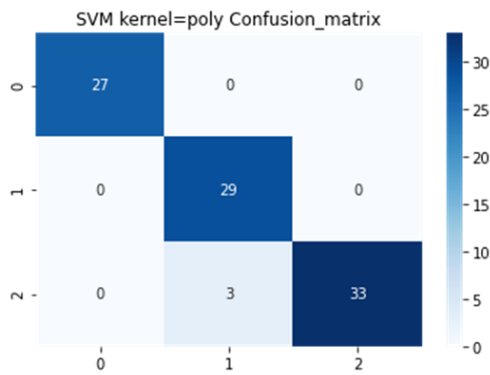


Fig. 19. The confusion matrix for the SVM Model with poly kernel.

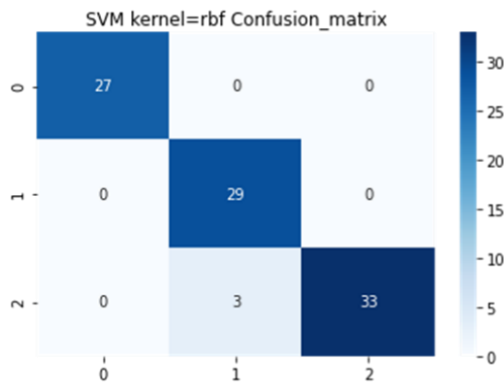


Fig. 20. The confusion matrix for the SVM model with RBF kernel.

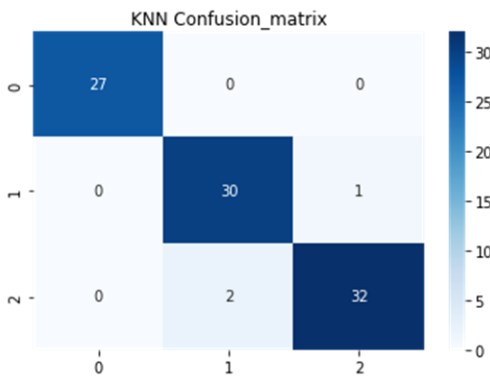


Fig. 21. The confusion matrix for the KNN model.

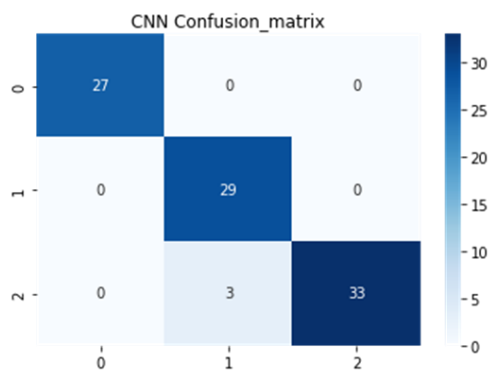


Fig. 22. The confusion matrix for the CNN model.

## VI. CONCLUSION AND FUTURE WORK

In this paper, an Arabic system was proposed to assist Saudi psychologists in making the diagnosis process of mental disorders accurate, easier, and faster. The methodology followed involved requirements collection and analysis, design, implementation, and testing. The machine learning approach was adopted to diagnose the patient based on the symptoms, prior to deciding which psychological test to take. The focus was on three popular mental disorders namely, Depression Anxiety, and OCD. The dataset was built from scratch for them by collecting anonymous data from psychologists. The ML model was trained by using three different algorithms SVM, KNN, and CNN. The CNN algorithm was chosen to deploy on the system, because it was the most accurate algorithm with a minimum number of errors. Two main limitations were encountered during the work on this research. The proposed system did not cover all mental disorders; it covered three prevalent mental disorders. In addition, the collected dataset was limited to 305 observations. The dataset was balanced with around 100 observations for each mental disorder. The main symptoms needed to diagnose the disorders were considered as features in the dataset. The dataset did not contain the less important features such as the background and history of the patient.

As a future work, we are planning to add more mental disorders that can be diagnosed, add more psychological tests that can be taken by patients, and suggest a treatment plan to the psychologist using a machine learning approach.

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# The Evaluation of a Persuasive Learning Tool using Think-Aloud Protocol

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**Abstract**—e-Learning has become a platform for students to gain and expand their knowledge through mobile applications or web-based systems. Even though e-learning systems usually aim to facilitate students' understanding of the subject, some fail to convey the underlying learning outcomes. These circumstances emerge as most e-learning methods or tools fail to attract students to engage in their studies continuously. Therefore, to overcome the problem, the Persuasive Learning Objects and Technologies (PLOT) model comprises persuasive design elements for online learning, is developed. A web-based statistical analysis assistant system called TemanKajianKu (Study Buddy) has been developed based on PLOT elements to assist students in identifying the correct approach to conduct and analyze their experiment. This paper aims to evaluate users' experience and examine the effectiveness of the persuasive design elements of the system. Ten participants were involved in interviews using the Think-Aloud protocol method. The study results showed that most participants conveyed positive opinions by giving good feedback on the system design. Most also stated that the system could help them make decisions by utilizing persuasive elements such as reduction, social signal, tunnelling, tailoring, and self-monitoring. This concludes that the Persuasive Learning Tool is effective in helping develop an e-learning application or web-based system that helps students in decision-making concerning their studies.

**Keywords**—Learning technology; persuasive technology; persuasive learning; persuasive design

## I. INTRODUCTION

Technology can solve many problems by enhancing students' learning capacity using mobile applications and web-based platforms. According to Ahmad [1], computing technologies are intended to assist individuals with daily activities like conducting administrative work or teaching in a classroom and to influence and drive people to change their attitudes or behaviors toward specific issues or things. Numerous applications from various fields must be developed to support students' learning in helping to produce students who are sensitive to using internet platforms as tools to gain knowledge. Problems can arise when students cannot make timely decisions, and their workload grows. With the help of digital learning technology, which can change students' attitudes and improve knowledge content, especially in decision-making aspects like methods, strategies, or selection in research activities, this problem can be resolved. Decision-making and critical thinking are essential in solving a problem, especially in the student's learning process. It has been discovered that technology-assisted learning can influence attitudes, improve research performance, and offer learning experiences for making critical decisions. The need to enhance

the research and student learning level was determined to be met by multimedia components alone, such as audio, video, and interactivity. Student performance must improve to raise learning motivation.

Even though experience is one of the most essential factors in building a technology or application, and if each technology or application is designed to persuade people, the user's decisions are still influenced by experience [2]. Effective persuasive designs are essential when developing an e-learning system [3]. Because e-learning programs are flexible enough to meet needs, this saves students who already understand some concepts in a course from having to review them. On the other side, they might like more complex material, whilst individuals just discovering a field would choose to concentrate on the basics [4]. After that, to better comprehend student decision-making in their study, a system called TemanKajianKu was developed to assist students in understanding statistical analysis. The main aim of this study is to evaluate the persuasive learning tool implemented in the system using a think-aloud protocol for the students. According to studies, failing to think critically might delay or prevent graduate students from finishing their studies and impede the advancement of research [5]. Although universities provide courses designed exclusively for graduate students, including Research Methodology, some students find them too general because each student's studies are unique based on the topic of their studies. Examples of research tasks requiring analytical skills include selecting research methodologies and statistical analysis approaches for user studies and evaluations. Then, the material and methods used in the evaluation study will be further described in the following section of this paper. Next, the result and discussion are presented to explain the evaluation system. The final part of this paper is the conclusion.

## II. BACKGROUND WORK

### A. Persuasive Technology

Persuasive technology is designed to change user attitudes and behavior without coercion [6]. Persuasive technology can be used and implemented to help students adjust and at the same time be able to accelerate their attitude changes without any coercion [7]. This technology can bring people together through computer interaction [8]. It could trigger positive emotions in users by employing various persuasion principles or methods to gain trust and successfully persuade them to adopt the desired attitude or behavior [9]. Persuasive technology has been used in various fields, such as e-commerce, health, and marketing. Persuasive technology is also applied in education by focusing on changes in learning



behavior towards students on e-learning [10]. According to the table below, Gram-Hansen and Sandra Burri (2012) identified nine persuasive design principles for system development.

Persuasive learning experiences, such as being actively involved in learning, could be established with persuasive design ideas or principles applied in education [11]. A persuasive learning design framework is also explicitly developed to target changes in student attitudes toward learning technology [12]. Table I shows the persuasive elements of system design outlined under the learning design framework [13]. Each of these persuasive elements has its application design function in decision-making to produce a more compelling user experience.

### B. Persuasive Technology in Education

As the world strives for new technologies and the IR4.0 era, education must be prepared to provide content through mobile applications. Using persuasive technology in education can significantly benefit students' language learning, stress management, school safety, and other areas. An application called VocabGame was created in Arab nations using persuasive design elements to assist students in understanding word meanings and so expanding their vocabulary. Additionally, it supports educators working to enhance their country's systems for teaching and studying English as a foreign language [14].

Most students in Canada experience stress and anxiety, which is likely related to poor time management. SortOut is an application developed with seven persuasive strategies integrated as six essential elements that assist students in time management and time savings by encouraging organizational behavior [15]. Then, it may be challenging for students and teachers to enhance language learning and raise learners' motivation when English is a second language. From the 17 review frameworks for mobile education applications, the Vocabulary Game EVG prototype has been offered. It uses persuasive design elements to focus on three criteria (mobile, game, and language learning) [16].

1) *Persuasive learning*: According to Gram-Hansen (2015), persuasive learning and design can be related to facilitating the learning process by inspiring learners to engage in the learning experience and encouraging a sustainable behavior change [17]. Furthermore, through learning opportunities provided by online platforms, persuasive learning can develop an emotional bond between users and systems. Using persuasive design features in websites and applications, persuasive learning can also aid in motivating users and students to learn.

2) *Educational technology*: Educational Technology creates a way to broaden the scope of education and learning by disseminating information using online platforms. According to Voronov (2021), educational technology gives advantages to students throughout their studies, such as online learning, and needs to be in a place with a stable network [18]. Pham (2022) stated that technology is a field of study that investigates analyzing, designing, developing, implementing,

and evaluating the instructional environment and learning materials to improve teaching and learning [19].

Although utilizing educational technology can improve student decision-making in learning and teaching skills, this problem can be solved with learning technology that could change students' attitudes and increase their knowledge. Learning technology is a broad category of communication, information, and related technologies used to support the learning process, teaching, and assessment. Tools such as tutorials, simulations, productivity tools, and communication tools such as email were used as materials for students' activities. After that, to ensure that learning technology is widely implemented on websites and applications, persuasive design should be employed to assist higher education and school learner in learning things more quickly and efficiently as well as accurately decision-making in their study.

TABLE I. PERSUASIVE DESIGN PRINCIPLE (GRAM-HANSEN & SANDRA BURRI, 2012)

Principles	Description
Reduction	Reduction is a design method for reducing a process that might otherwise be difficult. For example, Shopee purchase allows users to skip many time-consuming navigations and tiresome form filling to make an immediate purchase.
Tunnelling	Tunneling is a design method in which the user is placed inside a process with a predetermined path. For example, most installation processes necessitate the completion of multiple stages by the user before the installation can be completed.
Tailoring	The degree to which a site or application offers appropriate content to users or user groups is referred to as tailoring. User demographics can be reflected in navigational options, filtering processes, and labeling systems.
Suggestion	Suggestion is a persuasion design method that involves conveying a message at the right time. For example, when Kindle suggests several books that are linked to the one you were going to purchase.
Self-monitoring	Self-monitoring is a design method that enables users to keep track of progress. For example, sites that need a login before allowing the user to track their weight reduction progress.
Surveillance	Surveillance is like self-monitoring, except the monitoring is done by the system or the system's owners, not by the user. Users of a weight-loss website, for example, may be encouraged not just by tracking their success, but also by sharing their experiences and receiving feedback from other users who are dealing with similar problems.
Conditioning	The method of incorporating emotional input into a design is known as conditioning. It is frequently presented in the form of praise and prizes, but more subtly than with Persuasive Social Actors.
Simulation	Simulation is a design method that allows users to experiment and explore in a safe, non-threatening setting. It plainly and immediately demonstrates a link between cause and effect, and it may look like a subtle form of persuasion as the user gains personal experience through the simulation.
Social Signals	Social signals are a form of the design principle that, like conditioning, incorporates emotional feedback into a design but is more direct. For example, delivering positive feedback and social support to users. Chatbots, which can be seen on websites providing advice and comments in a human-like manner, are examples of persuasive social actors.

### III. MATERIALS AND METHOD

A semi-structured interview was conducted with participants in a lab, or some were in a room free from distractions. All participants were given information about the objectives of the TemanKajianKu system and instructions to implement the think-aloud protocol throughout the interview session. There are three different tasks, the first one being the scenario task. The scenario task is divided into two different scenarios and participants need to solve all the scenarios given by using functions in the TemanKajianKu system.

There are two objectives throughout this pilot study:

- To evaluate the user experience on persuasive learning object technology (PLOT) in the TemanKajianKu system.
- To evaluate the effectiveness of persuasive design elements in a TemanKajianKu system.

Next, a total of ten questions will be asked on persuasive elements that are applied in the system. Each persuasive element will have two related questions; all participants must answer the questions through conversation. Besides that, three open-ended questions were asked about user experience when using the TemanKajianKu system. All these questions are used to study the effectiveness of persuasive design elements and users' feedback for system improvement.

A think-aloud protocol is a technique that is implemented during the interview session. A think-aloud protocol is a technique that encourages participants to share their opinions with interviewers while engaging with the product [20]. Usually, this technique was applied while doing qualitative empirical data collection. Participants verbally conveyed their opinions about the interaction experience, including their goals, justifications, and impressions of UX difficulties, to identify UX weaknesses [21]. Everything said by the user and the interviewer was documented and audio-recorded during the interview since the aim is to identify the response the user gave precisely.

#### A. Instructions and Scenarios

The first scenario asks participants to use the system sequentially following the eight steps set. Second, participants are given three types of storylines to solve to get the answers for each situation.

Table II shows all the steps for participants to follow and finish it. These are standard steps for a new user in understanding the functions and use of the system, which is from signing into the system, utilizing it, and logging out from the system. Therefore, Table III below shows three different situations for participants to solve. The situation asks the participants to use chatbots and charts to know the methods used in statistical analysis and sampling analysis.

Scenario one shows Ali, a post-graduate student who wants to use parametric analysis in his studies; participants are asked to help Ali find the appropriate statistical analysis method. Then, scenario two shows Fatimah, an undergraduate student who has just studied the subject of statistics and wants to know

about the quota sample; the participants are asked to help Fatimah find the appropriate method for sampling analysis. The last scene shows that participants are asked to find the most distant statistical analysis techniques in the diagram using chatbot help. All participants can ask questions about the scenarios if they don't understand them well.

TABLE II. LIST OF 8 STEPS FOR USERS TO USE THE SYSTEM

Step 1	Users are asked to register a new account to log into the system.
	↓
Step 2	Users are prompted to create a new project for Sampling Analysis.
	↓
Step 3	Users are asked to use the chatbot on the left side of the screen.
	↓
Step 4	The user is prompted to save the project and return to the home page.
	↓
Step 5	Users are prompted to create a new project for Statistical Analysis.
	↓
Step 6	Users are asked to use the chatbot on the left side of the screen.
	↓
Step 7	The user is prompted to save the project and return to the home page.
	↓
Step 8	Users are asked to test the edit and delete buttons.

TABLE III. LIST OF THREE SCENARIOS USERS NEED TO FINISH

Scenario	Description
Scenario 1	Ali is a postgraduate student who conducts research using analytical statistics. Ali used different 'continuous' data and means methods in his study. The study did not exceed two groups and the parametric analysis technique was the main technique used.  <u>Participant Task</u> Users are asked to use the chatbot to guide Ali to get information about parametric analysis.
Scenario 2	Fatimah is an undergraduate student who has just studied statistics. She still does not understand the information about analysis sampling. She wants to know more about the quota sample method.  <u>Participant Task</u> Users are asked to use the chatbot to guide Fatimah to get information about quota samples.
Scenario 3	The user is asked to select the most distant statistical analysis technique in the diagram and use the chatbot to get the steps to achieve the selected technique.

#### B. Questionnaires

This system implements five persuasive elements from the persuasive learning object technology (PLOT): reduction, tunneling, self-monitoring, tailoring, and social signal. Table IV shows that two questions were asked to the participants for each persuasive element used in the system to determine the effectiveness of the elements implemented. Next, three more open-ended questions were asked to get user feedback and experience in upgrading the system more efficiently.

TABLE IV. LIST OF QUESTIONS USED DURING THE INTERVIEW

Scenario	Description
Reduction	Is the TemanKajianKu system easy to use even if it is your first time using it?
	Are there any design elements in the TemanKajianKu system that are not required?
Tunneling	Does the TemanKajianKu system show you the steps to get the statistical method you need?
	Do you think the statistical method search process diagram shows easy-to-understand and accurate steps?
Self-monitoring	Does the TemanKajianKu system indicate your level of progress in obtaining the required statistical methods?
	Do you think statistical method search process diagrams help you figure out where you are right now?
Tailoring	Does the TemanKajianKu system provide the statistical methods you need?
	Do you think the use of chatbots in this system suggests a statistical method that matches your research needs?
Social Signal	Does the TemanKajianKu system use language that is easy to understand and clear?
	Does the chatbot used use positive language, complement, and give you good comments?
Open-ended Question	What do you think of this system?
	Does the system save you time and help you make decisions to find coincidental statistical analysis methods?
	Are there any other feature additions or system problems that can be updated in the system?

### C. Thematic Analysis

This section presents the results and findings from the pilot study data analysis. The data collected includes semi-structured interviews and recorded videos of users explaining their experiences with the TemanKajianKu system. We categorized transcriptions and arranged the themes of the findings based on thematic analysis after transcribing the recorded videos and interviews [22].

Clarke & Braun, (2017) defined thematic analysis as a method for analyzing qualitative data that entails searching across a data set to identify, analyze, and report repeated patterns [23]. Data familiarization was first applied by reading and re-reading the selected articles and marking early ideas or perceptions [24]. Then, coding was included in the data collection by using the Nvivo software to identify the themes. The preliminary themes were discussed and improved until the finalized themes were identified.”

### D. System Interface Design

The sign-in page for the TemanKajianKu system is seen in Fig. 1. To use the system, a user must first register a new account. Fig. 2 and 3 depict the system's dashboard, which lists two different analysis methods that users may select for their research methods, and a chart page where users can determine the most suitable strategy for the chosen analysis method from the information displayed on the page.

TemanKajianKu system applied a user-friendly design interface by implementing a suitable color theme to ensure users understand each tool or function available.

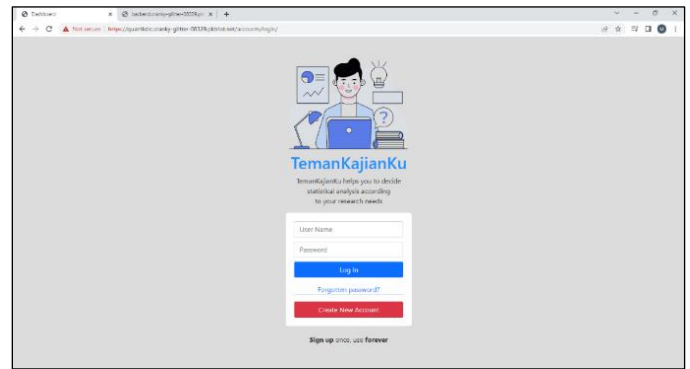


Fig. 1. Sign in page temankajianku system.

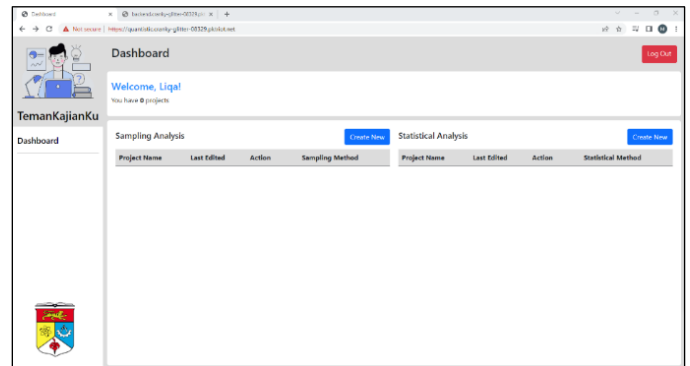


Fig. 2. Dashboard page temankajianku system.

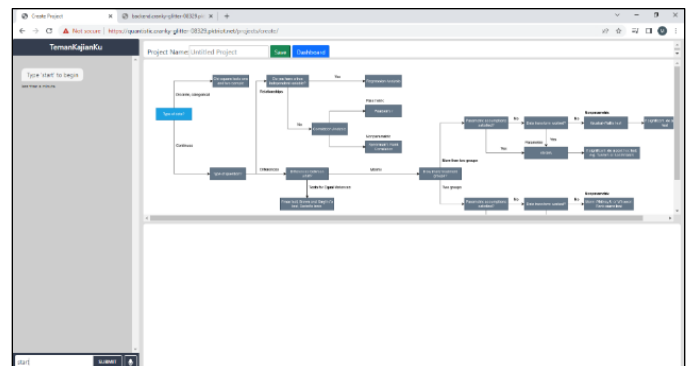


Fig. 3. Flow/chart diagram page temankajianku system.

## IV. RESULTS

In this system evaluation, 10 postgraduate students from the National University of Malaysia (UKM) with different backgrounds study were recruited as system users in this research. All system users must follow the system instructions and steps, where three different tasks must be completed by exploring the whole system. They were requested to finish the task within a maximum of 30 min using the laptop given while doing the interview.

Most of the participants were male (60%), postgraduate students (100%), and studied in the engineering field (50%). Most of the participants have learned statistics subjects (90%) and suggested platforms for online learning study. The demographic of users' information is presented in Table V.

TABLE V. DEMOGRAPHIC OF USERS' INFORMATION

Users (n=10)	n (%)
Gender	
Male	6 (60%)
Female	4 (40%)
Age	
18-20	-
20-30	8 (80%)
30-40	2 (20%)
Background study	
Undergraduate	-
Postgraduate	10 (100%)
Course study	
Engineering	5 (50%)
Health Science	1 (10%)
Science and Technology	4 (40%)
Year of Study	
1	3 (30%)
2	3 (30%)
3	1 (10%)
4	3 (30%)
Have you ever learned a statistic	
Yes	9 (90%)
No	1 (10%)
Have you ever used any online learning platform	
Yes	9
Type of platform:	Khan Academy Co space Deep learning My teams Mooc UKM Folio Netacad Coursera Domestika
No	1

A. The Effectiveness of Persuasive Element used, and User Experience based on TemanKajianKu

There are three different results of the persuasive using think-aloud experiment. First, think aloud about the result of the user using the TemanKajianKu system. Second, think-aloud results on persuasive questions that were asked during the pilot study, and third, think-aloud results on persuasive open-ended questions to know users' feedback about the TemanKajianKu system (see Fig. 4).

B. User Experience in Utilizing the TemanKajianKu

Understanding user experience is essential to understand how people think about the system from start to finish. User experience, according to Rex Hartson (2019), is the sum of the effects a user feels before, during, and following engagement with a system or product in ecology [25]. Additionally, user experience influences how interested users are in using the system long- or short-term. Three themes with eight subthemes were identified after data analysis. The themes include user-friendly, improvement of system functions and disadvantages of system tools. Based on the identified themes, the analyzed data is discussed below:

- User-friendly

The majority of users preferred to have complete access when using the system. As a result, users are free to use every

system component without needing permission. Furthermore, the system is simple to use and comprehend, making it simple for users to understand its function, how to utilize it, and obtain the required information. For example, participant 2 said, "Simple, easy to understand, the system has an easy-to-understand flow".

- Improvement of system function

The design of the system interface also contributes to users having a clear view of the system. Due to incorrect color selections, small text fonts, and displayed graph diagrams that need to be enlarged, some system components need to be visible. For example, participant 3 said, "This diagram must be enlarged a little because I cannot even read the one below. This diagram should be larger. Like below, the information cannot come out immediately because it cannot even be read". In addition, users recommend enhancing the system by including a zoom feature and a selection of system color themes.

- Disadvantages of system tools

Every system inevitably has flaws that must be fixed to increase usability. Some users of the system need clarification on the instructions and diagram provided. Based on the statement, the size and tool position of the part in the system is too close to one another and too small. Users said the systems occasionally required system instruction and were challenging to use. "It is difficult to move to the flowchart and drag the slider on the bottom page," says participant 4.

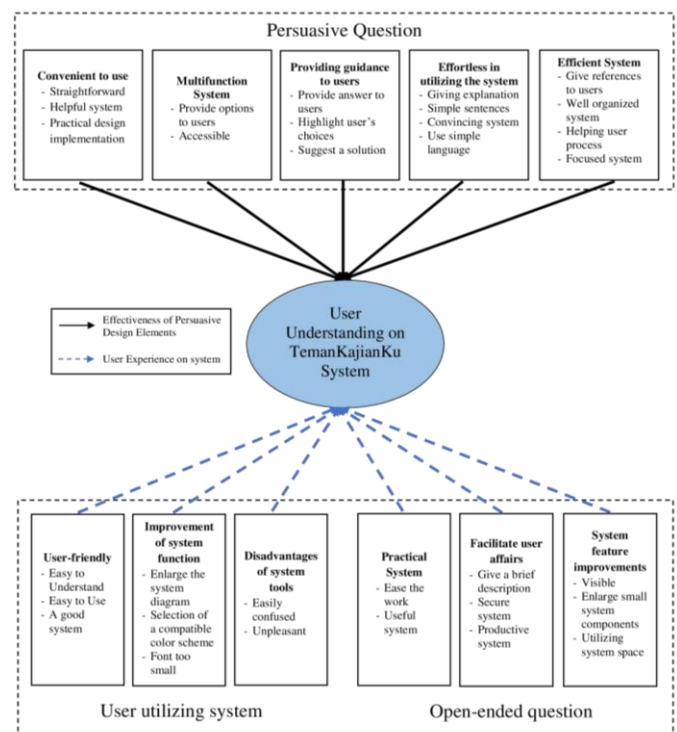


Fig. 4. User experience and the effectiveness of persuasive design implementations.

### C. User Experience based on Open-ended Question

After users had completed the persuasive questions, they were invited to answer three open-ended questions to know the user experience when using this system and give their opinions or suggestions about the TemanKajianKu system. As a result, three themes have emerged for each submitted question, which are practical systems, facilitate user affairs, and system feature improvements.

- Practical System

A practical system consists of good functions and features with various exciting elements. Based on user perceptions, this system is beneficial and makes it easier for users to achieve user goals. For example, participant 5 said: *"It is beneficial for statistical methodology, for those involved in this field, beneficial."* Participant 1 and participant 2 made a similar point.

- Facilitate user affairs

A system facilitates user affairs by saving the user time, explaining methods, and assisting the user in making decisions to locate compatible statistical analysis methods. Furthermore, a secure and productive system makes users feel more enthusiastic and safer. For example, participant 4 said, *"Yes. Because there is a definition, and it has an efficient flow chart, so time goes faster."* Other users also agreed that this system could save time and help make decisions about the statistical analysis method for their research.

- System features improvements

System features should be improved to ensure that the system is maintained and managed with better quality. There are several remarks made by users about their interactions with the systems. For instance, it may be necessary to expand small system components to be more visible. Additionally, complex features can be clarified to make them simpler to grasp, and voids in the system can be filled with fresh, more useful features. During the interview session, participant 10, said: *"I think for the flow diagram, it should be bigger than now. As for me, I can't see it clearly. For anyone short-sighted, they need to focus more to see the diagram."* Participant 7, Technology Student, makes similar thoughts.

### D. The Effectiveness of Persuasive Design Elements Used

Five persuasive elements from Persuasive Learning Object Technology (PLOT) were implemented in the TemanKajianKu system: reduction, tunneling, self-monitoring, tailoring, and social signal. Each persuasive element has a specific purpose in assisting and simplifying user system utilization. During the pilot study, the user was given a set of ten questionnaires, two of which were related to each persuasive element employed in the system. Users must answer all the questions. The interviews were recorded. 16 subthemes were created, which led to the formation of five themes. Each one of the five themes will represent each persuasive element implemented.

- Convenient to use

The first persuasive design elements approach in the system was a reduction, intending to make it simpler for users to utilize the system in line with their preferences and comfort

levels. The system is beneficial and comprehensive in providing a selection method that makes users feel easier to use and practical with the design found in the system. For example, participant 5 said, *"The system already has guidelines, and the website is also running smoothly. This diagram is also complete, it helps"*.

- Multifunction System

A design method called tunneling means inserting the user inside a process that follows a predetermined path. Users believe the system is straightforward and has an easy-to-follow flow that guides the user by displaying a simple and understandable user interface with instructions, labels, and page titles. Participant 8 gave positive feedback: *"The diagram shows the easy-to-understand steps"*.

- Efficient system

The aim of self-monitoring is a design method that enables users to keep track of progress. According to user comments, the system is simple to understand regarding the features and design that assist users in identifying the system's structure and comprehending the graph display. For example, participant 4 stated, *"Because there is a chatbot, so we don't have to worry about the flow, the flow as a reference."* Participant 2 had the same opinion, which is *"Changing the color helps, the system helps us to focus more on our purpose"*.

- Providing Guidance to Users

A website or application employs tailoring to give users or user groups the information suitable for them. According to the user, the system presents users with a choice between an option and an answer related to or applicable to their research, which can assist users in making more precise and effective decisions faster. *"The system gives suggestions. Because the system gives us a choice."* said participant 6.

- Effortless in Utilizing the System

Social signal is a design principle that combines emotional feedback into a design more directly than conditioning. This system was implemented by using clear and good language, large text, simple sentences, and color picks that correspond to the user's view. This system also helps users feel more secure in their answer options or methods through clear and comprehensive explanations. For example, participant 1 said, *"Okay, the chatbot language is very clear because it's just a short sentence"*, and participant 9 agreed, *"The chatbot boosts my confidence in making decisions. The explanation provided is simple and understandable"*.

## V. DISCUSSIONS

Generally, educational technology is a scientific and ethical practice of boosting learning and improving performance by creating, using, and managing appropriate technological processes and resources [26]. This study has developed a system based on persuasive design elements that assist students in research decision-making. The study continued by asking ten users to participate in semi-structured interviews to determine their thoughts on the system. Think-aloud protocol interviews were conducted to understand more about users' viewpoints and their benefits from using the system. This in

continuously helps to attain the study's research objectives which consist of; the effectiveness of implementing persuasive elements and user experience while using the system. This was done by utilizing thematic analysis to examine the data that had been gathered.

In this section, we will discuss two components of the findings from the conducted interviews. First, how effectively the system's persuasive design aspects work, followed by how well users experience utilizing the system. According to the first theme created by the persuasive elements' effectiveness, most users offer the system positive feedback and believe that the system's persuasive design elements can aid them in making research decisions. Because the human brain is not a rational information processor or decision-maker, persuasive information design helps influence user decision-making [27], and reduction aids in developing a more positive attitude about the behavior, [6] which persuades people to choose the best action. Next, the user identified that the system provides simple guidelines for understanding the appropriate statistical methods for research through graphs, explanations, and focusing on the objectives of the user's study. The persuasiveness of information offered by computing technology will increase if it is catered to the requirements, interests, personality, usage context, or other characteristics relevant to the individual [28]. In the process of tailoring, the relevant information is provided to the individual to meet their needs in a context unique to that instant in time [29]. After that, some users stated that the system did a great job motivating them to grasp statistical analysis using straightforward language and short, basic sentences. According to Oinas (2008), a system should use compliments expressed through words, visuals, symbols, or sounds to provide positive feedback to a user [30]. Because positive feedback might affect users' perceptions of social support [31], and by utilizing social influence, social support aims to inspire people [32], where it is employed in persuasive design elements of social signal.

Furthermore, some users have expressed dissatisfaction with the system's usability due to its functional limitations. They thought using system tools like graphs and chatbots was occasionally challenging because the system is often too confusing. Even if Lukas (2022) asserts that a user-friendly design solely focuses on making a task as simple as possible for the user to complete and does not try to change the action the user wants to accomplish, a persuasive design must be kept apart from a user-friendly design [33]. Nevertheless, persuasive design can enhance the user experience by making a website simple and engaging user by understanding psychological triggers and their behavior. Most users then claim the system's functionality and toolkit can be enhanced further. For instance, the text and graph are too small, the theme color choice is inappropriate, and more features are added to the available area. Users' feedback on system upgrades makes us more sensitive to ensuring the system is more functional and user-friendly. As a tool, the system should identify user preferences and offer solutions to problems while guiding the user through a step-by-step procedure (Fogg, 2002) because the user experience is crucial to an information system's success (Li & Samir, 2010). In addition, users described each statistical or sampling analysis result briefly, demonstrating the system's

stability in managing users' information. Fogg (2002) claimed that persuasive software could understand humans because it is more persistent than humans and employs various influencing modalities [6]. Oinas (2009) asserts that a system should appeal to its users and offer information that is accurate, impartial, and fair [28].

To the best of our knowledge, Malaysia universities should also provide additional training to improve academics' online teaching skills to ensure more successful lesson performance [34]. Concerning that, using systematic platforms or applications, such as TemanKajianku, would be a plus point in enhancing online learning. Based on the study, it can be concluded that TemanKajianKu is a system objectively developed as an online learning platform to assist students in selecting the most effective research methods. E-learning enables people to meet their educational needs through various digitally enabled services [35] and a web-based system that makes information or knowledge available to users or learners without regard to time constraints or geographic proximity [36]. In meeting this objective, this system implemented a chatbot as a user and system communication platform. One of the key tools in this system is the chatbot, which helps users find recommended methods that are appropriate for their research. Another key tool in the system is the graphs for statistical analysis or sampling analysis methods, highlighting the steps to be performed in user research. In general, it was discovered that persuasiveness has a significant role in facilitating users and is beneficial in helping users reach their desired goals in this system based on the discussion. The findings were gained through the study of system usage.

## VI. CONCLUSION

The results of this study conclude that our participants liked the TemanKajianKu system because it helped them in decision-making for statistical analysis for their research study. This system provides two different analyses, sampling, and statistical analysis, for users to choose the corresponding and appropriate method. As predicted, PLOT helps motivate, increase confidence, and engage users to achieve users' goal. Therefore, some participants said the system could be improved with more effective functions or features. Future developments of the TemanKajianKu system will emphasise the efficiency of user-system communication through the current chatbots. The present chatbot will be upgraded further to identify the objective and goals of the user research in greater depth, hoping that the system's proposed analysis approach is more suitable to the user. Additionally, it is feasible to enhance the persuasive design elements to make the system more organized, productive, inventive, and efficient. All the recommendations will be considered for the improvement of the TemanKajianKu system.

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# Real-Time Intrusion Detection of Insider Threats in Industrial Control System Workstations Through File Integrity Monitoring

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**Abstract**—Industrial control systems (ICS) play a crucial role in various industries and ensuring their security is paramount for maintaining process continuity and reliability. In ICS, the most damaging cyber-attacks often come from trusted insiders rather than external threats or malware. Insiders have the advantage of bypassing security measures and staying undetected. This research focuses on developing a real-time intrusion detection system for ICS workstations that effectively detects insider threats while prioritizing user privacy. The approach employs file integrity monitoring to identify suspicious activities, particularly file violations such as data tampering and destruction. The model presented in this research demonstrates low system resource consumption by utilizing an event-triggered approach instead of continuous polling of file data. The model leverages built-in operating system functions, eliminating the need for third-party software installation. To minimize disruptions to the ICS network, the model operates at the supervisory level within the ICS architecture. Through extensive testing, the model achieves a high level of accuracy, detecting insider intrusions with a high true positive rate. This reliable detection capability contributes to enhancing the security of ICS and mitigating the risks associated with insider threats. By implementing this real-time intrusion detection system, organizations can effectively protect their control systems while preserving user privacy.

**Keywords**—Industrial control system; insider threats; intrusion detection; file integrity monitoring; SCADA security

## I. INTRODUCTION

The industrial control system is very important for various industries in our life. As with any other system, security is now a top priority, and it must be achieved without affecting process continuity and reliability. ICS faces different kinds of threats from outside the system as well as threats from insiders. The security threat from within can be even more powerful than many external attacks [1], [2]. This is particularly the case with ICS networks, which manage critical infrastructure and manufacturing plants. A smart, motivated, perhaps disgruntled employee or ex-employee with knowledge of a plant and access to the network, can cause a variety of disruptions that may result in information breaches, financial losses, equipment damages, and even threaten human lives [3]. Industrial control systems should be very secure to ensure plant resource availability and integrity without any disturbance or production loss. The system should imply a very secure means of

protection including fast detection of insider intrusion, to avoid exploitation getting even worse.

An insider threat occurs when someone close to a company with authorized access misuses that access to harm the company's key information or systems [1]. This individual does not have to be an employee; third-party vendors, contractors, and partners may represent a threat as well. Privileged employees, such as IT team members, superusers, knowledge workers, resigned or dismissed people, and managers are all possibilities to be insiders [4].

Several recent security surveys report a high increase in insider threats. In the report [1] more than half of organizations have experienced an insider threat in the last year. Based on the survey, 74% of insider attacks have become more frequent over the last 12 months. In the report of [5], about 4700 reported attacks were subjected to analysis and it showed that 23% of attacks were attributed to malicious insiders while 63% were attributed to employee and contractor negligence. In [4] survey report The negligent insider is the root cause of most incidents that come from insider threats. According to the Kaspersky 2019 Status of industrial cybersecurity study, staff mistakes and accidental activities were responsible for 52 percent of incidents affecting operational technology (OT) and industrial control system (ICS) networks in 2018 [5]. Sometimes, unaware or negligent employees can unintentionally cause security breaches without knowledge of doing so [1]. According to a recent Ponemon Institute (2022) research sponsored by ObserveIT and IBM Insider, risks have increased in the last two years [4]. As a result, enhancing the approaches of early identification of any source of insider attack requires more security controls and solutions.

Network intrusion detection, Firewall, and antivirus systems have been shown to be ineffective to detect attacks coming from insiders. Large security operations centers have started to implement endpoint-based sensors that give their organizations broader visibility into low-level occurrences [6]. Therefore, employing techniques and tools specifically designed to address the threat of insiders will be more effective. Furthermore, these tools should consider the phenomena and requirements of the industrial system.

In the field of (ICS), applying traditional IT countermeasures and solutions blindly is not recommended due to several differences between the two environments. While IT systems prioritize confidentiality, ICS focuses on availability

as its major priority. Additionally, the expected reaction time in ICS should be below a millisecond, compared to a few seconds in IT systems [7]. Outages in ICS can have severe consequences, including production stoppage and financial losses. In ICS, security will include ensuring safety for company assets and personnel as well as the environment [8].

## II. LITERATURE REVIEW AND RELATED WORKS

Industrial control system (ICS) is a term used to describe different control systems and related instrumentation, including the devices, networks, and controls used to operate and automate industrial manufacturing processes [7]. It includes a distributed control system (DCS), supervisory control and data acquisition system (SCADA), Safety Instrumented Systems (SIS), Emergency Shutdown Systems (ESD), and programmable logic controllers (PLC) [9], [7]. They are core parts of every technical infrastructure globally, ranging from the small controller used in air conditioning in our cars and homes to the extensive control networks used in factories [10]. These factories include power production and distribution, oil and gas, chemical production, water distribution systems, and even nuclear plants[3]. These systems help control and automate industrial operations, providing remote monitoring and recording for different data and parameters on the field side.

A typical IACS design seen in any modern facility might have a DCS as the primary control system, with interfaces to additional systems such as PLCs and SCADA System. The plant data is sent to a central control room to be used for monitoring and controlling purposes [9]. These data are saved on a workstation known as the Historian to help the panel operator view historical trends. Panel operator workstations are used by plant operators to monitor the process. Besides operator workstations, Engineering Workstations are used to configure the DCS controllers and maybe the subsystems such as PLCs, as well as the associated systems such as SIS [11].

The architecture of ICS is hierarchical and has several operational levels as in Fig. 1 including Process Level, Basic Control Level, Supervisory Control Level, Process Management, and Corporate Network Levels by ISA 99 (control system automation security and safety standard) [8]. To guarantee greater security, security measures should be implemented at every level. The intrusion might have taken place at any level of this hierarchy or on multiple levels at once. Understanding the components of these levels enables more professional security measurement implementation.

The first level of the architecture is called Process Level, and it interfaces with the physical process through actuators and sensors instrumentation. The second level, known as Basic Control Level, is where the system's overall control takes place. The primary goal of the basic control level is to use controllers to regulate the physical process that interfaces with instrumentation components [8]. The supervisory level is the following level in the hierarchy. This level is in charge of interacting and gathering data from the process and control levels so that the operator workstations can monitor and view the control state and field reading of the process [8]. In this level, engineering workstations also exist which are used to access controllers setting and programs. Supervisory level

workstations have a good supply of memory and processors in comparison with two lower levels, which make them more suited to deploy a security intrusion detector than the previous two levels.

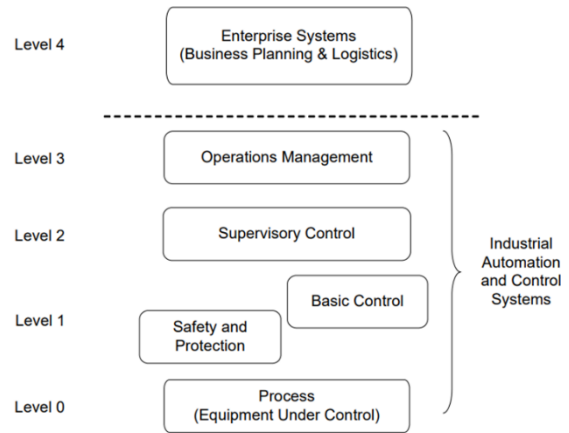


Fig. 1. Reference model for ISA99 standards.

Source: [8]

There is a lack of research and studies done on the field of ICS insiders, because of the gap between IT security researchers and operating technology [8]. In this part, we discuss the research which discusses insider intrusion detection solutions in IT system and ICS system as well. In the last few years, many ICS-oriented intrusion detection approaches have been explored in the research community. Several ICS-oriented IDS taxonomies with various categorizations are found in the literature. Some approaches attempt to detect insider threats by using machine and deep learning approaches and other approaches which depend on monitoring internal logs and system commands.

Some research on insider threat detection shows that potential insider threats can be proactively identified through psychological changes and language habits before the execution of malicious activities. These researchers argue that variations in an individual's behavior and communication patterns can serve as early warning signs of potential threats. The studies that focus on psychological changes and language habits are primarily designed to identify potential malicious insiders such as traitors. They can be very effective at detecting individuals who might be planning to intentionally harm an organization [12]. However, when it comes to negligence or unintentional insiders, these psychological and linguistic-based detection methods may not be as effective.

Another research discusses insider intrusion detection through user behavior monitoring. By monitoring user activities during using the system like login and logoff beside other activities during doing normal task and then deploying these data by using deep learning to detect insider [13]. Keystroke and mouse dynamics have a lot of information about how a user operates the host [14]. Because this type of data source contains information that can be used to identify legitimate users using behavioral biometrics, it is best suited for detecting masqueraders [15]. Although such a log may be

verbose at times due to a significant number of duplicated entries, the information contained within it may still be worth investigating. A particularly extended sequence of authentication failures, for example, may indicate a brute-force password attack [15].

In the paper [16], the authors propose a method that combines deep learning techniques with mouse biobehavioral features to detect insider threats. This approach achieves both rapid user authentication and high accuracy. The study focuses on five fundamental mouse actions: click, move, drag, stay, and scroll. These actions, along with authentication events, are used to extract features that capture the user's unique behavioral characteristics. Support Vector Machine (SVM) classification methods are then employed to categorize and analyze these features, enabling effective insider threat detection.

As per the survey of 2023 insider threats most businesses possess end-to-end user activity monitoring, which includes both access logging and automatic user behavior monitoring and is even more alarming. One big obstacle to this technology is that it violates user privacy and does not comply with the EU's general data protection law (GDPR), which leads to many businesses avoiding utilizing it [1]. The survey shows also that cybersecurity units within organizations are intensifying their employment of User Behavior Analytics (UBA) tools. These sophisticated instruments are utilized to identify, categorize, and raise alerts in response to aberrant behavior. An impressive 86% of organizations are reported to actively observe user behavior via one methodology or another [1].

Another research discusses using audit log windows detection of fraudulent behavior. The research suggests that Windows audit logs provide sufficient information to enable the reliable detection of fraudulent behavior while generating manageable data streams on endpoints. Audit logs offer a cost-effective and efficient alternative to more expensive breach detection systems that rely on agent-based approaches [6]. Another research explores the utilization of Multi-Source Logs for detecting insider behaviors. The security logs are converted into text format and compiled as a corpus. By training a model using Word2vec with the corpus, the researchers were able to approximate the posterior probabilities associated with insider behaviors. The proposed approach proves to be effective and scalable for practical applications in insider threat detection [17]. The problem with this method is detecting malware incidents that will happen after they have bypassed perimeter security layers. Audit logs, like any other endpoint software, can be modified or destroyed once malware has administrative access to the target endpoint. This issue is reduced in part because most enterprise setups store audit logs on a remote server, and the audit logs' integrity can be verified using cryptographic protocols [18].

Another research discusses creating a USB-Watch which is a Generalized Hardware Assisted Insider Threat Detection. The statement suggests that the framework utilizes hardware to capture real-time USB traffic, enabling the collection of data before advanced attackers have the opportunity to tamper with it within a compromised operating system. Additionally, the framework employs a decision tree anomaly detection

classifier, which is implemented in the hardware itself. This classifier analyses the behavioral patterns of connected USB devices, allowing for the detection of anomalous behavior [19]. However, this method is not effective with insider threats which do not need USB connections.

A new research focuses on the proactive detection of insider threats through the application of graph learning and psychological context [20]. The MEWRGNN utilizes graph neural networks to capture the contextual relationship of user behaviors and achieve accurate anomaly identification. It ranks the contribution of different edge-representation features, providing interpretability and understandable insights for security analysts. Experimental results show that the MEWRGNN can learn from limited sample data sets and achieve quick and accurate insider threat detection [20].

There are many researches which try to implement machine learning in intrusion detection such as in [21], [22]. With respect to ICS, studies based on machine learning normally faced the difficulty of finding a real dataset from an industrial control system. The industrial company always tries to reveal any data related to industrial control as a kind of security [23]. In our research, our objective was to create a model that does not rely on machine learning but rather utilizes signature-based anomaly detection, primarily functioning at the host side. This model is designed to operate independently of the operating system security logs file. Our focus is specifically on detecting unauthorized changes that occur in the monitored files.

In our model, we will try to utilize an important point related to industrial workstations which is: these workstations will be provided by a system vendor with the required installed software. The vendor will ensure its security configuration and hardness. It is not allowed to install new software or change configuration filled by any unauthorized person [24]. Many application software activities depend on the configuration which is stored on known paths and directories. Any change in working application configuration will affect the working of related services and could have a bad effect on some process working set points or on the panel operators monitoring screens. Determining the underlying cause of the intrusion or any file system problem is critical, but manual analysis extends the time it takes to resolve threats [25]. Finding a model which can detect any changes for these files on any one of the operator and engineer workstations will help to detect if there are some suspicious activities from an insider.

There are Many Files Integrity Monitoring (FIM) tools available today developed by private companies in response to these industry needs. Some examples include Tripwire [26], Samhain [27], and OSSEC [28]. FIM tools can help in detecting file integrity intrusions in monitored host computers [29]. These tools continuously monitor the file system for changes, including changes to file attributes, content, and timestamps. They can generate alerts when unauthorized or unexpected modifications occur [30], [26].

Monitoring file integrity in ICS environments can be challenging due to the unique requirements and constraints of these systems. For example, ICS often use specialized hardware and software that may not be compatible with standard FIM tools. Additionally, ICS typically have strict

performance requirements, making it important to minimize the performance impact of monitoring activities [31]. FIM solution has its own drawbacks and issues such as Delays in detection, and Complex deployment. Current FITs work off-line pattern which means these tools will monitor the files at scheduled times to check the integrity of the system. Delay in detection is the biggest issue because this will create an opportunity for the intruder to take advantage of the system [30].

One of the main challenges when building a FIM is real-time detection, which should have minimal performance overhead to ensure it can be used effectively in real production environments. High-performance overhead can cause system slowdowns, reduced productivity, and user frustration, which could lead to the tool being disabled or ignored [30]. Implementing a FIM in an ICS poses specific challenges due to the constraints of computing resources and the need for continuous system operation. The installation of third-party software may also introduce compatibility issues and potentially disrupt the system's functionality. Therefore, it is crucial to carefully evaluate and minimize any adverse effects on system performance during the implementation of any intrusion detection tools.

A good File Integrity Tracking (FIT) tool should collect comprehensive information about file changes, enabling administrators to make informed decisions and use the tool effectively. Detailed information can help identify the root cause of an issue, track unauthorized changes, and mitigate potential security risks. In the process of selecting files for monitoring, priority should be given to those that are integral to your system and applications. Emphasis should be placed on files that are not anticipated to undergo changes without premeditated scheduling. Opting to monitor files that are frequently altered by applications or the operating system, such as log files and text files, could generate a surplus of data, subsequently obscuring the identification of a potential attack [32].

### III. RESEARCH METHODOLOGY

We propose an intrusion detection approach that centers around the automated identification of unauthorized alterations in Monitored File lists. These modifications may occur intentionally or unintentionally, involving employees or contractors, and can stem from both legitimate and malicious intents. Whether resulting from human actions or software interventions, any such changes are regarded as potential security concerns. To address this, our model generates alerts to promptly designated personnel to review and assess these alterations for suspicious activity.

The supervisory level In ICS architecture is the best place to implement the Intrusion detection model. This is the primary level of interest in our research. At this level, operational operators and engineers interact with physical system programming and configuration. This study aims to improve the detection of intrusions at the level of operator and engineering workstations. The other higher layers are often managed by IT and should be kept separate from the ICS system. This isolation is already accomplished with a hardware firewall and DMZ, or with a data diode.

At the supervisory level, the operators' and engineers' workstations and servers existed [8]. These workstations are equipped with a group of certain software and tools which are already provided by the system vendors. A limited number of services should be working with a minimum number of listening open ports [8]. Many working software depends on configuration files to define their working environment as well as their responses. In addition to that, many system engineers depend on written text file scripts to automate daily tasks with the help of operating system task schedules. Improving a technique to monitor the integrity of these files and services and providing a mechanism to notify the right people in case of suspicious changes, and providing data to help cybersecurity teams take the best possible course of action is very important. Such tools will contribute to enhancing and maximizing the ability to stop incidents from occurring or getting worse. The data collected by this model will provide a good data source for other troubleshooting activities in case of a security incident happening, because it will save a history record for the monitored file and the changes that happened to them.

The following flowchart in Fig. 2 describes how the philosophy of the model works to detect any malicious activities on monitored files. The initial phase of our methodology involves establishing a baseline by creating a comprehensive list of crucial files that need to be monitored for potential malicious alterations in the targeted industrial workstations. This process requires identifying the critical systems and software applications operating on these workstations, as compromising them could have significant operational consequences. When selecting which files to monitor, it is important to consider the files that are vital for the proper functioning of the system and applications. These are the files that you expect to remain unchanged unless planned modifications are made. On the other hand, monitoring files that are frequently changed by applications or the operating system, such as log files, can introduce unnecessary noise and make it more challenging to detect an actual attack.

When selecting files related to industrial control systems, it is important to include operational and configuration files of the main component such as SCADA software, PLC programming tools, and other specialized applications. To effectively understand the critical components of the system and the primary software, a thorough examination of the OT system vendor's documentation is necessary. This documentation provides insights into the system's architecture and the essential software components, including vital configuration files, and data files that are crucial for the system's proper functionality. To gain further insights, engaging with system administrators, operators, and other experts within the organization is highly valuable. These individuals possess specialized knowledge and experience with the system, allowing them to provide valuable input on the most crucial files that should be included in the monitored list.

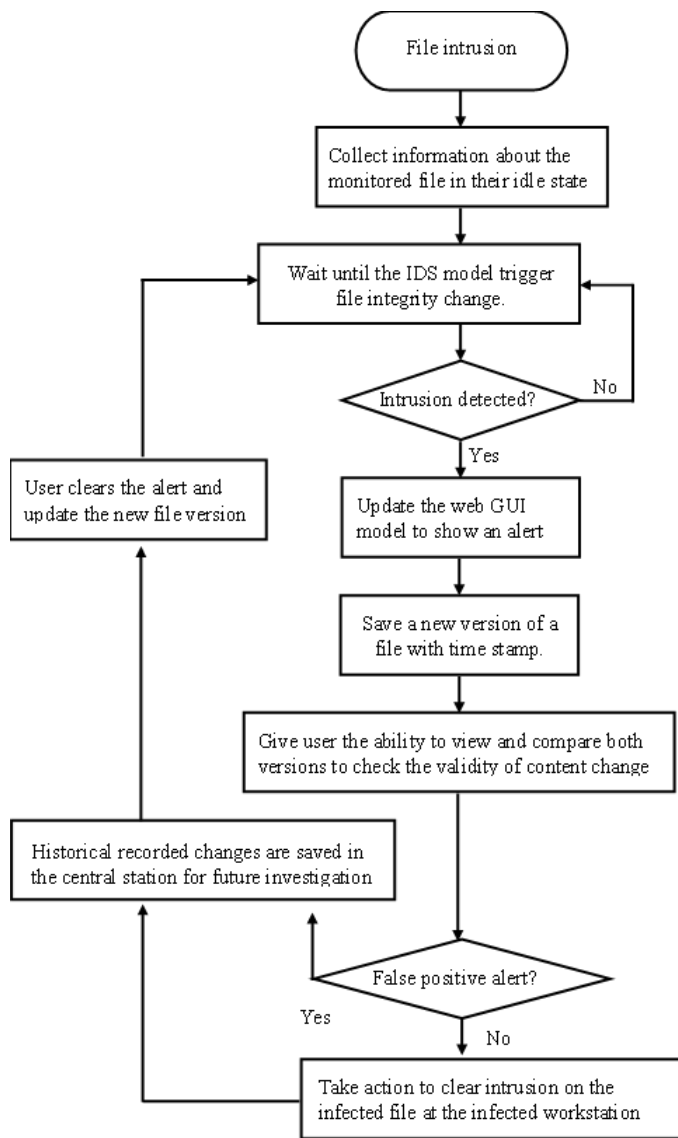


Fig. 2. Flowchart describes the methodology.

Various types of data can be collected for files to monitor their integrity and detect potential malicious activities. Some of these data attributes encompass file metadata such as filename, file path, file size, file extension, file permissions, file owner, file attributes, file content hash, and file timestamps. While the date-modified timestamp is a valuable data attribute for detecting file changes, its reliability can be compromised due to timestamp tampering. Timestamps can be effortlessly manipulated or spoofed, enabling an attacker to alter the timestamp following modifications to conceal their activities. Consequently, timestamps alone become an unreliable source for detecting unauthorized changes. To address this issue, file content hashes can be employed in conjunction with timestamps. A file content hash is a unique, fixed-length string generated from a file's contents using a cryptographic hash function. This hash functions as a digital fingerprint of the file, facilitating the effortless identification and verification of the file's contents. Cryptographic hash functions, such as SHA-256, SHA-1, or MD5, accept an input (in this instance, the file

contents) and generate a fixed-length hash value. Moreover, a file content snapshot of the monitored value can be stored in a secure location, which can be utilized in the event of intrusion detection to revert to a healthy condition. A file content snapshot is a copy or representation of the file's content at a specific moment in time, which can be employed for comparison with subsequent versions of the file.

The focus of the model developed in this research is on insider attacks involving file content changes or file deletions within industrial control systems (ICS). These attacks encompass several categories, including data tampering, data destruction, unauthorized access with modification, malicious code injection, accidental data modification, negligence, and accidental file deletion. Data tampering refers to the deliberate alteration of critical ICS configuration files, program files, or databases by insiders with the intent of manipulating process data or creating falsified records. Data destruction involves insiders intentionally deleting or corrupting critical ICS files or backups. Unauthorized access with modification occurs when insiders misuse their legitimate access credentials to gain unauthorized entry to sensitive ICS files or systems and then make unauthorized changes to the content. Malicious code injection involves insiders introducing malicious code or scripts into ICS files where this malicious code is designed to compromise the system, extract sensitive process data, or disrupt industrial operations. Accidental data modification can occur when insiders inadvertently modify the content of ICS files due to human error or a misunderstanding of the system or processes; these unintentional modifications can have adverse effects on process control, safety systems, or data integrity. Accidental file deletion refers to instances where insiders unintentionally delete important ICS files, resulting in data loss or disruptions in industrial processes. By focusing on these various types of insider attacks involving file content changes or file deletions, the model aims to enhance the detection and mitigation of such threats within industrial control systems, thereby improving overall system security and integrity.

To ascertain the efficacy of our model, we conducted tests in an environment that mirrored the workgroup network for workstations at the supervisory level. This was achieved either by creating a small, real local network or constructing a virtual network using VMware Workstation virtual machines. In this research, we utilized a group of workstations operating on the Windows operating system.

For the real-time testing of the intrusion detection system model in a Windows OS environment, we employed the Register-ObjectEvent cmdlet in PowerShell. The Register-ObjectEvent cmdlet is designed to monitor events on .NET objects with minimal system resource usage. It employs an event-driven model, triggering an action when a specified event transpires, as opposed to continuous polling for changes, which can be more resource-intensive. Despite the comparatively low resource usage of the Register-ObjectEvent cmdlet, especially when contrasted with continuous polling methods, it is crucial to manage event subscriptions meticulously and unregister them when no longer required, to avert unnecessary resource consumption.



To illustrate the operation of our model, we predefined a list of files requiring monitoring. Initially, the model collects data such as the last modified time and file content hash value of these files, storing this information in a remote station. This data serves to confirm file integrity violations in case of intrusion detection and is preserved for subsequent incident investigation. To gauge the model's effectiveness, we devised a comprehensive list of 100 potential scenarios that could compromise file integrity and observed the model's capacity for intrusion detection. These scenarios encompass all conceivable insider threats, whether originating from employees or contractors, and whether they are intentional or unintentional. Concurrently, we recorded the model's response to these scenarios to measure its performance. In the event of intrusion detection, the data is transmitted to a remote station that maintains a database to record file information and the history of recorded attacks. This station also manages the display of alarms in a Graphical User Interface (GUI) form. This GUI can be accessed from any network station using a standard web browser.

#### IV. RESULT AND DISCUSSION

After conducting 100 simulated insider intrusion scenarios targeting file integrity violations, the model demonstrated a high true positive score, as depicted in Table I. These results indicate its high sensitivity in detecting this type of intrusion. This outcome aligns with expectations within the context of industrial control system workstations, where configuration files should be modified under a management of change (MoC) process, thereby minimizing the risks associated with these changes. Any modification outside of the MoC will be detected.

On occasion, the model might flag false positives. However, this is an expected occurrence, as these false alarms may be generated during an authorized modification of any of the monitored files. In the context of industrial control systems, alterations to any configuration file or settings are ideally conducted within a structured (MoC) process. Consequently, the occurrence of such false alarms is anticipated. Moreover, the model possesses the ability to enter a state of inhibition during approved changes, thus preventing the triggering of unnecessary alarms. Significantly, the model reported a rarely false-negative rate. This result is consistent with the operational characteristics of the model, which is designed to raise an alarm whenever there is a change or deletion in the file content. In all other instances, the model remains inactive, thus ensuring no false negatives are reported.

By analyzing the results of the model test, it can be observed from the data presented in Table I that the model demonstrates a notable level of efficiency and precision when it comes to detecting alterations in file content. The percentage of true positive detections is significantly high, indicating the model's ability to accurately identify instances of insider intrusion in real-time. However, it is important to note that there were occasional occurrences of false positives during the testing phase. Despite this, the model's overall performance remains strong, highlighting its capability to effectively identify unauthorized changes in file content and mitigate the risk of insider threats. This successful detection and prompt

response contribute to enhancing the overall security of the system.

TABLE I. INTRUSION DETECTION PERFORMANCE

Scenario	Actual Intrusion	Model Detection	Result
Scenario 1	Yes	Yes	True Positive
Scenario 2	Yes	Yes	True Positive
Scenario 3	Yes	Yes	True Positive
.....	Yes	Yes	True Positive
Scenario 99	Yes	Yes	True Positive
Scenario 100	No	Yes	False Positive

By focusing on file integrity monitoring, the model avoids the need to scrutinize user behavior, offering a distinct advantage for organizations that prioritize privacy. This approach ensures that employees' personal habits and actions remain confidential while still effectively safeguarding the system. This respect for privacy, combined with robust intrusion detection, supports a balance between security and individual privacy rights, aligning with best practices for ethical workplace monitoring. Therefore, this model possesses an advantage over other research approaches that rely solely on monitoring user behavior and actions.

In the initial phase of the methodology, identifying the files to be monitored in their optimal state allows for the establishment of a signature-based detection approach specific to those files. The model can readily detect intrusions by identifying deviations from the expected state of the files, without the need for implementing machine learning algorithms. Therefore, this approach offers the advantage of effective intrusion detection with low false positive rates, in contrast to research that relies on anomaly algorithms and data training. However, it is important to note that the model may encounter challenges in detecting new or unknown attacks that do not match any existing signatures, as well as attacks that do not involve file content violations. In the context of machine learning research, acquiring specialized datasets for (ICS) also poses significant challenges due to the complexities involved in accessing data from industrial environments. These challenges are primarily driven by security concerns, which restrict the availability and sharing of such datasets.

The model works based on an event-driven approach. This means it only springs into action when a specific event - in this case, a change to a file - occurs. This is different from a continuous polling approach where the system would constantly check the files for changes. The benefit of the event-driven response model is its remarkable efficiency in utilizing system resources, while also enabling real-time detection of intrusions as they occur. There's no need to wait for the next round of checks or polling cycle. As soon as a file changes, the model knows about it and can respond immediately. This real-time detection is crucial for catching and responding to intrusions as quickly as possible.

Leveraging the inherent capabilities of the PowerShell Register-ObjectEvent cmdlet, the model confines its operation

to the monitored workstation, thus eliminating the need for the installation of additional third-party software. The model's avoidance of third-party software installation is indeed a substantial advantage, particularly given the specific needs and constraints of industrial control systems. The introduction of third-party systems can lead to compatibility issues with existing software and configurations. Typically, the installation of any new software on industrial workstations requires explicit vendor permissions, thus adding another layer of complexity. Moreover, the introduction of new software necessitates the implementation of patching and updating plans, potentially imposing additional burdens on maintenance operations. Hence, a model that operates effectively without the need for additional software installations alleviates these potential challenges, thereby enhancing the model's applicability and ease of use in an industrial control system environment.

Storing file information and the history of file changes in a remote station negates the need to use the local storage of the workstation under normal conditions. The storage of file modification time and file hash value in a remote station enhances security by mitigating the risk of file metadata tampering by an attacker. The secure remote storage of file information enhances accessibility, enabling the review of history from any network station. This feature simplifies the investigation of file event history in the event of incident response following attack detection. Moreover, the storage of file content snapshots effectively supports system continuity by facilitating the restoration of files to a healthy condition.

The decision to implement the intrusion detection model at the supervisory level of the Industrial Control System (ICS) architecture offers numerous benefits. This level, in contrast to the control and field levels beneath it, has an abundance of system resources. Crucially, the operation of the model at this level does not burden the bandwidth of the control and field-level networks, which are known for their resource limitations. Further, the supervisory level is uniquely positioned as the sole access point to both the control and field levels. These lower levels are particularly sensitive to disruptions due to their resource limitations, and any interference could lead to significant production process impacts. By placing the intrusion detection model at the supervisory level, we ensure minimal intrusion, optimal use of resources, and maintain the integrity of the lower levels, safeguarding the overall production process.

## V. CONCLUSION

The implementation of file integrity monitoring has proven to be a highly effective and accurate method for detecting insider intrusion involving file violations in control system workstations. These violations include data tampering, data destruction, unauthorized modifications, malicious code injection, accidental data modifications, negligence, and accidental file deletion. The model also facilitates the detection of other types of attacks that involve file content alteration, such as ransomware and remote code execution. The detection process is performed without the necessity of monitoring user behavior and actions, thereby upholding user privacy.

While the model examined in this research demonstrates its efficacy in detecting insider threats related to file integrity violations, it does not possess the capability to identify other forms of insider threats that do not involve modifications to file content, such as Intellectual Property Theft and Unauthorized Data Access. Exploring and addressing these additional categories of insider threats could serve as a promising area for future research. Another crucial aspect to consider is that the model solely focuses on detecting intrusions and does not possess the capability to independently prevent their consequences. Therefore, to achieve maximum effectiveness, it is essential to seamlessly integrate a file integrity monitoring strategy with an organization's incident response plan. This integration ensures that timely and appropriate measures are taken to mitigate the impact of file integrity intrusions, thereby preventing further unwanted consequences.

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# Clustering Based on Gray Wolf Optimization Algorithm for Internet of Things over Wireless Nodes

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**Abstract**—The Internet of Things (IoT) creates an environment where things are permitted to act, hear, listen, and talk. IoT devices encompass a wide range of objects, from basic sensors to intelligent devices, capable of exchanging information with or without human intervention. However, the integration of wireless nodes in IoT systems brings about both advantages and challenges. While wireless connectivity enhances system functionality, it also introduces constraints on resources, including power consumption, memory, and CPU processing capacity. Among these limitations, energy consumption emerges as a critical challenge. To address these challenges, metaheuristic algorithms have been widely employed to optimize routing patterns in IoT networks. This paper proposes a novel clustering strategy based on the Gray Wolf Optimization (GWO) algorithm. The GWO-based clustering approach aims to achieve energy efficiency and improve overall network performance. Experimental results demonstrate significant improvements in key performance metrics. Specifically, the proposed strategy achieves up to a 14% reduction in energy consumption, a 34% decrease in end-to-end delay, and a 10% increase in packet delivery rate compared to existing approaches. The findings of this research contribute to the advancement of energy-efficient and high-performance IoT networks. The utilization of the GWO algorithm for clustering enhances the network's ability to conserve energy, reduce latency, and improve the delivery of data packets. These outcomes highlight the effectiveness and potential of the proposed approach in addressing resource limitations and optimizing performance in IoT environments.

**Keywords**—Internet of things; energy consumption; clustering; optimization; gray wolf optimization

## I. INTRODUCTION

As technological advances advance, instruments and objects in our environment can exchange data through technologies such as Radio-Frequency Identification (RFID) and Wireless Sensor Networks (WSNs) [1, 2]. The emergence of wireless communication and seamless integration of different technologies between devices has resulted in the concept of the Internet of Things (IoT) that facilitates data exchange among a variety of items and their associated things over a network protocol or standard at any time [3-5]. All IoT devices and things are assigned unique IP addresses. The devices can be configured to sense and collect raw data from the physical environment to process it and make decisions [6]. The integration of Blockchain [7], humanitarian logistics [8], cloud computing [9], machine learning [10-14], and artificial intelligence [15, 16] within the IoT ecosystem plays a crucial role in enabling secure and efficient data exchange, optimizing resource allocation, improving decision-making processes,

and enhancing overall system resilience, making it a transformative force in various domains such as healthcare, transportation, energy management, and disaster response.

In such energy-constrained networks, clustering has proven to be an effective method of designing energy-efficient routing algorithms [17, 18]. This method groups the nodes together in clusters. Each cluster is headed by a Cluster Head (CH) whose responsibility is to gather the data of its members. Clustering can provide scalability, conserve bandwidth, and reduce the routing problem among all sensors [19]. The CHs are responsible for relaying the data to the sink node, thus reducing the total number of hops needed [20]. This way, the energy consumed by relaying data is reduced since the nodes only need to relay data over short distances. Furthermore, clustering helps in balancing the load on the network, which in turn improves the network performance. Moreover, clustering ensures efficient data aggregation, which further minimizes the amount of data that needs to be transmitted to the sink node. The result is an efficient use of the available resources and a better overall experience for all participants [21].

Clustering approaches currently available are primarily time-based. A clustering approach can be static, dynamic, or hybrid. Static clustering is used when the data points and clusters can be defined ahead of time and do not change over time. Dynamic clustering automatically adjusts the clusters as the data points change [22]. Hybrid clustering combines the two approaches, using static clustering to define the initial clusters and then dynamic clustering to adjust them over time. There is minimal overhead associated with a static performance network, and it is stable for a short period of time. Although dynamic performance increases the lifetime of a network, it has a high overhead cost. Hybrid clustering allows for a more flexible approach to clustering, as the clusters can be adjusted over time without having to start from scratch. This helps to reduce the computational overhead associated with clustering, as well as the time it takes to create an optimized clustering solution [17].

## II. RELATED WORKS

A mechanism is proposed by Said [23] for dividing the IoT environment into various zones based on the characteristics of the network. Afterward, the ACO algorithm is applied to the areas in order to resolve the routing problem. It is evident from the results of NS2 that the proposed routing algorithm meets the target energy consumption, packet loss rate, latency, bandwidth consumption, and overhead criteria. By using the genetic algorithm, Fouladlou and Khademzadeh [20] developed an effective routing approach and extended the

lifetime of a network by clustering IoT objects. Several experiments have shown that the proposed scheme performs better than IEEE 802.15.4 in terms of transmission rate, energy consumption, delay, and bit error rate.

Mohseni, et al. [24] proposed a cluster-based routing strategy in the IoT by combining the fuzzy logic system and the Capuchin search algorithm, called CEDAR. It involves two stages, namely the clustering process and intra- and extra-cluster routing. This strategy significantly cuts energy consumption by IoT devices through clustering the nodes in the network, and each cluster is responsible for routing the packets of the nodes in its own cluster. Additionally, the fuzzy logic system allows the nodes to adapt to the changing network conditions, and the Capuchin search algorithm ensures that the packets are routed in the most efficient way. Simulation results reveal that CEDAR is superior to comparative approaches regarding energy consumption, delay, and network lifetime. An optimized routing strategy based on neuro-fuzzy rules has been proposed by Thangaramya, et al. [25]. The results of the experiments conducted in this study demonstrate that the modeled routing protocol performs well in terms of network lifespan, latency, delivery rate, and energy consumption.

Geetha, et al. [26] propose a new energy-aware future load prediction and cluster communication strategy for IoT networks. It determines an optimal number of CHs and forecasts the incoming load on the network. It comprises two main phases: clustering with the satin bowerbird algorithm and load estimation using deep random vector functional link networks. A comprehensive analysis of the results and discussion indicates that the proposed method of regulating renewable energy usage in IoT networks is extremely effective.

Lakshmana, et al. [27] introduced a novel cluster-based IoT routing protocol. The objective of this design is to ensure optimal energy utilization and network lifetime. This is achieved by developing an enhanced Archimedes optimization algorithm-driven clustering approach to facilitate the selection of CHs and establishing cluster structures. The suitability function takes into account the number of hops that the data must take to reach its destination, how far apart the nodes are from each other, and the amount of energy consumed. The teaching-learning-based optimization algorithm then uses this information to determine the best route for the data to take. As a result, the network is more efficient and reliable, leading to improved performance.

### III. PROPOSED METHOD

The proposed method divides a network's lifespan into multiple cycles. It operates under two distinct stages, namely, initialization and stabilization. During the initialization stage, the base station collects location and energy information about nodes and determines CHs based on this information and the Gray Wolf Optimization (GWO) algorithm. Data collected by the cluster heads are sent to the base station during the steady state phase. In the proposed method, to conserve energy, the initialization stage is performed when the current cluster heads are close to death. This process eliminates the need to send and receive control packets during the setup phase, reducing

energy consumption. The proposed method is illustrated in Fig. 1.

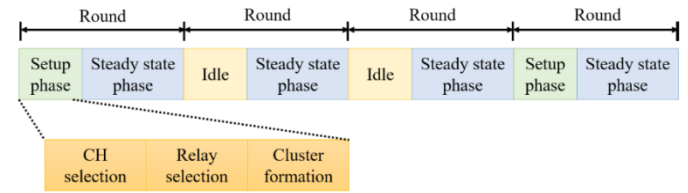


Fig. 1. The process of the proposed method.

#### A. Cluster Head Selection

In this subsection, the clustering problem is modeled as an optimization problem, and an optimization algorithm is employed to select cluster heads. A parameter called dead time ( $T_D$ ) is defined for each node. The number represents the maximum number of iterations a node may survive, given its role in the network and its remaining energy. This definition can be formulated as Eq. (1), in which  $E_r(i)$  stands for energy remaining on node  $i$ , and  $E_c(i)$  denotes the amount of energy consumed by a given node per iteration.

$$T_D(i) = \frac{E_r(i)}{E_c(i)} \quad (1)$$

$T_D$  values differ between nodes based on the solution. Maximizing the average  $T_D$  between all nodes is the most effective solution. As an optimization problem, this definition can be expressed as follows:

$$\text{maximize } f = \text{avg}(T_D) = \frac{1}{|\text{nodes}|} \sum_{i \in \text{nodes}} T_D(i) \quad (2)$$

which presupposes the following assumptions:

$$Er(CH_j) > \frac{1}{|\text{nodes}|} \sum_{i \in \text{nodes}} E(i), 0 < j \leq m \quad (3)$$

The above condition states that the residual energy of all cluster heads should surpass the average energy of all nodes. This is necessary to ensure that the cluster heads have enough energy to effectively manage the clusters and maintain effective communication between the cluster heads and the other nodes in the network. The death time for each node in the network is determined according to the role of that node in the network. This calculation excludes the energy spent on sensing and data processing since these activities are negligible compared to communication. The energy consumption of each normal node is calculated by Eq. (4). This calculation does not include the energy associated with the exchange of control packets since our goal is to determine the maximum number of cycles a node may survive before re-clustering.

$$E_c^{member}(i) = E_{Tx}(L, \text{dis}(i, CH_i)) \quad (4)$$

In Eq. (4),  $ch_i$  is the cluster head of node  $i$ ,  $\text{dis}(i, j)$  indicates the distance between two nodes,  $L$  specifies the size of the data packet in bits, and  $E_{Tx}$  represents the transmission energy. The amount of energy consumed by a cluster head is calculated by Eq. (5).

$$E_c^{CH}(j) = E_{RX}(L \times CM_j) + E_{DA} \times L \times (CM_j + 1) + E_{TX}(L, dis(j, next(j))) \quad (5)$$

In Eq. (5),  $E_{RX}$  refers to the energy consumed for receiving a packet,  $CM_j$  is the number of cluster nodes,  $E_{DA}$  is the required energy for data aggregation per bit, and next represents the next hop, which can be another node or the base station. Some cluster heads may act as a relay for another cluster head. The energy consumption for relaying data by relay node is given by Eq. (6).

$$E_c^{relay}(r) = E_{RX}(L) + E_{TX}(L, dis(r, BS)) \quad (6)$$

The proposed method finds an optimal solution to this problem using the gray wolf optimization algorithm. This algorithm is described in detail in the following section.

### B. Selection of Relay Nodes

To avoid the rapid exhaustion of the energy source of cluster heads far from the base station, each cluster head is assigned a relay node, which is used by only one cluster head at a time. Therefore, several cluster heads lack relays and transmit data to the base station in a direct manner. To assign relays to the cluster heads, we choose a suitable relay for each cluster head, from the farthest cluster head to the central station to the closest cluster head to the central station. The desired goals in choosing the cluster head are to minimize the total energy consumption and create the greatest balance between the energy consumption of the cluster head and the relay. Fig. 2 shows the central station, a cluster head, and a hypothetical relay.

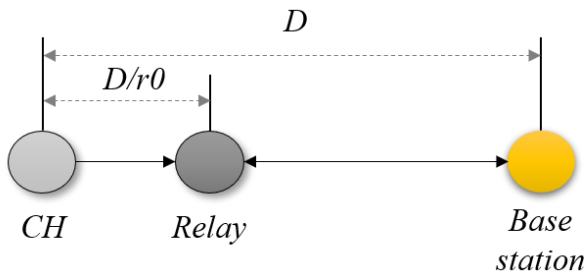


Fig. 2. Process of relay nodes selection.

It can be proved that there is a specific and fixed value for  $r_0$  to guarantee the lowest energy consumption and the greatest balance between the energy consumption of the cluster head and the relay. Furthermore, a private point exists on the line segment linking the cluster head and the base station that serves as the optimal relay point. The calculated value for  $r_0$  is 1.8. To select a relay for each cluster head, first, according to the value of  $r_0$ , the best point for the relay, located on the segment of the line between the cluster head and the central station, is calculated. The nearest cluster head, not previously selected as a relay, is calculated as the desired cluster head relay is chosen. Also, when no relays are located within a threshold of the desired point, the cluster head sends messages immediately to the base station. This process is advantageous in several ways:

- It significantly reduces the energy used to transmit packages to the base station.

- It minimizes the problem of being spot-hot. This is because the balance of energy consumption between the cluster head and the relay is guaranteed, and different relays are selected periodically.
- The relay is selected for the maximum possible number of cluster heads.

An example of the result of this process to select relays is shown in Fig. 3. There are 100 cluster heads in this network, and the base station is in the middle. Notably, some cluster heads do not have relays; these cluster heads are displayed as crosses without lines.

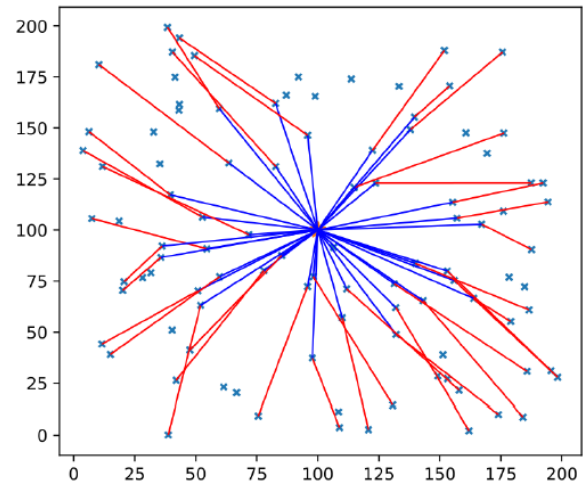


Fig. 3. An example of assigning relays to CHs.

### C. Formation of Clusters

During the initialization stage, the nodes send a node-MSG message to the central station. This message contains the remaining energy and the location of the node. This information is needed for clustering by the base station. In the next step, the base station selects the cluster heads using the presented method based on the gray wolf optimizer that leads to the maximization of the fitted function given in Eq. (2). Then the base station sends a broadcast message that contains the ID of the selected cluster heads and the corresponding relays. After the cluster heads receive this message and realize their selection as the cluster head, each cluster head broadcasts a CH-ADV message to introduce itself to the network. The remaining nodes choose a nearby cluster head based on the strength of the received CH-ADV signals and transmit a Join-MSG message. Relays also broadcast the Relay-ADV message to the network. At this stage, since each cluster head already has its relay ID, it waits for the Relay-ADV sent by its relay and sends an RJoin-MSG message in response. After completing these steps, all nodes will be aware of their role in the network, and the network will enter the stabilization stage. The initialization stage will not be performed unless one of the nodes has consumed 50% of its energy since the last initialization stage.

### D. Clustering with GWO Algorithm

In the proposed method, the gray wolf optimizer is used to maximize the fitting function shown in Eq. (2). For this purpose. Each solution should be displayed as a



multidimensional vector. In other words, because the wolves represent the solutions in the gray wolf optimizer and have a multi-dimensional position vector, then the clustering solutions should be displayed as multi-dimensional vectors. To perform this mapping, we consider a vector with the number of dimensions expressed as the number of network nodes. Each dimension of this vector indicates the chance of a node becoming the cluster head. To select the heads of the clusters, a predetermined number of nodes with the highest chance value in the alpha wolf position vector are selected as the heads of the cluster. Then every ninety members of the nearest cluster head are considered, and the relays of the cluster heads are also selected according to the presented method.

Assumption 1: A suitable value of  $r_0$  to minimize energy consumption is the value of  $\frac{1}{\sqrt[3]{2}} + 1 \approx 1.793$ .

Proof: According to the scenario depicted in Fig. 2, the amount of energy consumed by the cluster head is obtained from the following equation:

$$E_{dual-hop}^{CH} = E_{TX}\left(L, \frac{D}{r_0}\right) \quad (7)$$

which corresponds to the energy required to send a packet of length  $L$  bits to the distance  $r_0 D$ . The amount of energy consumed by the relay is also obtained from Eq. (8), which represents the transmission of two packets, each with a length of  $L$ , from the relay to the base station. As a result, the total energy consumption is calculated by Eq. (9).

$$E_{dual-hop}^{relay} = 2 \times E_{TX}\left(L, \left(D - \frac{D}{r_0}\right)\right) \quad (8)$$

$$E_{dual-hop}^{total} = E_{TX}\left(L, \frac{D}{r_0}\right) + 2 \times E_{TX}\left(L, \left(D - \frac{D}{r_0}\right)\right) \quad (9)$$

In order to achieve the lowest amount of energy consumption, Eq. (9) should be minimized. Assuming that the extra-cluster connections follow the fading multipath model, by expanding the above relation using Eq. (1), we reach Eq. (10), which can be written as Eq. (11). Here because  $L$ ,  $E_{mp}$  and  $E_{elec}$  are constant values, it can be said that to minimize the above expression, it is enough to minimize the expression 12. In addition, since  $D$  is also a constant and non-zero value, the function  $h1$  is minimized when the function  $h2$  is minimized.

$$E_{dual-hop}^{total} = L \times \left( E_{mp} \times \left( \left( \frac{D}{r_0} \right)^4 + 2 \times \left( D - \frac{D}{r_0} \right)^4 \right) + E_{elec} \right) \quad (10)$$

$$E_{dual-hop}^{total} = L \times \left( E_{mp} \times \left( \left( \frac{D}{r_0} \right)^4 + 2 \times \left( \frac{D^4(r_0-1)^4}{r_0^4} \right) \right) + E_{elec} \right) \quad (11)$$

$$h_1 = \frac{D^4}{r_0^4} + 2 \times \left( \frac{D^4(r_0-1)^4}{r_0^4} \right) \quad (12)$$

Assumption 2: The best value for  $r_0$  to create a balance between the energy consumption of the cluster head and the corresponding relay is approximately equal to 1.84.

Proof: In accordance with the preceding proof, to create a balance between the energy consumption of the cluster head and the relay, their absolute magnitude difference should be minimized according to Eq. (13).

$$\text{minimize } g = \left| E_{dual-hop}^{CH} - E_{dual-hop}^{relay} \right| \quad (13)$$

By expanding the above relation using Eq. (1), we reach Eq. (14). Because  $D$ ,  $L$ ,  $E_{mp}$  and  $E_{elec}$  are constant values, the  $g$  function is minimized at a point where the  $g_0$  function given in Eq. (14) becomes zero.

$$g_0(r_0) = \frac{1 - 2 \times (r_0 - 1)^4}{r_0^4} \quad (14)$$

The roots of the above function are the best values for  $r_0$  to balance the energy consumption of the cluster head and relay. A suitable root for this function is 1.8. As a result, choosing  $r_0=1.8$  will lead to the equal energy consumption of cluster head and relay. As a result, to simultaneously achieve both goals of optimality and balance, the value selected for  $r_0$  is equal to the average of these two values, i.e., 1.8.

Assumption 3: The complexity of the control packets of the presented algorithm equals  $O(N)$ , where  $N$  is the number of nodes within the network.

Proof: During each cycle,  $N$  Node-MSG packets are transmitted to the base station. In addition, every node issues a Join-MSG message to its CH. Each CH also sends one CH-ADV message, one Relay-ADV or Rejoin-MSG message, and two packets. If we assume that the number of CHs is 5% of the total number of nodes, the total number of control packets is equal to  $2N + 2 \times \left( \frac{N}{20} \right) = \frac{21}{10} N$ , which is related to  $O(N)$ .

#### IV. SIMULATION RESULTS

The proposed method is simulated and implemented using CPU core i5 and 4GByte RAM. A Matlab simulator has been used to obtain the results. The method was tested under various conditions, such as varying the number of nodes, to ensure accurate results. The results were then compared with those obtained from other methods to prove the proposed method's performance. Table I summarizes the key parameters and variables used in the proposed method's simulation.

The energy expended in delivering the sensed data to the base station is one of the most important parameters of analyzing routing methods in the IoT environment. By properly assessing the energy expenditure, it is possible to optimize the routing methods and improve the overall performance of the IoT system. This measurement can compare different routing methods and select the most energy efficient one. Moreover, it can be used to identify areas of high energy consumption, which can be addressed to further optimize the IoT system. According to Fig. 4 to 6, our method is more energy-efficient than previous methods. Fig. 4 compares our method's average residual energy with R-LEACH when the number of rounds is increased. According to this figure, our algorithm significantly increases the number of alive nodes compared to the comparative algorithm. Fig. 5 and 6 illustrate the comparison between the energy consumption of our method and RDDI. The results show that

our algorithm can reduce energy consumption while ensuring that more nodes remain alive. This is because it can identify clusters that consume less energy, thus reducing the entire network's energy consumption. Additionally, by optimizing the selection of cluster heads, our algorithm can reduce the amount of energy wasted due to redundant communications. The packet delivery rate can be described as the ratio of traffic correctly delivered to the base station as a percentage of all traffic carried within the network. As shown in Fig. 7, our algorithm achieves a higher percentage of packets delivered than the comparative algorithm. The packet delivery ratio decreases as the number of nodes increases and the density increases. Data collisions will result as network density increases, leading to a higher rate of data transmission failures and packet loss.

TABLE I. SIMULATION VARIABLES

Variable	Value
Network dimensions	(100 × 100)
Number of nodes	50-300
Packet size	800 bits
Node distribution	Random
Initial node energy	Different based on the scenario
Iterations	100-500
Efs	10 pj/bit/m2
Eelec	50 nj/bit
Eamp	0.0013 pj/bit/m4

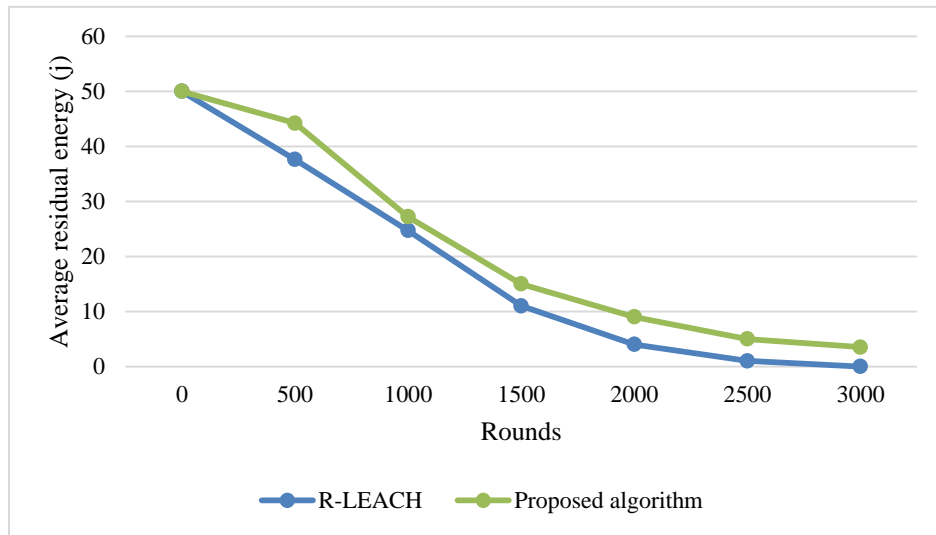


Fig. 4. Average residual energy comparison.

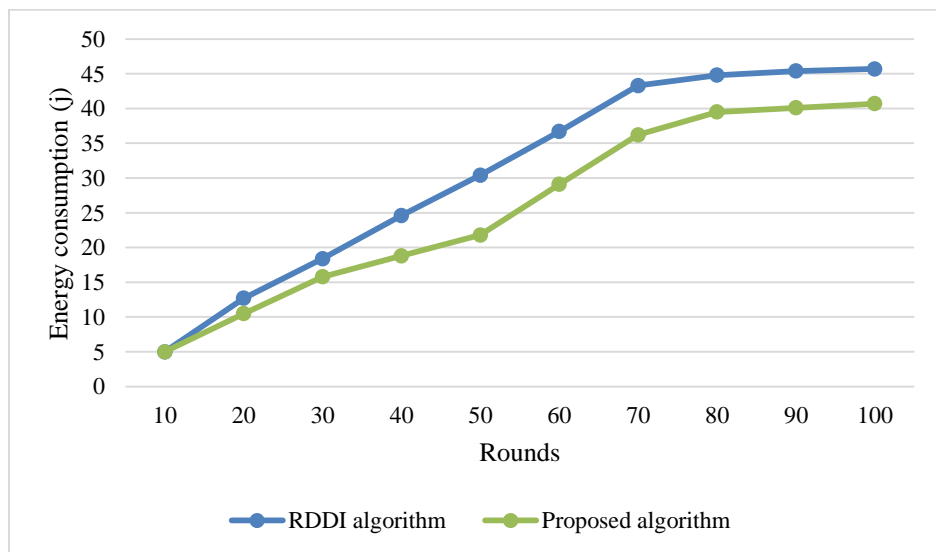


Fig. 5. Energy comparison for 20 clusters.

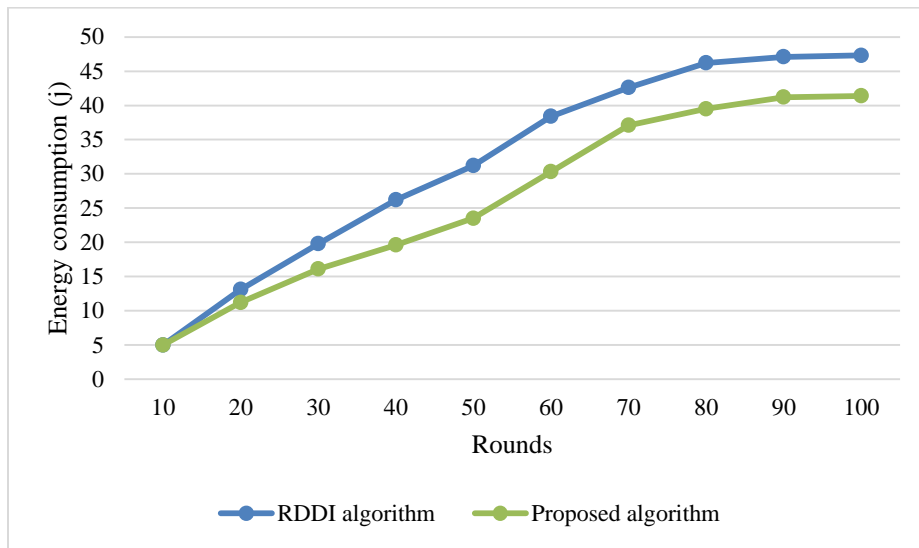


Fig. 6. Energy comparison for 50 clusters.

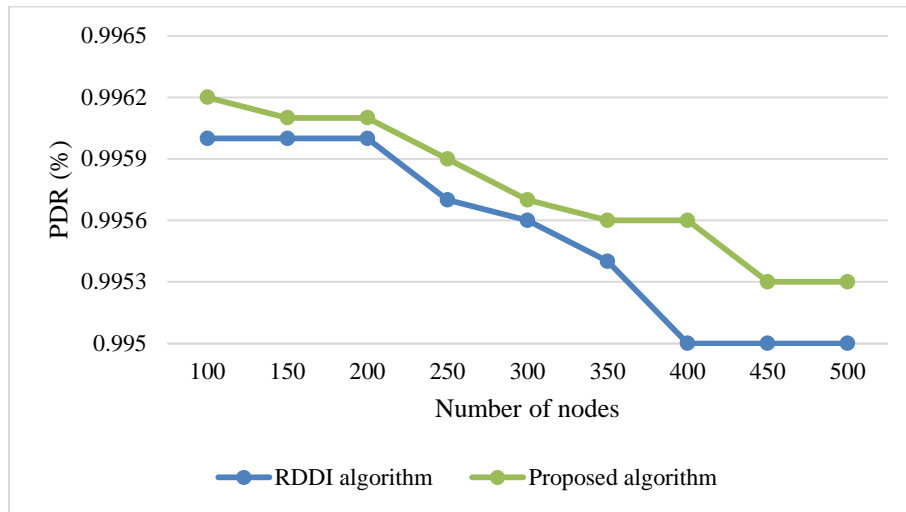


Fig. 7. Packet delivery ratio for 20 clusters.

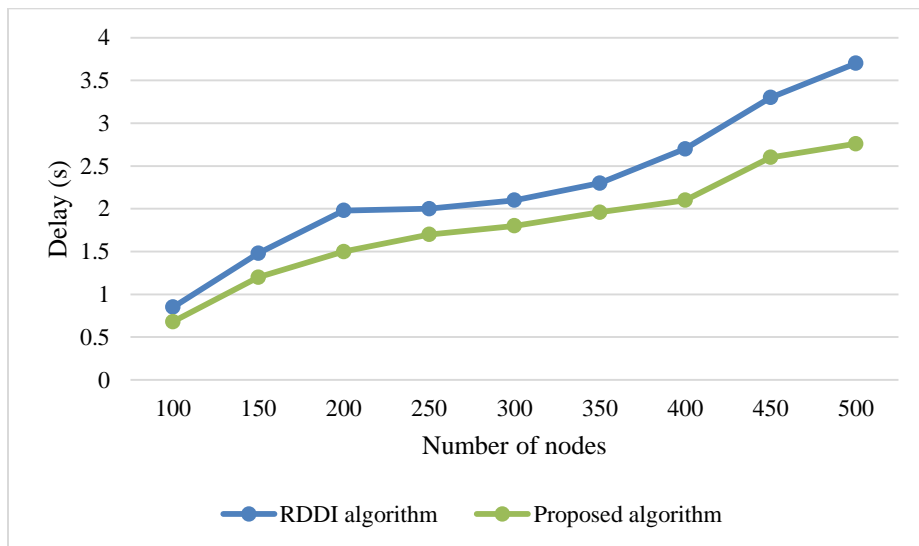


Fig. 8. End-to-end delay for 20 clusters.

As the name suggests, end-to-end delay refers to the time a packet travels from the source node to the destination node within a network. This delay encompasses various factors, including the propagation delay, which represents the time required for a signal to traverse a specific transmission medium. Additionally, the processing and queuing delay must be considered, as it accounts for the time network nodes take to handle and process the data before placing it into the appropriate queues for further transmission. By evaluating these delay components, a comprehensive understanding of the overall transfer time can be gained. Fig. 8 serves as concrete evidence of the superiority of our proposed method in terms of end-to-end delay compared to the RDDI method. The comparison showcased in the figure highlights the effectiveness of our approach in minimizing the total transfer time. Our method efficiently manages the propagation, processing, and queuing delays, resulting in a significantly improved end-to-end delay performance.

## V. CONCLUSION

Data transmission from sensor nodes poses a major issue for IoT-enabled networks. This paper proposed a novel clustering strategy based on the GWO algorithm. The protocol comprises two stages, namely initialization and stabilization. During the first stage, the base station collects location and energy information about nodes and then determines the cluster heads using this information and the GWO algorithm. Data collected by the cluster heads are sent to the base station during the steady state phase. To conserve energy, the proposed method executes the setup phase only when the current cluster heads are nearing death. This process eliminates the need to send and receive control packets during the setup phase, reducing energy consumption. According to the results, our method outperforms previous ones regarding the end-to-end delay by up to 34%, energy consumption by up to 14%, and packet delivery rate by up to 10%.

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# Intelligent Moroccan License Plate Recognition System Based on YOLOv5 Build with Customized Dataset

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**Abstract**—The rising number of automobiles has led to an increased demand for a reliable license plate identification system that can perform effectively in diverse conditions. This applies to local authorities, public organizations, and private companies in Morocco, as well as worldwide. To meet this need, a strong License Plate Recognition (LPR) system is required, taking into account local plate specifications and fonts used by plate manufacturers. This paper presents an intelligent LPR system based on the YOLOv5 framework, trained on a customized dataset encompassing multiple fonts and circumstances such as illumination, climate, and lighting. The system incorporates an intelligent region segmentation level that adapts to the plate's type, improving recognition accuracy and addressing separator issues. Remarkably, the model achieves an impressive precision rate of 99.16% on problematic plates with specific illumination, separators, and degradations. This research represents a significant advancement in the field of license plate recognition, providing a reliable solution for accurate identification and paving the way for broader applications in Morocco and beyond.

**Keywords**—License plate recognition; YOLOv5; intelligent region segmentation; customized dataset; Moroccan license plate issues; fonts-based data

## I. INTRODUCTION

Over the past few decades, the global vehicle population has grown significantly, with estimates placing the number of vehicles in use at around 1.36 billion by late 2016, a number that has likely increased even further in the years since. However, obtaining an exact number is difficult due to the responsibility of each country's administration to keep track of and identify vehicles within its borders. The rapid growth of the global vehicle fleet is driven by a combination of demographic changes, shifts in lifestyles, and advancements in the automotive industry. To accommodate this growth, many countries have developed their vehicle registration systems, assigning unique license plates to each vehicle, including cars, trucks, and motorcycles, using a combination of numbers, letters, or a combination of both. Some countries also associate the license plate with the vehicle owner, providing an alphanumeric identifier for easy identification.

In order to efficiently track vehicles and monitor their activities, automatic number plate recognition (ANPR) systems were developed. ANPR utilizes optical character recognition (OCR) technology to analyze pre-captured images of license

plates, taken by specific cameras, extract the plate numbers, and thus identify vehicles and owners [1]. This eliminates the need for manual plate identification, which was previously done by human agents but was prone to errors. ANPR is widely used by law enforcement agencies for enforcement purposes, as well as by highway agencies for road pricing [2] and automated parking systems for charging purposes [3].

With the advancement of computer science and technology, as well as the improvement of databases, Automatic Number Plate Recognition (ANPR) has become a key aspect of traffic management systems in smart cities [4, 5, 6]. ANPR is seen as a valuable tool for collecting traffic data and improving road efficiency and safety, which are the primary goals of Intelligent Transportation Systems (ITS) [7]. The ANPR process involves several techniques and automated algorithms, which are typically composed of four steps: capturing an image of the vehicle, detecting the license plate, separating the characters on the plate, and finally recognizing the characters.

## II. LITERATURE REVIEW

### A. License Plate Recognition System

The development of license plate recognition systems began at the end of the 20th century. One of the early contributions, by authors in [8], proposed an algorithm that used gray-scale morphological operations to detect the license plate region from an image, with no restrictions on the input. The Car License Plate Recognition System (CLPR-system) proposed by G. Nijhuis et al. in 1995 [9] aimed to identify vehicles by their license plate contents for speed-limit enforcement purposes. This system combined neural and fuzzy techniques to achieve an acceptable recognition rate and a low error rate. Another early contribution was made by S. Draghici [10] who constructed an artificial vision system that used a neural network to analyze images, locate the registration plate, and recognize the registration number. This system showed successful plate position and segmentation of 99%, successful character recognition of 98%, and successful recognition of complete registration plates of 80%. In 2005, J. Matas and K. Zimmermann [11] submitted a study of a new class of locally threshold separable detectors that utilized external regions adaptable by machine learning techniques. This improved license plate detection. With the advent of Convolutional Neural Networks, Q. Wang [12] used a small but powerful network to classify characters on plates extracted by the Single



Shot MultiBox Detector (SSD) [13]. Several extensions of these neural networks have been proposed.

### B. YOLO-based Approaches

In [14], an ALPR system for Chinese license plates was proposed utilizing two CNNs based on the YOLO2 framework. The system was compared to YOLOv2 and YOLOv3 and implemented on PYNQ, resulting in a detection precision of 99.35% and a recognition precision above 97.89% with a speed of 12.19 ms. In [15], a robust and efficient ALPR system based on the state-of-the-art YOLO object detector was presented. The system was fine-tuned and trained for each ALPR stage, and achieved a recognition rate of 93.53% with 47 frames per second (FPS) on 2,000 frames extracted from 101 vehicle videos. The system was tested on a large, public, and realistic dataset, UFPRALPR, and the recognition rate exceeded 78% with 35 FPS. In [16], a sliding window technique was suggested as a means of identifying Taiwan's license plates, resulting in a license plate detection accuracy of around 98.22% and a license plate recognition accuracy of 78%, with each image taking 800 ms to process. Also, a new Automatic License Plate Recognition (ALPR) system based on YOLOv2 was presented by S. M. Silva and C. R. Jung [17], with a focus on capturing license plates in uncontrolled scenarios where views might be distorted. The authors introduced a unique Convolutional Neural Network (CNN) capable of identifying and correcting multiple distorted license plates within a single image. The final outcome was obtained via an Optical Character Recognition (OCR) approach. Another real-time system for recognizing Jordanian license plates using YOLOv3 was proposed by S. Alghyaline [18]. The system was tested on genuine videos obtained from YouTube and achieved an accuracy of 87% in recognition. A similar YOLO framework was implemented by A. Tourani et al. [19] to detect and recognize Iranian license plates. After testing over 5000 images, the system obtained an accuracy of 95.05%.

### C. License Plate Recognition in Morocco

Authors of [20] presented a two-step Moroccan license plate recognition system where a hypothesis is first generated step and then verified. They performed the Connected Component Analysis technique (CCAT) to detect the rectangles that are considered the generated license plate candidates. Then, edge detection is applied inside the generated candidates and the close curves method is performed to ensure the candidate is a license plate and to segment the character. The experiment results so far are satisfying and promising (96,37% accuracy when tested on three videos from Moroccan road. F. Taki and A. El Belrhiti El Alaoui submitted a three-phase method [21]. First, license plate localization under different environmental conditions is based on a combination of edge extraction and morphological operations. Second, the segmentation part exploits the features of Moroccan license plates. Third, the optical character recognition phase is based on the Tesseract framework, considered by the authors as the most accurate open-source OCR. The proposed method is able to recognize several plates in the same image under different acquisition constraints in real-time. No accuracy rate is given. In addition, authors in [22] presented a new robust method to detect and localize Moroccan license plates from images. The proposed approach is based on the edge features and

characteristics of license plate characters. To verify the robustness of the model, various images, including Moroccan's VLP taken from different distances and under different angles were used. The experimental results showed almost 95% precision rate obtained for a recall rate value equal to 81%. In addition, the standard measure of quality was equal to 87.44 %. One of the last YOLO-contribution models for the Moroccan plate context is A. Alahyane, M. El Fakir, S. Benjelloun, and I. Chairi's [23]. Indeed, they constructed a dataset for the Moroccan license plate OCR application. Almost 705 unique and different images manually collected and labeled. This dataset is free to use and suitable for CNN models like Yolov3. Also, contribution [24] proposed a one-stage modified tiny-Yolov3 for real-time Moroccan license plate recognition improved with transfer learning techniques. The latter method achieves an excellent trade-off between speed and accuracy, as well as the system executes the detection /recognition process in a single phase with 98.45% accuracy and 59.5 Frames Per Second (FPS).

In this article, we address the challenges of license plate recognition in Morocco, considering the growing fleet, local plate specifications, and plate detection issues. Section III discusses the license plate recognition scenario in Morocco, emphasizing the need for a robust system that considers local plate specifications and the challenges posed by different plate types. Section IV presents our proposed solution based on the YOLOv5 framework, highlighting its efficient and accurate license plate recognition capabilities. Section V focuses on the experimental setup and results, including the customized dataset used for training and the achieved outcomes. Section VI concludes the paper. This enumeration provides a concise overview of the different sections covered in this article, offering a comprehensive understanding of our intelligent Moroccan license plate recognition system.

## III. LICENSE PLATE RECOGNITION IN MOROCCO

### A. Growing Fleet

In Morocco, as elsewhere in the world, the fleet has jumped and is expected to even more. Table I summarizes the growth observed in vehicle numbers registered in Morocco.

TABLE I. MOROCCAN FLEET GROWTH FROM 2016 TO 2019

Vehicle type	2016	2017	2018	2019
Passenger vehicles	2 670 614	2 808 782	2 950 056	3 090 063
Commercial vehicles	1 065 338	1 117 559	1 170 177	1 225 878
Motorcycles	55 517	130 257	191 611	236 415
<b>Total</b>	<b>3 791 469</b>	<b>4 056 598</b>	<b>4 311 844</b>	<b>4 552 356</b>
<b>Evolution</b>	<b>5,61%</b>	<b>6,99%</b>	<b>6,29%</b>	<b>5,58%</b>

Along with that significant amount of vehicles, Morocco receives each year more than 400 000 additional vehicles. In fact, the African country is experiencing strong growth in tourism activities due to its important diaspora (up to 3 million Moroccans resident overseas), its location in the Northwest of Africa, its historical monuments, its gastronomic cooking, and the hospitality of its people. Enough reasons to make the country the most attractive destination on the continent with more than 11 million air passengers and motorists. In the summer of 2019, the last tourist season before the border

closure imposed by Covid-19 control measures, 600.000 vehicles were registered in the northern regions of the kingdom, shipping almost 2.9 million MROs, an important fleet that increases the number of vehicles in use in Morocco.

**B. Local Plate Specifications**

The most used Plate in Morocco is the Horizontal White Plate (HWP), shown in Fig. 1 and composed of three sections:

- The First section includes the specific number of the prefecture or province to which the vehicle is attached.
- The Second section represents the registration series, which is characterized by one or two letters of the Arabic alphabet. After the exhaustion of the group of registration series starting with the letter A up to the letter S, the second group of registration series will be made up of a combination of the fixed letter A and the first letter of the order.
- The Third section indicates the order of registration ranging from one to five digits (1 to 99999) at most.

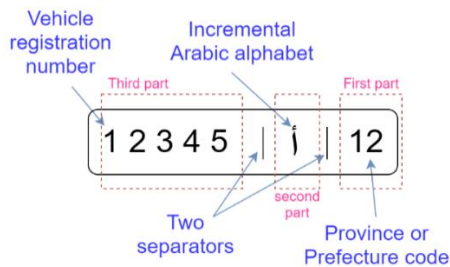


Fig. 1. Moroccan horizontal plate composition (HWP).

Some vehicles can accept two horizontal lines plate, as shown in Fig. 2. This arrangement of two horizontal lines is shown on the first line, the first and the second part, separated by a vertical line. On the second line are placed the digits of the third part, separated from the first line by a horizontal line.

Authorities in Morocco have a specific plate, specific in colour and regions but written with the same fonts. These plates, presented in Table II, are composed of two major parts, one at the right composed of an Arabic character that indicates the concerned authority. This part can contain one, two or three characters, and sometimes it can contain the word “Morocco” written in Arabic. The second part, the one at the left, is a generic number specific to the vehicle. In the presented model, these plates are called DP like “Dark Plates”.

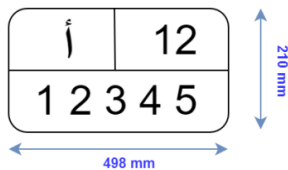


Fig. 2. Moroccan two lines plate (VWP).

In addition, official vehicles of ministers, parliamentarians, and municipal elected officials have specific registration numbers made up of two numbers in black on a white background. The left part represents the registration of the vehicle, while the right part is made up of two digits relating to

the function of the person to whom it is allocated (96: Official cars of senior officials e.g. Walis, governors, general secretaries, etc. 97: Official carriages of the royal court, 98: Official cars of Parliament and 99: Ministers' official cars). Because of their limited number and their specificity, these plates are not taken into consideration in our model.

TABLE II. LOCAL AUTHORITY PLATES (DP)

SIGNE	ARABIC	AUTHORITY	PLATE STYLE
ش	الشرطة	POLICE	1 2 3 4 5 6 ش
ج	الجماعات المحلية	LOCAL AUTHORITY	1 2 3 4 5 6 ج
وم	الوقاية المدنية	CIVIL PROTECTION	1 2 3 4 5 6 وم
ق س	القوات المساعدة	AUXILIARY FORCES	1 2 3 4 5 6 ق س
ق م م	القوات المسلحة الملكية	ROYALE ARMED FORCES	1 2 3 4 5 6 ق م م
المغرب	سيارات الدولة المدنية	NATIONAL AUTHORITY	1 2 3 4 5 6 المغرب

Diplomatic, consular agents, representatives, experts, and officials of international or regional organizations in Morocco have a specific plate divided into two parts as shown in Fig. 3. Also, the same plate is reserved for staff of the "international cooperation" registration series for vehicles belonging to employees benefiting from temporary importation and having their main residence outside Morocco. These plates are reserved for those whose activity falls within the framework of international cooperation in Morocco.

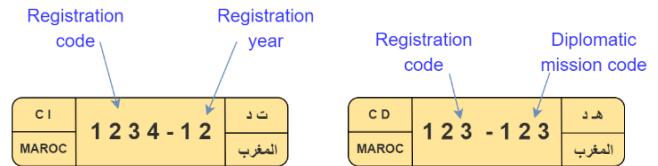


Fig. 3. Diplomatic or consular plate (YP).

Another kind of plates to consider is WW and W18 presented in Fig. 4. In fact, the first concerns the declaration of provisional entry into service of a motor vehicle. The second is attributed to vehicles purchased or sold by an automobile dealer holding. These plates are exclusively delivered by importers, manufacturers or traders of new motor vehicles to buyers in Morocco.

WWP and W18P plates concern almost 256 000 Moroccan new vehicles during at least their first 30 days of use, according to vehicle registration of 2022.

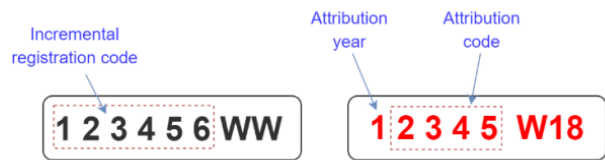


Fig. 4. WWP and W18P plates.

C. Plate Detection Issues

Moroccan LP presents, inter alia, the issues proposed in Fig. 5. These issues are rather morphological, related to both the form of the LP and the character used (separators, Arabic characters, shadows, dirt, degradations, etc.), or technical and concern the device used to capture the LPs (angle, illumination, etc.).

a) *Multiple fonts*: local legislators allow vehicle owners free to choose the font of their LPs. The fonts presented in Table III are mainly observed.

TABLE III. FONTS IN USE IN MOROCCAN PLATES

FONT	LABEL	CHARACTERS	SAMPLE
Clarendon Regular Extra	CRE	0123456789	14167     68
Hight Security Registration Plate	HSRP	0123456789	7556     54
FE-Schrift	FE-S	0123456789	20138     42
Ingeborg Heavy Italic font	IHF	0123456789	4578     26
Metalform Gothic JNL font	MGJF	0123456789	48847     20
Morton of (400)	MOTF	0123456789	88225     20
Moroccan Rekika Font	MRF	0123456789	73215     8

b) *Separators*: Moroccan plate constructors use different types of separators. Even if the most common separator is the vertical line, some constructors use hyphens to separate the three parts of the plate while others prefer to use slashes, and others, looking for distinction, avoid using separators. This difference between separators chosen or not changes the configuration of plates and remains an issue for plate recognition systems.

c) *Distance between Characters*: Because of the huge number of plate constructors in Morocco, their plates are not homogeneous and the distance between characters is not fixed in all plates edited. In fact, the distance between characters is not the same and constitutes a considerable issue to ALPR.

d) *Additions*: Even if local authorities have engaged in a massive campaign against additional features in vehicle LPs, some owners still, voluntarily or involuntarily add drawings, logos, stickers, or cameras to plates.

e) *Arabic characters*: Some of the Arabic letters used in Moroccan license plates are written as fragments. For example Arabic character "B" has a point out of its body. Also, short marks are placed above particular characters or may appear as isolated characters (case of Arabic character "A"). Thus, during the character segmentation step, these kinds of characters cannot be correctly segmented because dots or marks are omitted [21].

f) *Illumination*: The presence of objects' shadows can cause various challenges because of the illumination change in the shadow region to be removed to avoid any false positive detections. To accomplish this task, we implement a filtering method, namely median filtering for the removal of certain types of noise.

g) *Camera noise*: Among these issues, the sensor used can alter the taken image. We talk here about camera vibration that can cause blur along with noise caused by rain and climate conditions. This technical degradation can occur due to vehicle position and speed that make it difficult to clear images or video sequences.

h) *Degradations*: Vehicle owners still display their plates when they are damaged, either when they have scratches of painting failures:

- *Scratches*: on metallic plates similar to lines or even new features that can be assimilated to characters if they have the appropriate dimensions;
- *Character's painting failure*: with misleading interpretation or omission of the character altered.

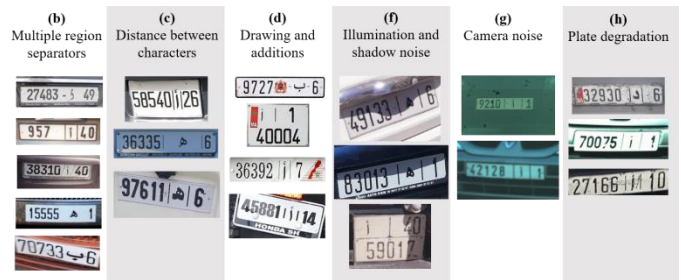


Fig. 5. Common Moroccan plates detection issues.

IV. PROPOSED SOLUTION

A. YOLOv5

YOLO is a real-time object detection algorithm that transforms the detection process into a regression problem. It generates the bounding box (BB) coordinates and class probabilities directly, without extracting the region of interest. YOLO improves detection speed compared to faster R-CNN[25]. YOLOv5, the latest version introduced by Ultralytics in 2020, surpasses all previous versions in both speed and accuracy. YOLOv5 is written in Python, which makes it easier to install and integrate with IoT devices, unlike previous versions written in C. It also has a new PyTorch training and deployment framework that improves object detection results. During training, YOLOv5 uses a data loader with online data augmentation, including scaling, color space modifications, and mosaic augmentation (combining four pictures into four random-ratio tiles).

The YOLOv5 algorithm offers four models - YOLOv5s, YOLOv5m, YOLOv5l, and YOLOv5x - by adjusting the width and depth of the backbone network using the depth\_multiple and width\_multiple parameters. YOLOv5s is the simplest and fastest among them, with the least number of parameters. The network topology of YOLOv5s consists of various modules such as focus, Convolution, Batch Normalization and Leaky-ReLU (CBL), Center and Scale Prediction: CSP1\_x, CSP2\_x, and Spatial Pyramid Pooling (SPP) [26].

The input image is processed by the focus block, which primarily comprises four parallel slice layers. The CBL block includes a convolutional layer, batch normalization layer, and hard-swish function. The CSP1\_x block contains CBL blocks and x residual connection units, while the CSP2\_x block is



composed solely of CBL blocks. The SPP block consists of three max-pooling layers. The YOLOv5s model is made up of three main components: the backbone, the feature improvement section, and the head, each serving a unique purpose [27] as depicted in Fig. 6.

1) *Backbone*: The backbone is a convolutional neural network that collects and compresses visual features at various levels of detail. It starts by using the focus structure to periodically extract pixels from high-resolution images and reconstruct them into low-resolution. To improve the receptive field of each point and minimize information loss, the four edges of the image are stacked, and the information in the width and height dimensions is condensed into the C channel space. This is done to reduce the number of calculations and speed up the process. The CSP1\_x and CSP2\_x modules are then designed based on the CSPNet concept [28]. The module splits the main layer's feature mapping into two parts before combining them using a cross-stage hierarchical structure, reducing calculation time and increasing accuracy. The SPP network is used in the final section of the backbone network to separate contextual features and increase the receptive field.

2) *Neck*: The neck network in YOLOv5 uses a Path Aggregation Network (PANet) [29] to improve the fusion of extracted features. It consists of several layers that combine the features of the image before passing them on for prediction. The network employs a Feature Pyramid Network (FPN) structure to transmit strong semantic features from the top down, and a feature pyramid structure created by the PANet module to transmit strong positional features from the bottom up. This approach is designed to combine features from different layers.

3) *Head*: In YOLOv5: the head uses features from the neck to make box and class predictions. The head structure in YOLOv5 is similar to that of YOLOv3, with three branches. Its purpose is to make dense predictions, which consist of a vector containing the predicted bounding box coordinates (center, height, and width), a prediction confidence score, and class probabilities. The improvement in YOLOv5 is the use of complete intersection over union (CIoU) loss [30] as the bounding box region loss.

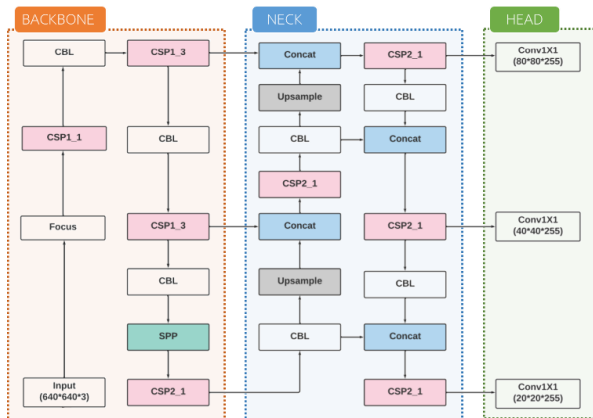


Fig. 6. Network topology of YOLOv5s [25].

## B. Model

Considering the above, the proposed Moroccan Automatic License Plate Recognition System (MALPR) as depicted in Fig. 7, addresses the recognition of all types of license plates used in Morocco, including both local and foreign vehicles, and is designed to meet the specifications of the country while mitigating as many challenges as possible. The MALPR system is divided into two major components [31]. The first component is an SDK-based system embedded with IoT devices such as GPS, GSM, and camera, along with a neural network framework for image analysis. The second component is an API server-side system where further processing such as character segmentation and recognition is performed.

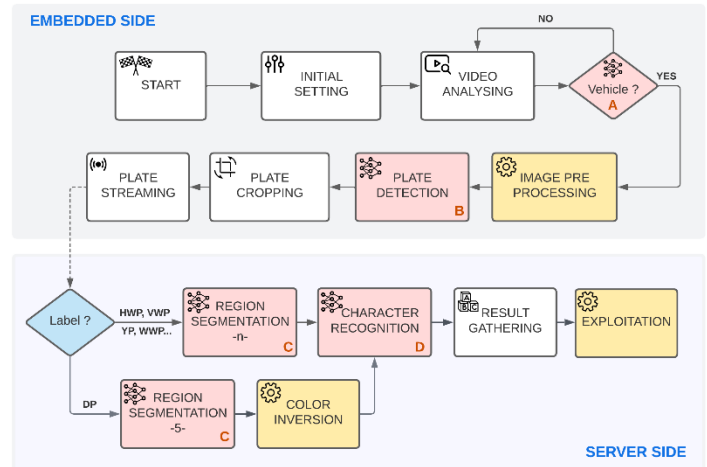


Fig. 7. Proposed solution overview.

The proposed architecture involves capturing a real-time video from a camera and converting it into a specific number of frames per second, based on the deployment location of the device. For instance, if the system is used for detecting parking activity, a low frame rate of one or two frames per second would suffice. However, in areas with higher traffic density, such as highways, a higher frame rate would be necessary to enhance the accuracy of the detection.

Initially, the device performs an analysis of the video and processes the frames to improve their quality and increase the accuracy of predictions through techniques such as compression, gray-scale conversion, etc. [30, 31]. Subsequently, the captured vehicle is classified using the YOLOv5 neural network, a framework that has proven its effectiveness [14-18] in object detection, vehicle classification, and plate localization within the frame. The better the vehicle classification, the more accurately the plate can be located within the image. YOLO can easily locate the plate with a simple configuration. Once the plate is detected, it is cropped and sent as a binary large object (BLOB). On the server side, the software development kit (SDK) completes the process by performing region segmentation, character detection, and gathering recognized characters to construct the final output. The current architecture extends beyond the steps outlined above.

1) *Initial setting*: The user sets initial parameters such as frame rate according to the area where the device is used which

defines the corresponding frames rate [15]. In the presented solution frames are tested with three rates (parking: 1f/s, road: 5f/s, and highway: 10f/s). In addition, night vision parameters are programmed to a specific time of the day. The schedule of night vision switching is implemented using the recurrent rule. The similarity rate of redundancy is set at the beginning, the information needed to select the relevant output from repeated frames of the same vehicle. The user can also choose the codec to be used in the transmission of potentially detected plates.

2) *Video analysis*: The Video Analysis stage involves the examination of the video captured by the camera using a pre-trained weight of YOLO. At this stage, whenever the model detects a vehicle (such as a car, truck, bus, trailer, or motorcycle) within a minimum range, the system crops the vehicle and forwards it to the processing step. The weight was initially trained on the COCO dataset [32] and has demonstrated strong performance in object detection across 80 object categories.

3) *Image processing*: The Image Processing stage involves a suite of quality-enhancement techniques aimed at improving the quality of the captured vehicle frames and enhancing the accuracy of predictions. At the start of the workflow, these techniques (including binarization, contrast maximization, Gaussian blur filtering, and adaptive thresholding) eliminate small components and noises to elevate the required quality for subsequent operations [33], while also reducing computational overhead. This stage may also be carried out following the Plate Detection step through the use of a high-quality second camera, which uses the coordinates from the Plate Detection stage to only capture the detected plate. The applied processing techniques include image binarization [33,34], thresholding [35] and histogram equalization.

4) *Plate detection*: The Plate Detection stage relies on a weight derived from the constructed dataset to determine the location of the plate on the detected vehicle. The weight enables the model to identify the type of plate, including HWP, VWP, DP, YP, or WWP. This stage can be expanded to encompass additional types of plates by incorporating the relevant weight-embedded device. The output of this stage consists of the coordinates of the predicted plate as presented in equation (1).

$$y = (pc, bx, by, bh, bw, c) \quad (1)$$

With  $bw$  and  $bh$  are the width and height of the rectangle,  $c$  stands for the class found and  $bx$  and  $by$  are the coordinate of the center of the box.  $pc$  corresponds to the confidence of the prediction:

$$pc = Pr(\text{Object}) * IoU \quad (2)$$

With  $IoU$  corresponds to the area of overlap between the predicted BB and the ground-truth BB [36] which corresponds to the labeled BB from the testing set that specify where is the object.

5) *Plate cropping*: simple stage, shown in Fig. 8, in which the image is cropped and saved. This stage prepares the result

of the embedded processing to be streamed to the server for further steps. With the use of YOLOv5, this stage consists of cropping the BB got from the above-mentioned grid. The cropped areas can admit color processing to be sent to the region segmentation stage depending on the type of the plate predicted.

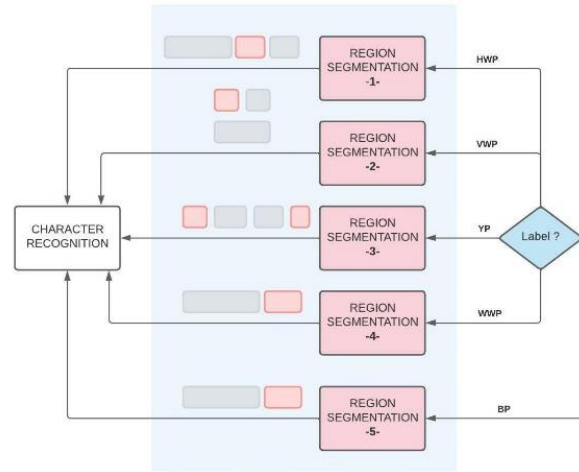


Fig. 8. Region segmentation overview.

6) *Region segmentation*: The proposed system boasts a noteworthy contribution in its region segmentation aspect. It categorizes the license plate into its major digit regions before extracting each character. This stage is crucial in ensuring that every part of the plate is analyzed individually and no section is overlooked. During the training phase, the regions are designed to be as large as possible to accommodate all possible fonts in the test phase. Careful consideration is given to avoid overlapping regions, as this is essential in the subsequent step of separating the digits for analysis. Unlike other Moroccan license plate recognition systems, this model does not consider separators, such as the long line of the Arabic letter "A" and sees no alphabet as separate parts.

7) *Color inversion*: this approach features a straightforward stage of color reversal, where plates with dark backgrounds undergo inversion and are promptly forwarded to region segmentation 5. Instead of compiling a separate dataset made up exclusively of dark plates, segmentation, and training, this process relies on the digit data that has already been acquired.

8) *Character recognition*: The character recognition stage is an optimized process that extracts characters and numbers from separated regions. During this stage, the system only accepts alphabetic letters or words as output in the red regions depicted in Fig. 8. Conversely, in other regions, the system focuses solely on numeric digits and does not permit any alphabetical characters.

9) *Result gathering*: Stage, where characters recognized, are assembled to form the final output.

10) *Exploitation*: Stage reserved for further processing like checking whether the vehicle is stolen or offending road traffic rules, etc.

## V. EXPERIMENT AND RESULTS

### A. Dataset

A significant amount of high-quality data is necessary for machine learning solutions. Although attempts have been made to address the problem of License Plate detection, recognizing license plates in uncontrolled and unrestricted environments is still a challenge. In fact, most proposed methods have low accuracy when attempting to detect license plates that are rotated, in uneven lighting, in snowy conditions, or in a dimly lit environment. Nearly all researchers have trained and tested their detectors on extremely small datasets, which only contain a limited number of unique images or minor variations in angles, restricting their effectiveness to specific scenarios.

To test the presented solution, a specific Dataset is built based on the type of plates (HWP, VWP, YP, WWP, DP) and the font in use in them (CRE, HSRP, FE-S, IHIF, MGJF, MOTF, and MRF). This Dataset, presented in Fig. 9, is composed of 8952 images of distinct vehicles on Moroccan roads under different circumstances (place, weather, time, rotation, backgrounds, illumination, and car type). These images are sorted according to the type of plate and the font utilized. Each annotated plate is cropped and then segmented (HWP-N, HWP-P, HWP-L, etc.). This constitutes segmentation dataset to be annotated and trained aside.

Also, specific folders are built to test the present model on problematic plates: plates with degradations (PDEG), plates with different illumination (PDI), plates with specific separators (PSS), and plates with additions (PADD).

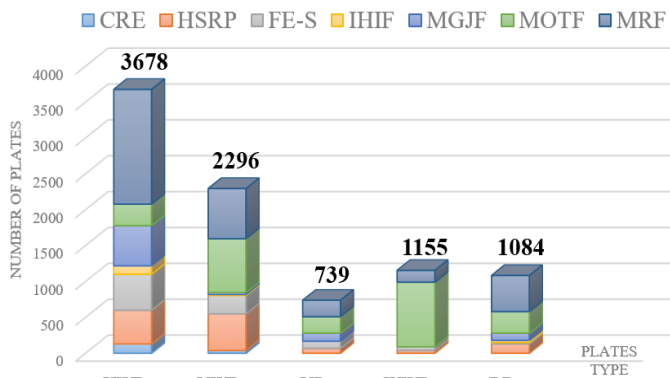


Fig. 9. Dataset composition (fonts and plate types).

### B. Training

The dataset used to test the present model is labeled using LabelImg [37]. This tool analyzes the image annotation process for training artificial intelligence models in modern image recognition systems. This tool creates a classes.txt file and saved annotations with the following structure, with the first character corresponding to the order of the class in class.txt. The next four values are the coordinates of the BB annotated.

Multiple datasets are trained using NVIDIA GeForce RTX 3070 (total memory 8G) build on AMD Ryzen 9 3900XT 12-Core Processor computer with 16384 MB RAM and Windows 10 Pro N 64-bit (10.0, Build 19045). The model was built with Python-3.9.13, torch-1.9.1+cu111 CUDA:0.

The model presented typically provides four cases to classify the results, represented by T and F indicating true or false predictions respectively. The letters P and N indicate whether the instance is expected to belong to a positive or negative class. The model's effectiveness can be evaluated by analyzing the ratio of these prediction outcomes, which are composed of different combinations of these categories. To assess the accuracy of the model, the following metrics are used.

$$\text{Accuracy (A)} = \frac{TP+TN}{TP+TN+FP+FN} \times 100\% \quad (3)$$

$$\text{Precision (P)} = \frac{TP}{TP+FP} \times 100\% \quad (4)$$

$$\text{Recall (R)} = \frac{TP}{TP+FN} \times 100\% \quad (5)$$

$$F_1 = 2 \times \frac{P \times R}{P+R} \quad (6)$$

$$mAP = \frac{1}{N(T)} \sum_{r \in T} AP_r \quad (7)$$

True positive (TP) corresponds to a test result that correctly indicates the presence of the characteristic, true negative (TN) stands for results that correctly indicates the absence of the region or the character, false positive (FP) is the result which wrongly indicates that a particular region or character is present and false negative (FN) represents test result which wrongly indicates that a particular condition or attribute is absent. Fig. 10 displays three different types of loss: classification loss, objectness loss, and box loss.

The box loss measures how accurately the algorithm can determine an object's center and how completely the estimated BB encloses an object. The probability that an object exists in a suggested zone of interest is basically measured by objectness. If the objectivity is high, an item is probably present in the image window. How successfully the algorithm can determine the proper class of a given object is shown by the classification loss. Before remaining stable after approximately 50 epochs, the model quickly increased in terms of precision, recall, and mean average precision. The validation box, objectness, and classification losses similarly shown a sharp drop up until about epoch 50. To choose the best weights, we utilized early stopping.

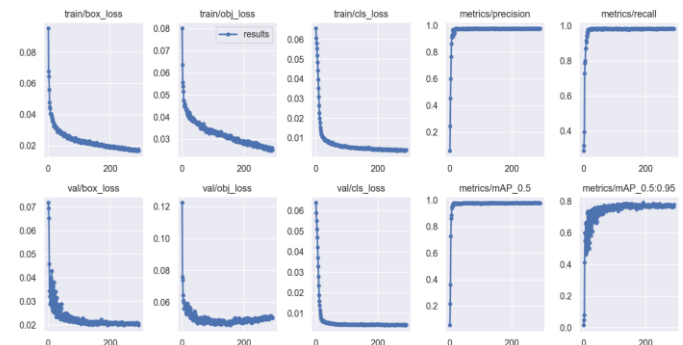


Fig. 10. Plots of box loss, objectness loss, classification loss, precision, recall and mean average precision (mAP) over training and validation epochs.



C. Result and Discussion

After performing precision of 97.492%, a recall of 98.259% and mAP 50% up to 97.768% in training, the model performed excellent rates on problematic dataset. In fact, as shown in Fig. 11, all PADD images were detected and correctly predicted and the model showed very good results when tested on PDEG, PDI and PSS datasets. The average speed of all detection stages (vehicle detection, plate type, plate segmentation, and plate characters) is up to 135.3ms when run under experimentation configuration. Fig. 12 and 13 show results displayed of the model stages A, B, C and D.

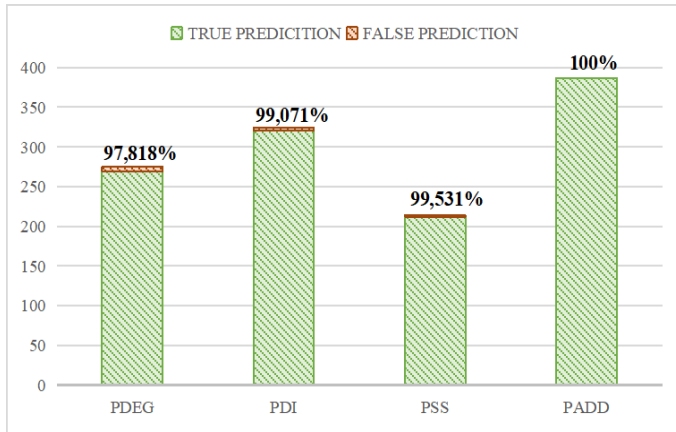


Fig. 11. Model precision on problematic datasets.

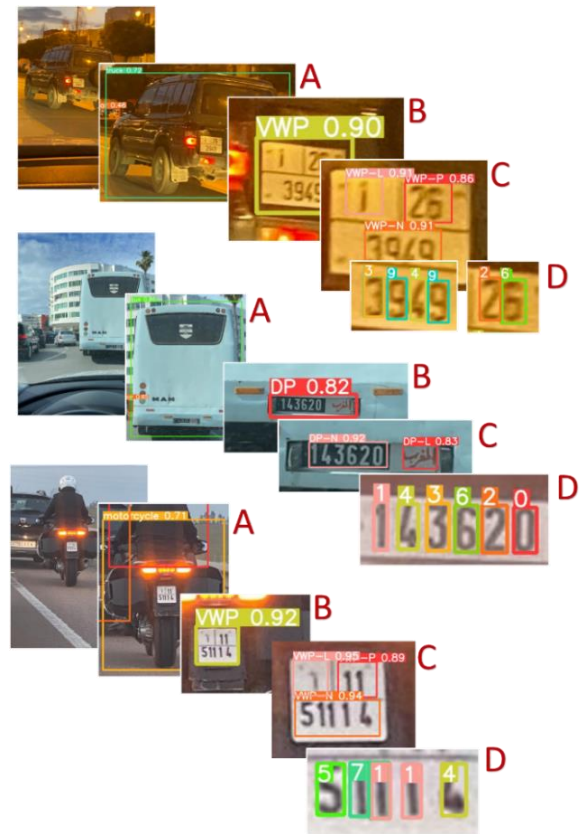


Fig. 13. Model's result on VWP and DP.

By adopting the presented architecture, the model has overwhelmed the above mentioned issues. The present model ensures the following results:

- The recognition of only characters inside regions and the remedy for the separators issue;
- No separators are recognized as characters, especially the Arabic letter "A";
- The mode performs under different conditions of illumination, camera noise, and no matter the distance between character is;
- No additional features are recognized and only essential parts of the plate are depicted;
- The specification of the intended result wanted from the region segmentation result. No letters are recognized as a number (case of "1" and Arabic letter "A" , "W" and the similar number "9", etc.)
- Optimization of the result of the recognition of Arabic similar characters and resolution of recognition of alphabet having separated parts (dots).
- The optimization of training dataset based on digits, different shadows and illumination specification, etc.
- Possibility of the adding of new plates (foreign plates) by adding of new categories in plate detection (HWP, VWP, YP, WWP, DP, FRP, GERP, etc.).



Fig. 12. Model's result on HWP, YP and WWP.

## VI. CONCLUSION

From what has been tackled above, since there are now more cars on the road than ever before, there is a greater demand for a reliable and versatile license plate recognition system. Like everywhere else, local governments, government agencies, and private businesses in Morocco require a robust License Plate Recognition (LPR) system that takes into account local plate specifications (HWP, VWP, DP, YP, and WWP) and typefaces used by plate manufacturers. This study presents a YOLOv5 framework-based intelligent LPR system that was trained on a multiple font-oriented datasets (CRE, HSRP, FE-S, etc.) and environmental factors (illumination, climate, light, etc.). This model contains an intelligent region segmentation stage that is dependent on the plate's type. This segmentation improves significantly recognition precision, and resolves the old separator issue. Results demonstrate that the trained model is capable of identifying automobiles, license plates of every type and font, as well as digits and plate portions with precisions of: 99.165% when test on issued plates.

## VII. FUTURE WORKS

In future research, it is important to explore various avenues to enhance the intelligent Moroccan license plate recognition system. These include extending its capabilities to recognize license plates in multiple languages, accommodating the diverse population and foreign vehicles in Morocco. Also, addressing privacy and security concerns should be a priority, ensuring the secure handling of captured license plate data. Additionally, continuous dataset updates are necessary to keep the system up to date with evolving license plate designs and new plate types. By considering these future works, the intelligent license plate recognition system can be further advanced to enhance its accuracy, versatility, and practicality for various applications in Morocco's context.

## VIII. DATA AVAILABILITY STATEMENT

The data used in this study was collected manually by the authors and sorted by type of plate: WWP, VWP, YP, and DP. After further analyzing the collected pictures, the data was sorted into four folders: PDEG, PDI, PSS, and PADD. A part of this datasets used in the analysis will be available upon request.

## IX. CONFLICT OF INTEREST

The authors of this manuscript declare that they have no financial or personal relationships with other people or organizations that could inappropriately influence their work. The authors confirm that this article is original, has not already been published in any other journal, and is not currently under consideration by any other journal. The authors also confirm that all the data presented in this manuscript are original and authentic.

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# Deep Learning for Personal Activity Recognition Under More Complex and Different Placement Positions of Smart Phone

(RDPARF)

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**Abstract**—Personal Activity Recognition (PAR) is an indispensable research area as it is widely used in applications such as security, healthcare, gaming, surveillance and remote patient monitoring. With sensors introduced in smart phones, data collection for PAR made easy. However, PAR is non-trivial and difficult task due to bulk of data to be processed, complexity and sensor placement positions. Deep learning is found to be scalable and efficient in processing such data. However, the main problem with existing solutions is that, they could recognize up to 6 or 8 actions only. Besides, they suffer from accurate recognition of other actions and also deal with complexity and different placement positions of smart phone. To address this problem, in this paper, we proposed a framework named Robust Deep Personal Action Recognition Framework (RDPARF) which is based on enhanced Convolutional Neural Network (CNN) model which is trained to recognize 12 actions. RDPARF is realized with our proposed algorithm known as Enhanced CNN for Robust Personal Activity Recognition (ECNN-RPAR). This algorithm has provision for early stopping checkpoint to optimize resource consumption and faster convergence. Experiments are made with MHealth benchmark dataset collected from UCI repository. Our empirical results revealed that ECNN-RPAR could recognize 12 actions under more complex and different placement positions of smart phone besides outperforming the state of the art exhibiting highest accuracy with 96.25%.

**Keywords**—Human activity recognition; deep learning; CNN; MHealth dataset; artificial intelligence

## I. INTRODUCTION

Human action recognition (HAR) has become an important research area. Particularly, smart phones came with sensors that are useful to know the activities of humans. At the same time wearable devices are available for monitoring human health or actions. Smart phones became handy to collect data pertaining to human actions. However, based on the position of sensor or smart phone on human body, the data contains details of specific human action that can be discovered automatically using machine learning (ML) and deep learning (DL) techniques [1]. As the position or placement of wearable device or sensor plays crucial role, it is important to consider different positions and corresponding action recognition possibilities. It is observed that learning based approaches in the form of ML and DL techniques have

potential to learn from large volumes of historical data and gain knowledge pertaining to activity recognition [4].

Extensive review of literature has revealed that the existing methods could recognize different number of human activities. Table 1 shows the details of different methods and how many actions they can recognize. In the same fashion, there are different devices that are used for the research on HAR as presented in Table 2. Literature has shown many existing approaches and their ability to recognize different human activities. In [5] a multi-model approach is designed to deal with automatic recognition of human activities. They used different methods for classification besides providing their merits, challenges, and future possibilities. Nandy et al. [7] uses smart phones and wearable devices to obtain data suitable for human activity recognition. In [8] an ultrasonic sensor grid is used in smart phone environment to collect data about human behaviour. In [11], there is an effort to monitor humans automatically besides knowing their actions in an adaptive fashion. In [12], there is exploration of different methods used for automatic recognition of human activities. In [14] adversarial learning is explored in order to improve training quality that leads to higher level of accuracy in human action recognition. From the literature, it is found that the main problem with existing solutions is that, they could recognize up to 6 or 8 actions only. Besides, they suffer from accurate recognition of other actions and deal with complexity and different placement positions of smart phone. Our contributions in this paper are as follows.

1) We proposed a framework named Robust Deep Personal Action Recognition Framework (RDPARF) which is based on enhanced Convolutional Neural Network (CNN) model which is trained to recognize 12 actions.

2) An algorithm known as Enhanced CNN for Robust Personal Activity Recognition (ECNN-RPAR) is proposed to realize RDPARF.

3) An application is built to evaluate RDPARF and its underlying algorithm for performance in detecting more human actions.

The remainder of the paper is structured as follows. Section 2 reviews prior works on automatic human action recognition based on ML and DL techniques. Section 3

presents the proposed framework, procedures, and proposed algorithm. Section 4 presents result of experiments. Section 5 draws conclusions and bestows scope for future possibilities.

## II. RELATED WORK

This section reviews related works pertaining to human activity recognition using sensors associated with devices like smart phones. Chen et al. [1] explored various ML models that make use of data collected from smart phone sensors to recognize human activities. They used a cycle detection algorithm to know the trends on the user behaviour. They discussed about different positions from which sensors are operated and the impact of the positions in human activity recognition. Nweke et al. [2] explored on the importance of data fusion and usage of multiple ML techniques for human activity recognition. Their work includes number of models and approaches that are existing for this kind of research. Gani et al. [3] explored different sensor placement positions targeting specific human actions. They proposed a ML based methodology for detection of various human actions. Thakur and Biswas [4] investigated on ML and DL models that are suitable for human activity recognition based on the data collected by smart phones. In [5] a multi-model approach is designed to deal with automatic recognition of human activities. They used different methods for classification besides providing their merits, challenges and future possibilities.

Suto et al. [6] studied different ML models that are suitable for human activity recognition. Their study has significance in terms of their approaches that work for offline and also online based human activity recognition. They found that sensor data changes based on its position and the position of sensor has to do with which kind of action it supports for recognition. Nandy et al. [7] uses smart phones and wearable devices to obtain data suitable for human activity recognition. From the data, they explored feature importance in order to leverage learning based phenomena in activity recognition. In [8] an ultrasonic sensor grid is used in smart hone environment to collect data about human behaviour. Their approach was found to be non-intrusive in recognizing human activities. Cornacchia et al. [9] reviews different existing studies on human activity recognition that are based on the data collected from wearable sensors. They investigated it with simple sensors and also hybrid sensors. Zdravevski et al. [10] considered Ambient Assisted Living (AAL) environment with feature engineering towards improving accuracy in activity recognition.

In [11], there is an effort to monitor humans automatically besides knowing their actions in an adaptive fashion. Based on the smart phone collected data, their research reveals the utility of automatic human action recognition in healthcare domain. In [12], there is exploration of different methods used for automatic recognition of human activities.

They also explored different approaches for federated learning to improve intelligence required for recognition. In [13] a novel approach is proposed considering swarm optimization algorithm and hybrid diversity enhancement. Besides it follows a selective ensemble approach towards improving detection accuracy further. In [14] adversarial learning is explored in order to improve training quality that leads to higher level of accuracy in human action recognition. A bidirectional LSTM method is explored in [15] for detection of human actions.

A boosting approach is exploited in [16] for to know well-being of humans based on their actions. Sensors of smart phone are used in [17] to obtain data pertaining to human behaviour for analysis and authentication purposes. Feature selection enhancement is the main research focus in [18] for leveraging detection performance.

Machine learning and opportunistic sensing based approach are explored in [19] and [20] respectively for monitoring humans about their actions. Other important researches found in the literature include feature extraction and deep learning [21], classification of sports and daily activities using ML models [22], deep learning for knowing human physical actions [23], monitoring of player activities in presence of mobility [24] and passive mobile sensing for continuous authentication [25].

As presented in Table 1, different prior works are summarized in terms of the activities, position of sensors and the techniques used for activity recognition.

As presented in Table 2, it is observed that different kinds of devices and sensors are used for finding human activities and behaviour associated with physical and mental health of humans. From the literature, it is found that the main problem with existing solutions is that, they could recognize up to 6 or 8 actions only. Besides, they suffer from accurate recognition of other actions and also deal with complexity and different placement positions of smart phone. This paper proposes a framework with underlying algorithm for addressing those issues.

TABLE I. SHOWS SUMMARY OF TECHNIQUES FOUND IN LITERATURE ALONG WITH ACTIVITIES AND SENSOR POSITIONS

Reference	Person's Actions	Smartphone Position	ML / DL Technique	#Activities
[26]	Sitting, standing, stairs-down, stairs-up, jogging, walking	Not Available	J48, LR, MLP	6
[27]	Walking, cycling, running, stairs-up, stairs-down, inactive, driving	Shirt pocket, pant pocket, handbag and hand.	DT, NB, C4.5, KNN and SVM	7
[28]	Sitting, standing and walking	Hand, belt, pocket and handbag	HMM and SVM	3
[29]	Walking, slow walk, fast walk, running, aerobic dancing, stairs-up and stairs-down.	Pant pocket and hand	MLP, SVM, RF, LMT and LR	6
[30]	Walking, jogging, kitchen activity and assembly line activity	Not mentioned	CNN	3

[31]	Walking, running, stairs-up, stairs-down and static.	Front pocket of coat and trousers' back pocket	NB, DT and SMO	5
[32]	Standing, sitting, walking, jogging, stairs-up and stairs-down.	Not mentioned	Ensemble of MLP, LR and J48	6
[33]	Walking, sitting and standing	Not mentioned	CNN	3
[34]	Walking, jumping, running, falling, quick walk, step walk, stairs-up and stairs-down.	Cloth pocket, trouser pocket and waist	CNN	8
[35]	Sitting, standing, walking, stairs-up, stairs-down and lying down.	Not mentioned	SVM	6
[36]	Sitting, standing, walking, stairs-up, stairs-down and lying down.	Not mentioned	KNN	6
[37]	Walking, sitting, standing, stairs-up, stairs-down and lying	Pocket	CNN	6
[38]	Walking, sitting, standing, running, cycling, stairs-up and stairs-down.	Pant pocket	SVM	7
[39]	Walking, sitting, standing and stairs-up.	Bag, belt, shirt pocket and right pant pocket.	LR	4
[40]	Staying still, walking and running.	Bag, pocket and hand	CNN	3
[41]	Sitting, standing, walking, jumping and lying	Not Mentioned	ML techniques with unsupervised learning	5
[42]	Sitting, walking, standing, stairs-up, stairs-down and lying	Not Mentioned	SVM with multiple classes	6
[43]	Walking, standing, running, casual movement, cycling and public transport	Not mentioned	Deep learning	6
[44]	Walking, standing, sitting, running and cycling.	In hand and trouser pocket	Adaboost	5
[45]	Walking, sitting, stairs-up, stairs-down, lying and climbing.	Not Mentioned	DT, SVM, KNN and Ensemble Learning	6
[46]	Sitting, walking, lying, stair-up, stairs-down, lying	Waist	RNN	6
[47]	Walking, sitting, standing, stairs-up, stairs-down.	Waist and belt	KNN and SVM	5
[48]	Walking, fast walk, running, static, stairs-up and stairs-down.	Backpack, shirt pocket and pant pocket	ELM and Ensemble Learning	7
[49]	Walking, standing, sitting, running, stairs-up and stairs-down.	Waist and belt	MLP	6

TABLE II. SHOWS DIFFERENT KINDS OF SENSORS USED IN THE PRIOR STUDIES TOWARDS FINDING HUMAN ACTIVITIES LINKED TO DIFFERENT APPLICATIONS

Reference	Device Type	Details
[50]	Sensors in wearable devices	Focused on the importance of wearable biosensors in healthcare industry.
[51]	Sensors in smartphone	Study designed to know physical activity and weight loss possibilities.
[52]	Sensors in smartphone	Study meant for to find long-term diseases and sensor usage in healthcare.
[53]	Sensors in smartphone	Study uses sensors to know mental disorders of humans
[54]	Sensors in smartphone	Investigation into bipolar disorders using iOS and Android smart phones
[55]	Sensors in smartphone	Explores human behavior linked to healthcare analytics
[56]	Sensors in smartphone and wearable devices	Studies on the mental health of humans
[57]	Sensors in smartphone	Explores mental health of humans using ML techniques
[58]	Sensors in smartphone	Explores human activity recognition, categorization and feature engineering.
[59]	Wireless Sensors	Studies the possibilities in remote healthcare and latest methods in the process.

### III. PROPOSED WORK

We proposed a deep learning based framework for automatic recognition of personal activities based on the smart phone sensor data. Several researchers have contributed earlier towards personal activity recognition as explored in [26], [27] and [28] to mention few. However, the number of activities recognized is limited to 3 to 8. However, in real world, smart phone sensors could be positioned and it is possible to recognise more activities. Towards this end, in our research, we could experiment with more complex activities due to

different placement positions. Our system recognizes 12 actions such as “standing still, sitting and relaxing, laying down, walking, climbing stairs, waists bends forward, frontal elevation of arms, knees bending, cycling, jogging, running and jump front & back”.

#### A. Our Framework

Our framework is illustrated in Fig. 1. The given M-Health dataset that contains smart phone sensors generated data under complex and different placement positions is used by the framework to explore possibilities of recognising 12 actions.



The dataset is subjected to pre-processing feature extraction. Then an enhanced CNN classifier is trained on the chosen features. The training of deep learning model has resulted in a knowledge model known as personal activity recognition system which is saved to persistent storage for reuse. This model is a multi-class classifier as we intend to recognize 12 personal activities. The pre-processing splits data into training and test set in order to have experiments without over fitting. We also defined an Early Stopping strategy based on validation loss value. If there is no change in validation loss after given patience value, this point is considered to be early stopping condition. This strategy has proved to be good as it could avoid over fitting issues. The saved trained model is reused with test data to perform personal activity recognition.

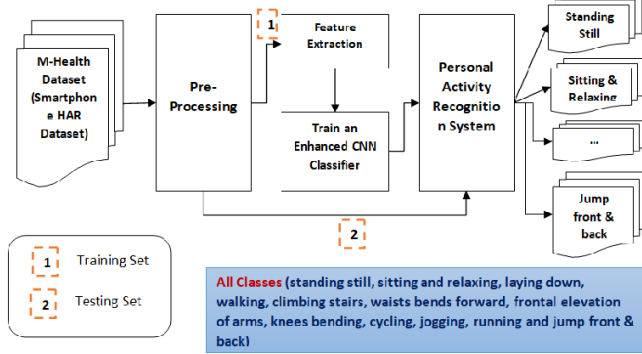


Fig. 1. Proposed framework known as robust deep personal action recognition.

Framework (RDPARF) for personal activity recognition considering more complex and different placement positions of smart phone

We enhanced CNN model to meet our requirement in this research. Layers are configured in such a way that they tend to produce best results with multi-class classification. CNN model is enhanced as one size does not fit all. In other words, the CNN used to solve one problem cannot be directly used for another problem.

### B. Enhanced CNN Model

We configured an enhanced CNN model in such a way that it is best suited for multi-class classification of personal activities. The dataset used for empirical study has sensor positions that are diversified to realize more human actions. The model performs convolutional operations to acquire features from the given data. It has carefully chosen hyperparameters set to improve prediction performance.

In Table 3 the sensor data input vector is denoted as  $x_i^0 = [x_1, \dots, x_N]$  where N refers to the per window values. The outcome of the first convolutional layer is observed and it can be expressed as in Eq. 1. Table 1 shows all the notions used in the proposed model.

$$c_i^{1,j} = \sigma(b_j^1 + \sum_{m=1}^M w_m^{1,j} x_{i+m-1}^{0,j}), \quad (1)$$

Where layer index is denoted by  $l$ , activation function is denoted by  $\sigma$ , the bias term for given feature map is denoted as  $b_j$ , filter size is denoted by M and weight for given feature

map is denoted by  $w_m^j$ . In the same fashion, the outcome of  $l^{th}$  convolutional layer is expressed as in Eq. 2.

$$c_i^{l,j} = \sigma(b_j^l + \sum_{m=1}^M w_m^{l,j} x_{i+m-1}^{l-1,j}). \quad (2)$$

Here  $c_i^{l,j}$  is used to obtain summary of nearby outputs through pooling layer which is meant for optimizing feature maps. We used max pooling as it is characterized by using resulting max value as expressed in Eq. 3.

$$p_i^{l,j} = \max_{r \in R} (c_{i \times T + r}^{l,j}), \quad (3)$$

where pooling size is denoted by R and stride by T. In the enhanced CNN architecture many convolutional and pooling layers are stacked to ensure a hierarchical feature extractor. The extracted features can have ability to discriminate among the personal activities. They have capability to discriminate simple to complex activities. In order to recognize personal activities fully connected layer and softmax layer are combined. This combination forms a top-most layer. The features obtained from convolutional layers and pooling layers are transformed into feature vectors denoted as  $p^l = [p_1, \dots, p_2]$  where number of units is denoted as  $l$  in the ultimate pooling layer. The outcome of these layers is given as input to fully connected layer as expressed in Eq. 4.

$$h_i^j = \sum_j w_{ji}^{l-1} (\sigma(p_i^{l-1}) + b_i^{l-1}) \quad (4)$$

TABLE III. SHOWS DIFFERENT KINDS OF SENSORS USED IN THE PRIOR STUDIES TOWARDS FINDING HUMAN ACTIVITIES LINKED TO DIFFERENT APPLICATIONS

Reference	Device Type	Details
[50]	Sensors in wearable devices	Focused on the importance of wearable biosensors in healthcare industry.
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[55]	Sensors in smartphone	Explores human behavior linked to healthcare analytics
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[57]	Sensors in smartphone	Explores mental health of humans using ML techniques
[58]	Sensors in smartphone	Explores human activity recognition, categorization and feature engineering.
[59]	Wireless Sensors	Studies the possibilities in remote healthcare and latest methods in the process.

Where activation function denoted as  $\sigma$  and it is same as that of previous layers. The bias terms is denoted as  $b_i^{l-1}$  and the  $w_{ji}^{l-1}$  denotes weights associated with  $i^{th}$  and  $j^{th}$  nodes in the  $l-1$  layer. The softmax layer, which is expressed as Eq. 5, is the final layer in the deep network for performance classification.

$$(c|p)=\operatorname{argmax}_{c \in C} \frac{\exp(p^{L-1}w^L + b^L)}{\sum_{k=1}^{N_C} \exp(p^{L-1}w_k)}, \quad (5)$$

Where the activity class is denoted as  $c$ ,  $p$  is the index of last layer while the number of activity classes is denoted as  $N_C$ . Equations from 1 through 4 perform forward propagation that result in getting error values of the network. SGD is used in training to minimize error cost and also update weights. Sensor data is used in the training process in the form of mini batches. In the fully connected layer back propagation is performed which is expressed as in Eq. 6.

$$\frac{\partial E}{\partial w_{ij}^l} = y_i^l \frac{\partial E}{\partial x_j^{l+1}}, \quad (6)$$

where the cost function is denoted by  $E$ , weight from  $u_i^l$  and  $u_i^{l+1}$  in the  $l+1$  layer is denoted by  $w_{ij}^l$ . Computation of  $y_i^l$  is done as expressed in Eq. 7.

$$y_i^l = (x_i^l) + b_i^l \quad (7)$$

Weights are adjusted using backpropagation in convolutional layers. This process is expressed as in Eq. 8.

$$\frac{\partial E}{\partial w_{ab}} = \sum_{i=0}^{N-M-1} \frac{\partial E}{\partial x_{ij}^{l-1}} y_{(i+a)}^{l-1}, \quad (8)$$

where map function is denoted as  $y_{(i+a)}^{l-1}$  which is equal to  $\sigma(x_{(i+a)}^{l-1}) + b^{l-1}$ . The results of  $\frac{\partial E}{\partial y_{ij}^l} \sigma'(x_{ij}^l)$  are equal to that of  $\frac{\partial E}{\partial x_{ij}^l}$ . The process of back and forward propagations are continued until stopping condition is met.

### C. Regularization

When it comes to weights in the network, it is possible that large weights can lead to weight vector to have local minimum due to small amendments to gradient descent in the optimization process. Thus it makes it difficult in exploring weight space. Therefore, it is required to have regularization mechanism to deal with large weights. It is achieved by adding penalizing term to every set of weights as given in Eq. 9.

$$E = E_0 + \lambda \sum_w w^2, \quad (9)$$

where  $\lambda \sum_w w^2$  is the penalizing term and  $E_0$  is the cost function prior to regularization. As the cost function is updated, the learning rule is updated and it is expressed as in Eq. 10.

$$w_i = (1 - \eta\lambda)w_i - \eta \left( \frac{\partial E_0}{\partial w_i} \right) \quad (10)$$

where the weight decay factor is denoted by  $1 - \eta\lambda$ . Gradient descent can be momentum based to have velocity to parameters that are under optimization. It is done such that only velocity is changed but not the position associated with the weight space. For each weight variable in  $v = [v_1, \dots, v_K]$ , there is corresponding velocity variable. The update of gradient descent rule is then expressed as in Eq. 11 and Eq. 12.

$$v \rightarrow v' = \mu v - \eta \nabla E, \quad (11)$$

$$w \rightarrow w' = w + v' \quad (12)$$

where the momentum coefficient is denoted as  $\mu$ .

We used dropout appropriately to get rid of overfitting problem. It is achieved by doing so instead of amending cost function. The overfitting problem is solved by temporary deletion of nodes without changing input and output neurons. It makes the training process more efficient. This process also makes neurons not to be influenced by other neurons while learning features. For each given training sample, dropout is followed by consideration of an include probability which is done independent of nodes. In the proposed enhanced CNN model dropout is used in fully connected layer of the network.

### D. Hyperparameter Tuning

In the proposed enhanced CNN architecture, there are large number of possibilities of hyper parameter combinations. We followed a greedy tuning process in order to assess the effect of hyper-parameter tuning on the network. The tuning is experimented in terms of pooling size, filter size, number of feature maps and even number of layers in the network. In our empirical study we explored with network layers 1 to 4, feature maps from 10 through 200 with interval of 10, pooling size considered from 1x2 through 1x15 and filter size is considered from 1x3 through 1x15. In all our experiments one softmax layer is used. Finally, best performing hyper-parameters are used.

### E. Proposed Framework

We proposed an algorithm known as Enhanced CNN for Robust Personal Activity Recognition (ECNN-RPAR). It is designed and implemented to realize our PAR framework named Robust Deep Personal Action Recognition Framework (RDPARF).

#### Algorithm 1: Enhanced CNN for Robust Personal Activity Recognition

<p><b>Algorithm:</b> Enhanced CNN for Robust Personal Activity Recognition (ECNN-RPAR)</p> <p><b>Inputs</b></p> <p>MHealth dataset <math>D</math> (reflects more complex and different placement positions of smart phone)</p> <p>Batch size <math>n</math></p> <p>Number of epochs <math>m</math></p> <p><b>Output</b></p> <p>Multi-class classification results of PAR <math>R</math> (12 classes)</p> <p>Performance evaluation results <math>P</math></p> <ol style="list-style-type: none"> <li>1. Begin</li> <li>2. <math>D' \leftarrow \text{DataPreparation}(D)</math></li> <li>3. <math>(T1, T2) \leftarrow \text{SplitData}(D')</math></li> <li>4. Initialize CNN model</li> <li>5. Add max pooling layer</li> <li>6. Add convolutional layer</li> <li>7. Add batch normalization layer</li> <li>8. Add convolutional layer</li> </ol>
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9. Add batch normalization layer
10. Add linear layer
11. Add batch normalization layer
12. Add linear layer
13. Add softmax layer
14. Tuning hyper-parameters
15. Compile the model  $M$
16. For each epoch  $e$  in  $m$
17. For each batch  $b$  in  $n$
18. IF early stopping criterion is FALSE Then
19. Update  $M$  using  $TI$
20. Else
21. Break
22. End For
23. End For
24.  $(R,P) \leftarrow \text{ModelTesting}(M, T2)$
25. Display  $R$
26. Display  $P$
27. End

$D$ : Dataset	$D'$ : Pro-processed dataset
$m$ : Number of epochs	$n$ : Batch size
$R$ : Classification results	$TI$ : Training set
$T2$ : Test set	$M$ : Proposed model
$e$ : each epoch	$b$ : each batch
$P$ : Performance statistics	

As presented in Algorithm 1, it takes MHealth dataset  $D$ , number of epochs  $m$ , number of batches  $n$  as input and generates personal activity recognition results  $R$  along with performance statistics. It has data preparation phase to improve given dataset with the help of linear interpolation, scaling and segmentation. Then it splits data into 80% training set and 20% test set. Then it initializes our enhanced CNN model. Afterwards, it configures all the layers as per the proposed model. Hyper-parameter tuning is carried out. Then there is an iterative process based on given number of epochs and batch size to train the model using  $TI$ . The model training process gets terminated if it satisfies early stopping criterion. This is considered because it is important to stop training before it overfits. Once the model is trained, it gains knowledge from the training process. This will result in a knowledge model that is saved to persistent storage for further reuse. This saved model is loaded in the testing phase and every instance of test set  $T2$  is subjected to prediction of personal activities. Finally, the algorithm returns personal activity recognition results  $R$  and performance statistics  $P$ .

#### IV. EXPERIMENTAL RESULTS

Experiments are made with the proposed enhanced CNN which is used in the framework and underlying algorithm

named ECNN-RPAR. The enhanced CNN is designed and implemented to cover all PAR classes under more complex and different placement positions of smart phone. Number of epochs used in the empirical study is 200 but it is subjected to early stopping criterion. Dropout is set to 0.5, batch size is 400, window size for data splitting is 50 and step value is set to 25. Total number of classes (including normal/no action class) is 13, size of max pool is 2 and stride of max pool is set to 2. Dataset for our empirical study is collected from [60] which reflects more complex and different placement positions of smart phone. The experimental results are provided in terms of confusion matrix as presented in Fig. 2.

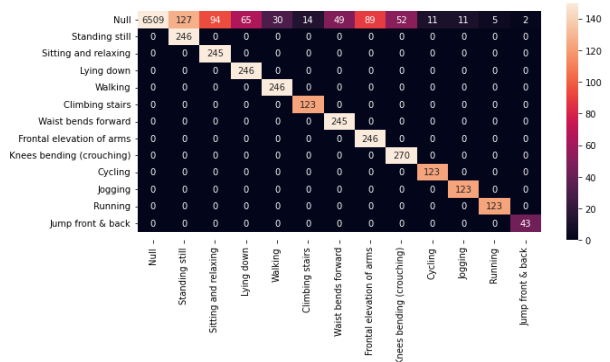


Fig. 2. Confusion matrix reflecting prediction performance of the proposed model for 12 classes.

As the statistics are provided through confusion matrix for all 12 classes, performance of the proposed algorithm ECNN-RPAR is ascertained. With 200 epochs used in experiments, the training loss and validation loss [65] are observed in presence of early stopping criteria.

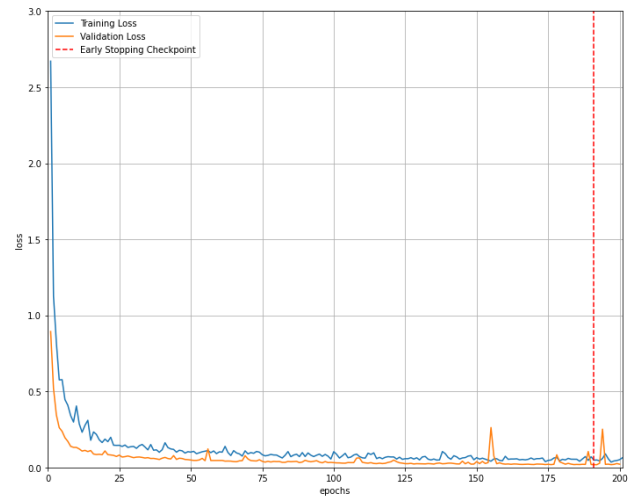


Fig. 3. Loss dynamics and early stopping criterion check point.

As presented in Fig. 3, visualization of the performance of ECNN-RPAR [63,64] is provided against number of epochs. Number of epochs used in experiments is 200 but it is subjected to early stopping criterion.

As the number of epochs is increased, it is observed that the training and validation loss is reduced gradually. Reduced loss indicates improved performance.

As presented in Table 4, the personal action recognition [61] performance of the proposed algorithm ECNN-RPAR is provided.

TABLE IV. PERFORMANCE OF THE PROPOSED MODEL

PAR Model	Performance (%)			
	Precision	Recall	F-1 Score	Accuracy
Proposed (ECNN-RPAR)	89.12	85.32	87.17	96.25

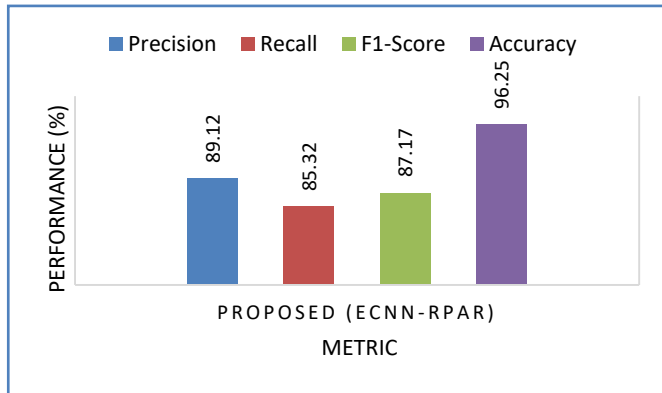


Fig. 4. Personal action recognition performance of proposed ECNN-RPAR algorithm.

As presented in Fig. 4, the action recognition performance of the proposed ECNN-RPAR algorithm is provided. It could achieve detection of 12 classes with 89.12% precision, 85.32% recall, 87.17% F1-score and 96.25% accuracy.

TABLE V. PERFORMANCE OF PROPOSED ECNN-RPAR ALGORITHM COMPARED WITH EXISTING MODELS

PAR Models	Performance (%)			
	Precision	Recall	F-1 Score	Accuracy
ANN	75.48	69.34	72.27	79.36
Baseline CNN	78.45	75.78	77.09	81.58
LSTM	80.25	73.23	76.57	85.73
Proposed (ECNN-RPAR)	89.12	85.32	87.17	96.25

As presented in Table 5, the personal action recognition performance of the proposed ECNN-RPAR algorithm is compared against the state of the art.

Performance of proposed ECNN-RPAR [62] algorithm is compared against ANN model, baseline CNN and LSTM. ANN showed least performance among all models. Its precision is 75.48%, recall 69.34%, F1-score 72.27% and accuracy 79.36%. Baseline CNN model showed performance better than that of ANN. CNN achieved 78.45% precision, 75.78% recall, 77.09% F1-score and 81.58% accuracy. LSTM showed better performance over CNN with 80.25% precision, 73.23% recall, 76.57% F1-score and 85.73% accuracy. The proposed ECNN-RPAR algorithm showed highest performance with 89.12% precision, 85.32% recall, 87.17% F1-score and 96.25% accuracy. It is observed from the results that the existing methods showed comparatively poor performance in accurately predicting 12 personal actions.

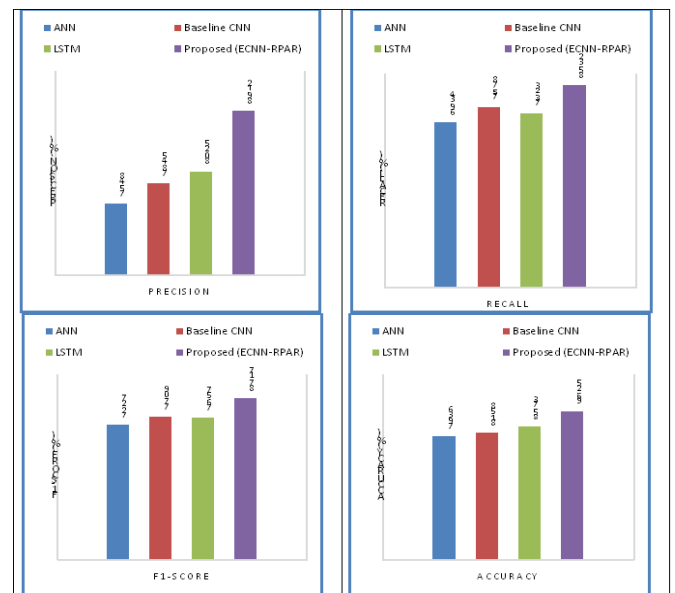


Fig. 5. Performance Of Proposed ECNN-RPAR Algorithm Compared With Existing Models.

## V. CONCLUSION AND FUTURE WORK

We proposed a framework named Robust Deep Personal Action Recognition Framework (RDPARF) which is based on enhanced Convolutional Neural Network (CNN) model which is trained to recognize 12 actions. The given M-Health dataset that contains smartphone sensors generated data under complex and different placement positions is used by the framework to explore possibilities of recognising more actions. The dataset is subjected to pre-processing feature extraction. Then an enhanced CNN classifier is trained on the chosen features. The training of deep learning model has resulted in a knowledge model known as personal activity recognition system which is saved to persistent storage for reuse. RDPARF is realized with our proposed algorithm known as Enhanced CNN for Robust Personal Activity Recognition (ECNN-RPAR). This algorithm has provision for early stopping checkpoint to optimize resource consumption and faster convergence. Experiments are made with MHealth benchmark dataset collected from UCI repository. Our empirical results revealed that ECNN-RPAR could recognize 12 actions under more complex and different placement positions of smart phone besides outperforming the state of the art exhibiting highest accuracy with 96.25%. However, we have directions for future scope of our work. First, it is interesting to explore pre-trained deep models with transfer learning towards performance improvement. Second, usage of hybrid deep learning models with our framework could leverage performance. Third, usage of Generative Adversarial Network (GAN) along with deep models for generator and discriminator is another direction for future work.

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# A Review on Security Techniques in Image Steganography

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**Abstract**—Given the increased popularity of the internet, the exchange of sensitive information leads to concerns about privacy and security. Techniques such as steganography and cryptography have been employed to protect sensitive information. Steganography is one of the promising tools for securely exchanging sensitive information through an unsecured medium. It is a powerful tool for protecting a user's data, wherein the user can hide messages inside other media, such as images, videos, and audios (cover media). Image steganography is the science of concealing secret information inside an image using various techniques. The nature of the embedding process makes the hidden information undetectable to human eyes. The challenges faced by image steganography techniques include achieving high embedding capacity, good imperceptibility, and high security. These criteria are inter-related since enhancing one factor undermines one or more others. This paper provides an overview of existing research related to various techniques and security in image steganography. First, basic information in this domain is presented. Next, various kinds of security techniques used in steganography are explained, such as randomization, encryption, and region-based techniques. This paper covers research published from 2017 to 2022. This review is not exhaustive and aims to explore state-of-the-art techniques applied to enhance security, crucial issues in the domain, and future directions to assist new and current researchers.

**Keywords**—Image steganography; data hiding; steganographic security; randomization; encryption

## I. INTRODUCTION

With the evolution of the internet and social networking as well as a rapid increase in communication facilities, a huge amount of information is being exchanged every moment. Security and privacy of exchanged data should be guaranteed, especially against malicious threats. Cryptography and steganography are techniques that are being used to achieve high security [1]. Cryptography is the process of converting raw information or plaintext to unreadable form called ciphertext, using an encryption algorithm with a key. The algorithm and the key utilized by the sender are, in most cases, used by the receiver for the decryption purpose. Hence, the original data is unreadable, and confidentiality is maintained. However, the availability of the ciphertext raises suspicions and draws the attention of opponents. On the other hand, steganography seems to be more appropriate and has recently received much attention, since it does not give rise to any signs detectable by the human eyes [2]. Steganography is the science of hiding relatively smaller information in a larger multimedia cover. Cover media could take the form of text [3], image [4], audio [5], or video [6]. Image steganography is the process of

concealing secret data within an image that appears normal to the human eye.

Several reviews on image steganography have been published in recent years. Study [7] reviews and compares various deep learning methods in the domain of image steganography. It categorizes these methods into three types: traditional, Convolutional Neural Network based, and General Adversarial Network based methods. It also discusses the datasets, experiments, and metrics used in the field. However, traditional steganographic methods are not discussed in this article. The authors of research [8] provide a comprehensive overview and evaluation of some of the latest steganographic methods. This article addresses the challenges of recent deep learning-based steganographic methods. It also discusses how to measure the performance of a steganographic technique using various criteria. Although it evaluates the security of the techniques vis-à-vis varied advanced attacks and tools, randomization-related security concepts, such as the chaotic map function, have not been mentioned or discussed.

The research [9] presents a review and a critical assessment of recently proposed steganography methods. It describes various schemes, along with their technical terms, main logics, as well as strengths and weaknesses in terms of important measures. This critical assessment is based on the type of cover object used, the algorithmic domain, and important properties used as evaluative measures for the steganographic system. However, this article might be outdated, because many of contributions have been published since then.

This research article provides an extensive and comprehensive review of the security principles used in spatial-domain image steganography. It presents and discusses various steganographic techniques according to the security concepts adopted by them, such as randomization, encryption, and adaptive embedding. Further, it provides an overview of image steganography, its goals, and traditional steganography methods along with their features, pros and cons, and performance evaluation metrics. It also provides analysis, discussion, and suggestions based on its study of image steganography security principles.

The remainder of this paper is organized as follows: Section II presents an overview of image steganography. Section III demonstrates the basic goals of image steganography. In Section IV, the search process is defined, followed by detailing of security techniques in image steganography in Section V. Section VI contains observations,

discussion, and recommendations. Finally, Section VII concludes the paper.

## II. AN OVERVIEW OF IMAGE STEGANOGRAPHY

The word steganography is of Greek origin and is constructed from two words: “steganos” and “graphie”. “Stegano” means covered and “graphie” means writing. Steganography is not a new art; it was used in ancient times to send secret messages by hiding them in certain ways. Fig. 1 summarizes the two ideas used to secure secret information [10].

Generally, cryptography is divided into symmetric and asymmetric keys, based on whether it provides authentication or confidentiality. Likewise, steganography techniques can be classified into spatial and frequency domain techniques. In the spatial domain, the secret information is directly embedded in image pixels; hence, pixel values are modified. On the other hand, in the frequency or transform domain, the image pixels are transformed into another domain, and the secret information is embedded by modifying the coefficient values. Image steganography is the process of embedding secret information within a cover image, wherein the embedded information is not visible to the human eye. The output image, which contains the secret information, is called a “stego image” [11]. Fig. 2 depicts a general steganographic system, wherein the sender optionally compresses or/and encrypts the secret information and then a certain steganographic algorithm is utilized to embed the information and produce a stego image. At the receiver’s end, the same sequence is followed in reverse to obtain the embedded information.

### A. Traditional Steganography Methods

As mentioned above, steganography techniques are classified into spatial domain and frequency domain techniques. In spatial domain techniques, pixel values are modified directly to incorporate the secret information. These techniques are famous for attaining high capacity, but they are not immune to statistical attacks and image manipulations [12]. Examples of spatial domain methods include Least Significant Bit (LSB) Replacement and its successors, Pixel Value Differencing (PVD), Pixel Indicator Techniques (PIT), and Exploiting Modification Direction (EMD) techniques, among others. In the transform or frequency domain techniques, the image pixels are first transformed into the frequency domain. Subsequently, the secret information is hidden by modifying the coefficient values. Finally, the inverse transform is applied to obtain the stego image. These techniques resist statistical attacks but achieve low capacity. The most well-known transform domain methods are the Discrete Cosine Transform (DCT), Discrete Fourier Transform (DFT), Discrete Contourlet Transform (CT), and Discrete Wavelet Transform (DWT) [12],[13].

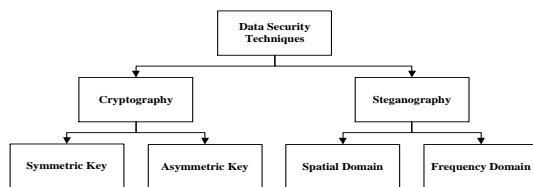


Fig. 1. Data security classes [7].

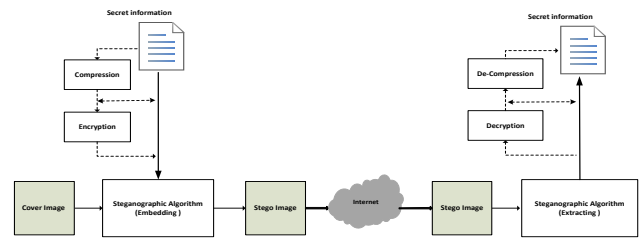


Fig. 2. General image steganographic system.

LSB Replacement (or simply LSB) is a well-known spatial domain technique, widely utilized due to its simplicity and potential to achieve high capacity. In this method, the secret information is embedded within the least significant bit of the cover image pixels, in order to minimize distortion. The resultant stego image is indistinguishable from the original image. Further, to increase payload capacity, more than one LSB of a pixel may be used to hide information; however, this might degrade the visual quality of the stego image [14]. It is worth mentioning that several enhancements of the original LSB have already been introduced. LSB Matching (LSBM) is an enhanced version of the LSB method [15]. Here, if the embedded bit does not match the cover pixel’s LSB, then +1 or -1 values are added randomly to that pixel, so as to avoid the asymmetry artefacts that are usually introduced by the standard LSB technique and can be detected by steganalysis techniques [16]. To improve upon the previous methods, the LSB Matching Revisited (LSBMR) method was introduced by [17]. It embeds secret information within the LSB, with minimum changes to the carrier image. It hides two secret bits into two pixels simultaneously, wherein the first bit is embedded directly, while the second secret bit value is produced based on the relationship between those two bits. The objective is to make the detection of the secret information more difficult, compared to standard techniques [14], [17].

Another approach towards embedding secret information in the cover image consists of hiding bits in the edge area where pixels’ intensity values change abruptly. Such techniques are referred to as Edges Based Embedding (EBE) Steganography, which allows the hiding of large payloads in those particular edge pixels. Several research studies have been published in this context, such as [16],[18],[19],[20]. PVD is another method of hiding binary data, wherein the cover image is considered to be in the form of non-overlapped blocks of two pixels each. The difference between the two pixels is calculated and quantized into several regions that determine the number of bits of the payload [21]. In the Cyclic Steganographic Technique (CST), the embedding process is cycled through color channels of consecutive pixels [22]. The color channel selected for the current pixel is not the same color channel used in the previous pixel, or the next pixel. For example, if the LSB of the red channel is selected for the current pixel, then the green channel is selected for the next pixel, and the blue channel is preserved for three consecutive pixels. The concept of randomization along with CST is proposed in [23] wherein secret information is randomly hidden in the pixels’ LSB.

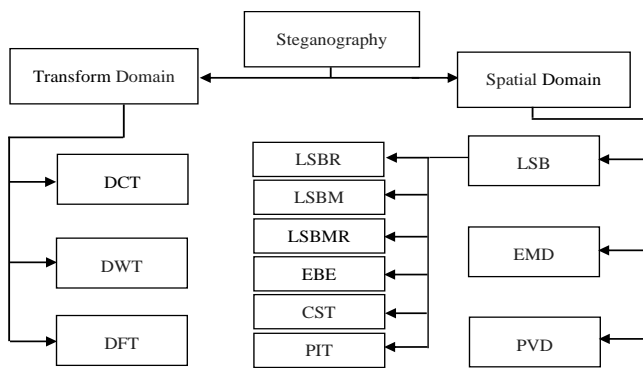


Fig. 3. Traditional steganographic techniques.

PIT is another variation of LSB techniques and is used to enhance the security and robustness of classical systems. In this method, one of the color channels of the pixel is selected as an indicator for the other two channels that are used for the embedding process [12]. An improvement is introduced in [24] takes into consideration the length of the secret message and uses two LSBs of a particular channel to indicate the presence of data in other channels. Another variation is introduced in [25]; it uses three LSBs of one of the pixel's channels as an indicator. EMD is another technique used to enhance security. In this method, the cover image is partitioned into blocks of  $n$  pixels. These  $n$  pixels of the cover image involve secret digits in a  $2n+1$ -ary notational system. One pixel is eventually altered by  $\pm 1$ . For a group of  $n$ , there are  $2n+1$  possible digits to be secretly hidden, since there are  $2n$  possible pixels' modifications and one case with no changes [26]. Article [27] presents a scheme to improve the EMD method called improved EMD (IEMD). This scheme uses an 8-ary notation system, wherein the secret digit is embedded into a group of two pixels. Fig. 3 summarizes the steganographic techniques explained above.

### III. BASIC GOALS OF IMAGE STEGANOGRAPHY

Several considerations must be taken into account while designing a steganography algorithm: capacity, imperceptibility, and security. The ultimate goal is to attain high capacity, better imperceptibility, and high security. However, these considerations are conversely related, and a trade-off needs to be made among the criteria mentioned above. More details are given in the following section [13],[28],[29].

#### A. Capacity

It refers to the amount of data in bits that can be embedded in the cover image. The objective is to hide as many bits as possible in the cover image, without affecting image imperceptibility and security. Embedding rate or Bits Per Pixel (BPP) is another widely-used term, which refers to the total amount of information relative to the total number of the cover image pixels.

#### B. Imperceptibility

When the secret information has been hidden, the resultant stego image should not create any signs that might be suspected by human eyes. Hence, the aim is to make the level of deterioration as low as possible. High imperceptibility

means low capacity and vice versa. Hence, these two concepts need to be balanced.

#### C. Security

Security is the main key to secure information sent over an unsecured network such as the internet. It refers to the ability to withstand the detectability of hidden secret information in the cover image as well as the capability of extracting it. Accordingly, the steganographic algorithm should resist the attacker's attempts to detect and extract the secret information.

As stated before, the aim is to achieve a high embedding rate, high imperceptibility, and high security. However, this is a challenging task since these metrics compete against each other. In other words, focusing on one of them will sacrifice one or more other metrics. For example, embedding high payloads will definitely lead to low imperceptibility and the possibility of low security.

## IV. SEARCH PROCESS

### A. Materials and Methods

This review study examines the existing methods and techniques of image steganography security researched between 2017 and 2022. Only studies that involved spatial image steganography are considered. This section includes subsections on data sources, search processes, data selection, and data extraction.

### B. Data Sources

The search and downloading phase has been implemented intermittently over the period from November 2021 to February 2022. The primary sources for the research have been selected from the following libraries:

- Institute of Electrical and Electronics Engineers Xplore Digital Library (<https://ieeexplore.ieee.org/Xplore/home.jsp>).
- Science Direct (<https://www.sciencedirect.com/>).
- Springer Link (<https://link.springer.com/>).
- Google Scholar (<https://scholar.google.com/>)
- Association for Computing Machinery (ACM) Digital Library (<https://dl.acm.org/>).

In addition, some other resources have been considered as well, such as the International Journal of Advanced Computer Science and Applications (IJACSA).

### C. Search Process

The search has focused on image steganography security and various keyword patterns have been used in this process. Boolean operators have helped refine the data on keywords for each research publication. Symbols and Boolean operators such as "OR" and "AND" have been used to look for the following keywords:

- ((digital image steganography) OR (security in image steganography) AND (randomization OR chaotic) AND (spatial domain)).

- ((chaotic map) AND (image steganography) AND security)) OR (randomization AND (image steganography)) AND (spatial domain).
- (((edge detection) OR (region based)) AND ((LSB image steganography) OR (LSB image steganography))) AND (spatial domain).
- (cryptography AND (image steganography)) OR (encryption AND (image steganography)) AND (spatial domain).

#### D. Data Selection

We have applied three filtering steps to select the relevant studies from the search results based on our keywords. The first step involves specifying the criteria for selecting the studies. Next, in the second step, the titles and abstracts of the studies are reviewed according to the research question in the second step. The third step involves reading the full texts of the selected studies and extracting the data. The following criteria have been mostly used for data selection:

- Has the paper been published in the last five years or so?
- Does the research article mention or discuss any of the security concepts in the image steganography field?
- Has the research article been included in any of the reference data sources?

#### E. Data Extraction

We have examined each preliminary study to identify if it was related to the security of image steganography. We have found about 220 papers upon concluding the search in February 2022. We have selected the relevant ones based on the criteria mentioned earlier. Finally, 100 related studies have been identified.

### V. SECURITY TECHNIQUES IN IMAGE STEGANOGRAPHY

One of the most challenging steganography aspects is the security attribute. Here, security refers to the process of making the hidden secret information undetectable or the embedded size and locations unguessable. Much research has been conducted in this domain, which employs different approaches to improve steganographic security. Fig. 4 depicts a summary of the findings related to securing image steganography, and Fig. 5 classifies research articles accordingly.

Encryption is a concept widely utilized to achieve security; it encrypts the secret information before embedding it. Also, the entire image may be encrypted as an intermediate step in an algorithm. Traditional encryption algorithms such as Rivest, Shamir, and Adleman (RSA), Advanced Encryption Standard AES, and Triple Data Encryption Standard (3DES) are utilized to achieve this goal. User-defined techniques are employed as well. Randomization is another approach towards attaining security, which embeds secret information in a randomized way by scattering it over the original image. As part of this concept, chaotic function, pseudorandom number generator, user-defined keys, and other techniques can be exploited. In addition, randomization can be used alone or combined with encryption techniques to add an extra layer of security. Chaotic

functions are famous for their random behaviour, wherein the outputs are unpredictable for certain input parameter values. The output is then exploited in the process of pixel location selection. Another technique to hide secret information and enhance security is transforming the cover image into another bit plane, embedding, and then retransforming the cover image to the original form. The region-based concept also improves the overall security, since it breaks the adjacent pixel correlations. In addition, some other techniques using different approaches are implemented. In the following section, more details about the above-mentioned categories have been presented.

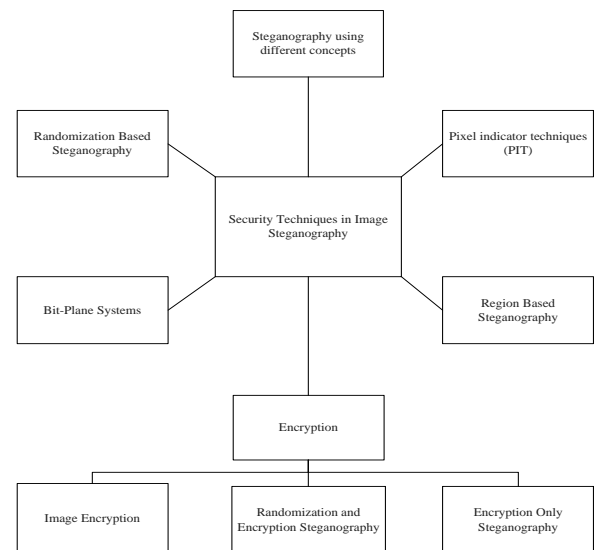


Fig. 4. Summary of findings.

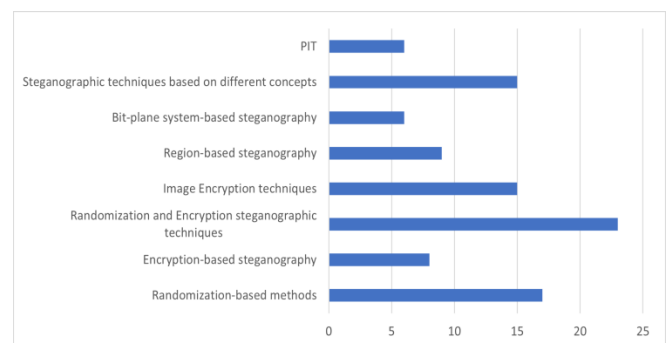


Fig. 5. Classification of the existing methods based on security technique.

#### A. Randomization based Techniques

These techniques rely merely on randomization to achieve security. In [30], random pixel positions are picked using Linear Congruential Generator (LCG). Eight bits from the secret message are embedded using the LSB technique with a sequence of 3-3-2, which means embedding three bits in the red channel, three bits in the green channel, and two bits in the blue channel. Authors in [31] suggest hiding three binary images within a grayscale image. Binary pixel values are rearranged using the mean of three random series and are hidden in a grayscale image employing the concept of Ultra Unique Numbers (UUN). Random numbers are used for pixel selection by generating multiple series in [32]. Similarly, [33]

uses Pseudo-Random Number Generator (PRNG) to choose a pixel for the embedding process. Three PRNGs are generated with the help of the Skew Tent Map (SKTM) in [34]. They are employed to scramble secret messages before insertion, choose an embedding color channel, and select a pixel location with a particular Red-Green-Blue (RGB) channel.

Authors in [35] proposed an improved 1D chaotic system model for choosing an embedding pixel location. The chaotic system utilizes a chaotic Logistic Map (LM) and a sine map function. A secret message is embedded at random positions using the Beta Chaotic Map (CM) in [36]. The algorithm in [37] selects random bits for embedding based on the use of PRNG. The key seed value and number of embedded bits are user-defined. Randomization of pixels is done via random chain codes of the key determined by the user in [38]. These chains contain a random sequence of bytes based on the hexadecimal representation of the bytes in the current key block. This sequence is used to embed the bits of secret message within the LSB of the pixels in the sub cover image. The authors of [39] suggest using two secret keys to randomize one bit of secret message; K1 chooses a channel, whereas K2 places the secret bit within a pixel. The Knight's Tour (KT) algorithm using the LSB technique is suggested by [40]. Here, the cover image is considered to be the surface of a chessboard, wherein the knight travels once to each square. In [41], the secret message is embedded in un-patterned fashion based on the outcomes of quadratic equations. In addition, combinations of RGB channels and image partitions are produced, wherein the Hungarian algorithm is employed to choose the least noisy combination, that is, the partitions of the cover image and the secret message.

In [42], standard deviation is utilized to select a richly-textured block of pixels to hold the secret message. Next, four Most Significant Bits (MSBs) of three diagonal pixels in the

treated block are selected using SKTM to generate three correcting bits [Hamming code H (7,4)]. Two of these bits are XORed with the two secret bits and embedded in the neighboring pixels. In [43], the embedding position is located by a key generated utilizing a chaotic LM. Next, these located positions are further optimized by using two approaches. In the first approach, Arnold's Cat Map (ACM) is applied to add more randomness by shuffling the pixels. In the second approach, LM parameters are adjusted using the Genetic and Bat algorithms to find the best key value for the LM, leading to minimal changes. In the scheme proposed in [44], two chaotic maps are considered for pixel selection purposes: 1-D (Tent map) and 2-D (Baker's map). The embedding is done within the red channel. To minimize distortions, pixels on the edges are avoided, while the embedding process employs one bit or two bits of LSB. In the method proposed in [45], the cover image is scrambled using Power Modulus Scrambling (PMS) with the aid of the Brownian motion concept. Lighter pixels or pixels with less intensity exhibit more randomness than the heavier, darker pixels. The embedding process is carried out considering certain conditional factors. Finally, the reverse Brownian-based scrambling is applied to generate the stego image.

A keyed PRNG is used to scramble pixels, in order to achieve random permutation, in [46]. The permutation order is first based on an 8x8 Sudoku puzzle. Next, the embedding is done using LSB Matching, wherein two bits are embedded in the red channel, one bit in the green channel, and three bits in the blue channel. The Cross-coupled chaotic system (using two chaotic LM) is utilized in [47] to generate a DNA sequence, which is then added to the secret message's DNA sequence using the ASCII format. The result is then embedded using the typical LSB method. Table I summarizes the references related to randomization-based methods.

TABLE I. SUMMARY OF THE MOST OF THE MENTIONED RANDOMIZATION-BASED TECHNIQUES

Ref	Features and Pros	Cons	PSNR (dB)	Evaluation metrics
[30]	<ul style="list-style-type: none"> <li>Cover image is 90 angular transformed</li> <li>Security is achieved through pixel randomization using linear congruential generator</li> <li>LSB embedding following 3R-3G-2B pattern</li> </ul>	<ul style="list-style-type: none"> <li>Few experiments</li> <li>Embedding does not take into account the image content</li> <li>Not compared to similar techniques</li> <li>No steganalysis experiments</li> <li>Not robust against statistical and geometrical attacks</li> </ul>	512 x 512 PSNR: R: 64.0484 G: 64.5621 B: 67.362	PSNR, MSE
[31]	<ul style="list-style-type: none"> <li>Able to hide three binary images in the cover image</li> <li>Shuffling based security using three random number series with the help of mathematical relations called UUN</li> <li>Simple implementations</li> </ul>	<ul style="list-style-type: none"> <li>Embedding does not take into account the image content</li> <li>No steganalysis experiments</li> <li>Not robust against structural and geometrical attacks</li> <li>Low PSNR</li> </ul>	PSNR: 37.71: 40.46	PSNR, MSE, SSIM, histogram analysis
[32]	<ul style="list-style-type: none"> <li>Binary image is embedded in a grayscale image.</li> <li>Randomization embedding using a random number series.</li> <li>Multiple series and reoccurring numbers are eliminated.</li> </ul>	<ul style="list-style-type: none"> <li>All image regions are considered</li> <li>No steganalysis experiments</li> <li>Not robust against structural and geometrical attacks</li> </ul>	Different resolutions images Payloads: (10:100%) 7680: 76800 bits PSNR: 83.97: 63.45	PSNR, MSE, Bit error, histogram
[33]	<ul style="list-style-type: none"> <li>Embeds 8bits/pixel 3R-3G-2B</li> <li>XORing a bit of 5 MSBs with a secret bit and embedded in the particular LSB.</li> <li>Randomization based on PRNG to choose a pixel and one of 5 MSB</li> <li>Simple yet efficient encryption using XOR operation</li> <li>Simple implementations</li> </ul>	<ul style="list-style-type: none"> <li>Security is about inability to retrieve the message</li> <li>All image regions are involved</li> <li>No steganalysis experiments</li> <li>Not robust against structural and geometrical attacks</li> </ul>	512x512 RGB bmp images Payloads 100: 262144 bits. PSNR: 39.263: 73.798	PSNR, MSE

[34]	<ul style="list-style-type: none"> <li>• SKTM to generate three PRNGs to: scramble secret messages, choose an embedding color channel, and select a pixel location.</li> <li>• 1 &amp; 4 LSBs versions</li> <li>• Chaotic map exhibits good statistical features</li> <li>• To make the algorithm more robust against statistical attacks</li> </ul>	<ul style="list-style-type: none"> <li>• StegExpose detects approximately half of the embedded information truly.</li> <li>• Security is about the secret bits' locations.</li> <li>• Embedding does not take into account the image content</li> <li>• Computational complexity</li> <li>• Many parameter to generate pseudorandom sequences</li> </ul>	<p>RGB 256x256 1-LSB, C=809:9041 Bytes. PSNR=65.97 :55.49</p> <p>4-LSB, C= 809:36,167 Bytes PSNR= 52.621:36.101</p>	<p>COR, HOM, CON, ENR and CoC. MSE, PSNR, MaxErr, L2RAT, ENT SSIM, MSSIM, FSIM steganalysis: StegoExpose tool</p>
[35]	<ul style="list-style-type: none"> <li>• Improved 1D chaotic behaviour (an improved LM and sine map)</li> <li>• Improved robustness against statistical attacks.</li> </ul>	<ul style="list-style-type: none"> <li>• Moderate PSNR</li> <li>• Histogram has many spikes</li> <li>• Not enough experiments against chi square test</li> <li>• Embedding does not take into account the image content</li> <li>• Parameters exchange overhead</li> </ul>	<p>Color images 128x192, 192x256 256x288, 256x384 Payload: 24,576: 98,304 B Avg PSNR= 38.209</p>	<p>PSNR, MSE, Image Fidelity, Entropy</p>
[36]	<ul style="list-style-type: none"> <li>• Using Beta chaotic map</li> <li>• Good Visual quality</li> </ul>	<ul style="list-style-type: none"> <li>• Clear Histogram deformity</li> <li>• Complexity of the Beta map</li> <li>• Embedding does not take into account the image content</li> <li>• Key exchange overhead</li> </ul>	<p>USC-SIPI Image Database. PSNR: 57.5 – 56.79</p>	<p>PSNR, MSE</p>
[37]	<ul style="list-style-type: none"> <li>• PRN generator to define embedding locations.</li> <li>• user-defined Key seed value &amp; number of embedded bits.</li> <li>• Not complex</li> <li>• Variable embedding capacity</li> </ul>	<ul style="list-style-type: none"> <li>• Embedding does not take into account the image content</li> <li>• Key exchange overhead</li> <li>• Few tests</li> <li>• Non-standard image</li> <li>• No steganalysis experiments</li> </ul>	<p>Message length: 343: 8866 characters Avg PSNR= 68.49</p>	<p>PSRN</p>
[38]	<ul style="list-style-type: none"> <li>• Uses chains of a random sequence of indices (codes) of the bytes in the carrier image.</li> <li>• Use of the full capacity of the cover image.</li> <li>• Robustness, and undetectability have been improved through extracting chains of randomly selected pixels from the cover image based on a user key</li> </ul>	<ul style="list-style-type: none"> <li>• Not compared to rival techniques.</li> <li>• Uses non-standard images.</li> <li>• Uses relatively large Stego secret key</li> <li>• No steganalysis experiments</li> </ul>	<p>Image size= 147456 Payload=18432 Bytes Image size=111156 Payload= 13894 Bytes PSNR avg = 51.31</p>	<p>PSRN</p>
[40]	<ul style="list-style-type: none"> <li>• Security achieved through encryption of secret message and randomization using KT algorithm (self-developed algorithm)</li> <li>• Performance against Chi-square is improved when using KT</li> </ul>	<ul style="list-style-type: none"> <li>• Not compared to rival techniques</li> <li>• Image content not considered</li> <li>• No numerical results</li> <li>• Stego-key value exchange overhead</li> </ul>	<p>Greyscale 512x512 from USC-SIPI</p>	
[41]	<ul style="list-style-type: none"> <li>• Finds message &amp; cover image combinations with minimum changes</li> <li>• Randomization through using an un-patterned quadratic embedding sequence with unbounded i/p parameters.</li> <li>• An artificially created assignment problem with an optimized solution of the Hungarian algorithm</li> </ul>	<ul style="list-style-type: none"> <li>• Security is related to the embedding locations</li> <li>• Image content not considered</li> <li>• Stego-key value exchange overhead</li> <li>• No steganalysis experiments</li> <li>• Complexity high</li> </ul>	<p>Color image: 256x384 Payload= 23KB. Avg PSNR =52.739</p>	<p>PSNR</p>
[43]	<ul style="list-style-type: none"> <li>• Randomization of embedding location with optimizations using Chaotic LM to achieve highest PSNR possible</li> <li>• Uses LSB replacement and LSB matching</li> <li>• Optimization using Arnold's Cat map and adjustment of LM parameters using Genetic and Bat algorithm</li> </ul>	<ul style="list-style-type: none"> <li>• High complexity</li> <li>• No steganalysis tests</li> <li>• Key exchange overhead</li> <li>• Image structure not considered</li> </ul>	<p>256x256 grayscale. Embedding rate: 20:100% 2LSB: PSNR Org= 47.52 Optimized=48.44 SM2LSB PSNR, Org= 44.53 Optimized=45.22</p>	<p>PSNR</p>
[45]	<ul style="list-style-type: none"> <li>• Randomization key generated using Brownian motion</li> <li>• Nonlinear Brownian motion adds more security</li> <li>• High capacity</li> </ul>	<ul style="list-style-type: none"> <li>• Image contents not considered</li> <li>• Complex</li> <li>• Payload size not mentioned in the steganalysis</li> <li>• Key exchange overhead</li> </ul>	<p>128 × 128, 256 × 256, 512 × 512 Avg. PSNR= 48.467 without Brownian  Avg. PSNR with Brownian = 48.45417</p>	<p>MSE, PSNR, SSIM entropy, Laplacian MSE Error (LMSE), Mean, S. deviation, Kurtosis, Skewness, KL Divergence, and NCC</p>
[47]	<ul style="list-style-type: none"> <li>• Randomization is achieved by combining two chaotic LMs to generate PRNG.</li> <li>• LM is utilized to generate a DNA sequence</li> <li>• The sequence is added to the secret message's DNA sequence using the ASCII format.</li> <li>• The result is LSB embedded.</li> </ul>	<ul style="list-style-type: none"> <li>• No tabulated experiments</li> <li>• Image regions not considered</li> <li>• Key exchange overhead</li> </ul>	<p>Payload: 37-character (296 bits) PSNR 99 dB</p>	<p>PSNR, Coefficient Correlation Test, Entropy</p>



## B. Encryption

In the following sections, steganographic techniques will be presented based on cryptography only or combined with randomization. In addition, some image encryption techniques will be presented, which can be utilized to encrypt the secret image and be used during the steganographic process.

1) *Encryption based steganography*: The technique in [48] proposes to encrypt the secret message using an XOR operation with a user-defined key. Next, a 4-bit shifting operation is applied to the encrypted text message in order to form the secret message to be hidden. The secret data is eventually embedded within the cover image using the standard LSB method. As per the technique suggested in [49], the letters of the secret message are initially transposed as an encryption process. Next, the secret message bit is XORed with the MSB of the image pixel based on a particular key hidden in the LSB of the cover image. In the method presented by [50], data hiding is performed using the typical LSB concept. The secret message is encrypted using the AES encryption algorithm with a 128-bit key in Cipher-Block Chaining (CBC) mode. Next, the order of pixel selection for embedding is obtained by utilizing a combination of the image attributes such as type and image resolution. The secret message in [51] is encrypted using XOR operation through a key generated via a circular bit shift operation having varying block sizes. Next, the encrypted message is embedded in RGB channels using the LSB algorithm in various ways for each channel. This process uses a 2-3-4 paradigm, wherein the insertion is done sequentially for the red channel, using raster scan pattern from right-left for the green channel, and using top-bottom raster scan for the blue channel.

The input RGB image in [52] is scrambled using a hyper-chaotic map to produce a permuted encrypted version of the cover image. The encrypted image is converted to YCBCR color space, and the luminance channel (Y) is then divided into  $8 \times 8$  non-overlapping blocks to apply DCT and quantization on each block. Finally, Huffman coding is applied to the secret message and embedded in the left MSB. In the technique suggested by [53], the secret message is encrypted using a symmetric key cipher. The encrypted message is XORed with selected bits from the cover image for obtaining a higher-order pixel to add more confusion to the stego image. A block-wise inversion technique is applied to minimize changes during embedding by inserting them to an LSB or inverting them. The stego key consists of a symmetric encryption key and the encoding key, which contains parameter settings such as the number of blocks, starting block, start pixel offset, and block selection rule. In [54], the author introduces a secure steganography scheme, which encrypts the secret information using the permutations concept. Two chaotic map functions are utilized to obtain a sequence that is XORed with secret bits. The cover image is JPEG compressed, and DCT coefficients are modified and adaptively selected to hide the secret bits using a histogram modification-based data hiding scheme. In [55], the cover image is flipped by  $180^\circ$ . Next, the blue channel is divided into four sub-blocks, each of which is shuffled. The

difference between the red pixels and the secret message is calculated and encrypted using a Multi-Level Encryption Algorithm (MLEA), which includes XOR, permutation, and shifting operations. The LSB embedding is done within the blue shuffled pixels. Subsequently, the sub-images are reshuffled and eventually combined using the red and green channels and re-flipped. Table II summarizes the encryption-based method in image steganography.

2) *Randomization and encryption based steganographic techniques*: The study [56] presents a scheme to improve the security of LSB steganography. In this method, the secret message is encrypted using a One-Time Pad (OTP) encryption. Subsequently, randomization is achieved by columnar transposition and RGB color plane scattering technique. Also, the technique in [13] uses OTP to encrypt the secret message, but it employs PRNG to select a pixel location for LSB embedding. In [57], the AES algorithm is applied to encrypt the secret message, which is then embedded using the LSB technique at a location randomly determined by the LCG method. The AES algorithm is also used in [58] to encrypt the secret message before dividing it into blocks. The cover image is segmented using a technique called a Non-Uniform Block Adaptive Segmentation on Image (NUBASI) algorithm. Finally, PRNG is used to randomly choose a message block to be embedded into an image segment. In fact, there are 32 predefined pattern orders of segments that can be selected at random. In [59], the secret message is encrypted and compressed by employing Vigenère Cipher and Huffman Coding, respectively. Next, the image is segmented into blocks in order to apply the KT algorithm to make groups of blocks. An arbitrary function is employed to select which blocks and groups can be used to conceal a specific pixel in the group randomly. Authors of [60] suggest encoding the secret message using bitwise XOR operations between adjacent pixels. Next, a local user selection is applied to find a particular position among the four least significant bits to hide a secret bit. The technique presented in [61] is based on Modified Least Significant Bit (MDLSB) to embed data in the cover image. It uses two layers of randomization: segment selection and pixel selection based on a user key. Further, a lossless compression algorithm, the DEFLATE algorithm, is applied to overcome the issue of embedding size in the subsequent layer. In addition, the AES encryption algorithm is utilized to encrypt the secret message in the next layer. The Artificial Bee Colony (ABC) algorithm is employed to reduce the noise caused by embedded information.

A randomized key based technique is proposed in [62]. First, the cover image is compressed, and then a secret key with the same length as the secret message is generated. Next, the secret message bits are XORed using the generated key. The resultant bits are embedded in the locations specified by the key. Finally, the image is encrypted using the 3DES algorithm. Authors in [63] proposed a secure digital image steganography scheme. In this approach, the secret message is initially compressed using the Run Length Encoding (RLE) algorithm, which is then encrypted using the Bernoulli map and the inverting bit map technique. During the embedding stage, the embedding location is selected by using KT algorithm and Henon Map (HM) function. The cover image is

divided into 8x8 blocks in order to apply the KT for selecting a block. HM function is employed to choose a pixel location among the 64 pixels in a particular block. The selected pixel is decomposed through Fibonacci, so as to embed the secret bit using a New Stego Key Adaptive LSB (NSKA-LSB), which maintains good imperceptibility.

In the technique proposed by [64], the location and the order of the image pixels are randomly chosen for embedding using a chaotic PRNG. The Pseudo-Random Number (PRN) is generated by exploiting the Duffing map and Circle map functions. In addition, the secret message is encrypted by XORing it with PRN before initiating the embedding process. In [65], the authors present a secure method that starts with encryption of the secret message using the RSA algorithm in

combination with the Diffie-Hellman (DH) key exchange algorithm. Next, the encrypted message is compressed using RLE. Finally, via the Direct Sequence Spread Spectrum (DSSS) technique, PRN is used to select random pixels and to embed the secret message through 1-bit LSB and 2-bit LSB. The research [66] suggests a new method to enhance steganographic security. In this technique, the secret message written in Turkish text is encoded and compressed using the Huffman coding. The secret message is encrypted using the XOR operation and an OTP key with an equal-length payload. The key is generated using the super Mandelbrot sets and with the help of the LM. Subsequently, the LSB plane is analyzed morphologically to avoid low entropy pixel locations. Finally, LSB hiding is applied with the help of the chaotic LM in order to randomly choose a pixel location.

TABLE II. SUMMARY OF ENCRYPTION-BASED STEGANOGRAPHY TECHNIQUES

Ref	Features and Pros	Cons	PSNR (dB)	Evaluation metrics
[48]	<ul style="list-style-type: none"> <li>XOR Encryption with bit-shifting of the secret message.</li> <li>Three RGB pixels used to hide an 8-bit data</li> <li>LSB based</li> <li>Simple encryption operation</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Steganalysis evaluation is missing</li> <li>Not robust against statistical attacks</li> <li>Same channel sequence followed</li> </ul>	RGB 512x512 87373 bytes Avg PSNR= 51.637	PSNR, SSIM
[49]	<ul style="list-style-type: none"> <li>Transposition of the secret message and XOR with MSB of the pixels then embedded in LSB</li> <li>Less computation and time complexities comparing to standard encryption techniques</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Secret key exchange</li> <li>Not robust against statistical attacks</li> <li>Limited capacity</li> </ul>	256x256 grayscale image Payload: 1: 4 KB. PSNR= 63.236 : 57.132	MSE, PSNR, Histogram
[50]	<ul style="list-style-type: none"> <li>AES-CBC Encryption of the secret message</li> <li>Embedding order of RGB depend on: file type &amp; resolution</li> <li>LSB based</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Not robust against statistical attacks</li> <li>Limited capacity</li> <li>Secret key exchange overhead</li> </ul>	512x512 color images bpp=1 Avg. PSNR=51.196	RMSE, PSNR, MSE
[51]	<ul style="list-style-type: none"> <li>XOR encryption of the secret message with a circular bit shift generated key</li> <li>varying block size</li> <li>LSB embedding in the 2-2-4 LSB's of the RGB channels</li> <li>Less complexity due to use of XOR encryption</li> </ul>	<ul style="list-style-type: none"> <li>All image regions considered</li> <li>Steganalysis evaluation is missing</li> <li>Secret key exchange</li> <li>Not robust against statistical and geometrical attacks</li> </ul>	128x128, 512x512, 800x600 Payload: 16 KB: 480 KB bpp = 8 Avg. PSNR =64.85	MSE, PSNR, Entropy
[52]	<ul style="list-style-type: none"> <li>Encryption by shuffling image rows &amp; columns with a help of hyper chaotic map</li> <li>The Y channel of YCbCr version is DCT quantized</li> <li>Embedding the Huffman of secret message into the MSB</li> <li>Huffman coding increases capacity &amp; security.</li> <li>Robust against geometric attacks such as cropping attack, rotation attack, scaling attack</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Parameters exchange overhead</li> <li>Tested against low payloads</li> <li>Computation complexity</li> </ul>	512x512 & 256x256 standard color 256x256 medical images Payloads: 100: 2050 Bytes PSNR=77.16: 53.68	PSNR, MSE, BER, SSIM, correlation, Quality Score prediction, Mean value, Standard Deviation, Entropy, Gradient
[53]	<ul style="list-style-type: none"> <li>Encryption followed by XOR encoding of the message with randomly selected higher-order pixel.</li> <li>Resultant bit alterations minimized using a block-wise inversion.</li> <li>Robust against chi-square, RS analysis, and sample pair test for the majority of stego images</li> </ul>	<ul style="list-style-type: none"> <li>Use public key to exchange stego-key</li> <li>Many parameters</li> <li>All image contents considered</li> <li>Clear Histogram spikes</li> <li>Low payloads</li> </ul>	256x256 Greyscale bpp=0.25: 0.9 PSNR: 57.475:51.629	MSE, PSNR, NCC, SSIM, Histogram based analysis (PDH), chi-square, RS groups analysis, sample pair test
[54]	<ul style="list-style-type: none"> <li>Hyper-chaotic system to permute the secret message and XORing it with the chaotic sequence</li> <li>DCT coefficients modified using histogram modification-based data hiding scheme for high capacity</li> <li>Low distortion</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Parameters exchange overhead</li> <li>Computation complexity</li> <li>Moderate embedding rate</li> </ul>	USC-SIPI&UCID database 512x512 bpp = 0.2671 PSNR= 36.05: 38.93 bpp=0.08:0.18 PSNR=38.322: 41.695	PSNR, MSE, SSIM, average embedding rate ER, Information entropy, Correlation coefficients
[55]	<ul style="list-style-type: none"> <li>Flipping of the cover image and blue channel is divided and shuffled.</li> <li>Multi-level encryption algorithm is applied to encrypt intermediate values</li> <li>The result is embedded in LSB of the blue, reshuffle, and combined with red &amp; green.</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Steganalysis evaluation is missing</li> <li>Parameters exchange overhead</li> <li>Computation complexity</li> </ul>	512x512 color images from USC-SIPI Payloads: 2:8 KB Avg PSNR= 65.9225 For 256x256 Payloads: 2:8 KB Avg PSNR= 71.0515	MSE, PSNR, MAE, NCC and SSIM, RMSE

In the scheme proposed by [67], the Bernoulli chaotic map function is utilized in three stages. It begins with encryption of the secret message by XORing it using a random sequence generated by the chaotic function. Then, one of the RGB channels is selected randomly using the random sequence. In addition, the secret message bits are randomly embedded in the rows and columns of the cover image. Embedding is done in the fourth least significant bit of the pixel. In [68], the secret data is transformed into binary form and then its CRC-32 checksum is generated. The data and its CRC are Gzip-compressed, followed by the AES encryption that is eventually appended to the header information. The last phase consists of information insertion using the Fisher-Yates Shuffle algorithm. This insertion enables selection of a pixel location for the embedding process, wherein all LSB channels are employed.

A method is suggested in [69] which starts by finding the best place to hide secret data using the LSB technique. Then, the secret information is encrypted using the 3DES algorithm; here, the RSA algorithm is used for the secret key exchange. The last stage is randomization, which is realized using a built-in randomization function based on the modulo Operation (mod) function with a secret seed. The secret seed is exchanged using the RSA. In the three-layered security suggested by [70], a small size fragile watermark is appended to the secret information to make it tamper-proof. The data is scrambled before the embedding process and partitioned into three vectors of varying length. The largest vector is embedded in the lowest order bit plane to minimize distortion that may arise after embedding. Before insertion, the host image is encrypted using the scrambling notion based on a Pseudo-Random Address Vector generated for image encryption, which is called PAVE. The concept of Pseudo Noise (PN) sequence generator is employed to generate the PAVE. The encrypted image is then partitioned. The embedding location is selected randomly by generating a random vector called Pseudo-Random Address Vector for Data Hiding (PAVH). Once the embedding is accomplished, the host image is decrypted to obtain the final stego image.

In [71], the first step towards achieving security comprises encryption of the secret image using RSA, which produces a 16-bit pixel cipher. The resultant cipher is rearranged to obtain a binary image, which is subsequently scrambled using a randomization concept relying on 2-D ACM transformation. The secret image is then embedded within the cover image using an inverted 2-bit LSB steganography wherein two bits are embedded. Bit inversion is based on the 3rd and 4th bits that are utilized as quantifiers. In [72], a chaotic LM and a support image are combined to generate a random binary sequence that is XORed with the secret message to get an encrypted version of the message. LSB embedding is done at positions determined randomly through random sequencing. The support image is pre-processed and utilized during the embedding stages to help resist steganalysis. In the method proposed by [73], the sequential color cycle is combined with pattern-based image steganography. The data to be hidden is encrypted using the AES algorithm. The cover image is divided into blocks and sub-blocks. Finally, a sub-block is chosen based on a predefined bow-tie shape pattern. The

embedding operation is accomplished sequentially for the LSB of the RGB channels.

An algorithm to enhance security using randomization and multiple encryptions of secret images is presented in [74]. This technique embeds three secret binary images inside an RGB cover image. First, the three-color planes are separated. The red channel matrix is further separated into even and odd matrices. Next, the bits of the first secret image are embedded in the LSB of the odd matrix and the second LSB of the even matrix containing red pixels. Further, the bits of the second and third secret images are encrypted by XORing them with the first secret image. Finally, the two encrypted images are inserted in the LSB of the green and the blue channels, respectively. A pixel locator sequence-based technique was suggested by [75] to enhance LSB steganography security. This scheme starts by enciphering the secret information using the AES algorithm. The encrypted information is randomly embedded within the LSB bits of the image pixels with the help of a pixel locator sequence. Modern Fisher-Yates shuffle is utilized to generate the random sequence. The pixel locator sequence is also encrypted and appended to the image to form the final version of the stego image.

To secure communication, [76] incorporates randomization in combination with encryption. Confidential data is first encrypted using the Blowfish algorithm. Next, the LCG algorithm is used to generate random numbers that are in turn used to select pixels for LSB embedding. The number of bits to be inserted varies depending upon the pixel's intensity. Chaos based steganography is presented in [77]. In the first step, the secret information is encrypted using the AES algorithm. Following this, chaotic LM and ACM are employed to generate random values. These values are used to choose the positions of pixels on the cover image within which the secret bits are embedded. The first and second bit planes are used to uniformly distribute bits of the message. Three variations of random values can be constructed using the two aforementioned chaotic maps. Table III summarizes the references related to randomization and encryption-based steganography methods.

*Image encryption:* Various image encryption techniques are explained in this section. In [78], image encryption based on the confusion process is followed. The RGB image is transformed into a square grayscale image in the first step. Next, ACM is applied to scramble image rows and columns, followed by the HM algorithm for further scrambling to obtain the final cipher image. Authors of [79] suggest enciphering digital images by incorporating the confusion and diffusion concepts. First, the 256x256 RGB image is divided into four quadrants. Each of these quadrants is subsequently divided into four sub-quadrants that are rotated 90° anti-clockwise to form 64 sub-blocks in total. Then, modified zigzag transformation is applied to each channel to break the association with the adjacent pixels. Up to this step, confusion is fulfilled. An Enhanced Logistic Map (ELM) is used to generate intermediate encryption keys that pick specific pixel values to guarantee diffusion. The final key 'K' is generated based on the chosen values from the image and external user key, which are then XORed with RGB channels produced earlier after the zigzag step.

TABLE III. SUMMARY OF RANDOMIZATION AND ENCRYPTION BASED STEGANOGRAPHY TECHNIQUES

Ref	Features and Pros	Cons	PSNR (dB)	Evaluations Metrics
[13]	<ul style="list-style-type: none"> <li>Simple encryption and reduced computation using XOR encryption</li> <li>OTP is randomly generated</li> <li>PRNG used to randomize the encrypted secret message into the cover image</li> <li>Simple implementation using LSB Substitution-based</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Image structure not considered</li> <li>Image size not mentioned and payload</li> <li>Not robust against statistical steganalysis</li> <li>Channels used in the same order</li> <li>Parameters exchange overhead</li> </ul>	RGB images bpp=3 Avg PSNR= 83.27	MSE, PSNR, SSIM
[56]	<ul style="list-style-type: none"> <li>Simple encryption using OTP encryption of the secret message</li> <li>Randomization is achieved by columnar transposition and RGB color plane scattering technique.</li> <li>Simple implementation</li> <li>Reduced computation and time complexities compared to conventional encryption</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Image structure not considered</li> <li>Image size not mentioned and payload</li> </ul>	RGB images Avg PSNR=58.47	MSE, PSNR, SSIM
[57]	<ul style="list-style-type: none"> <li>The secret message is AES encrypted</li> <li>Pixels are randomly chosen using LCG method</li> <li>Standard LSB embedding</li> <li>All RGB LSBs are utilized</li> </ul>	<ul style="list-style-type: none"> <li>Key exchange overhead</li> <li>AES complexity</li> <li>Steganalysis evaluation is missing</li> <li>Image structure not considered</li> </ul>	RGB images. Size of: 607x695 - 1,293x1,480 Payload = 8,230: 76,700 bytes PSNR=59.29:71	MSE, PSNR
[58]	<ul style="list-style-type: none"> <li>Three-layer securities through Encryption &amp; randomization</li> <li>AES and PRNG are used for message encryption and message block selection</li> <li>Uses NUBASI algorithm for the cover image</li> </ul>	<ul style="list-style-type: none"> <li>Secret key exchange overhead</li> <li>Complex</li> <li>Steganalysis evaluation is missing</li> <li>Image structure not considered</li> </ul>	512x512 RGB Payload= 2.5 KB Avg. PSNR = 63.755	PSNR
[59]	<ul style="list-style-type: none"> <li>Strength against electronic attacks by encryption, compressions, and randomization.</li> <li>Randomization using KT algorithm and arbitrary function</li> <li>Robust against Chi-square attack</li> <li>Exploiting Modification Direction embedding based technique</li> </ul>	<ul style="list-style-type: none"> <li>Encryption key, arbitrary function key, and Huffman table exchange overhead</li> <li>Complex</li> <li>Payload in the steganalysis not mentioned</li> <li>Not tested against other attacks</li> <li>Image structure not considered</li> </ul>	512x512 images from USC-SIPI bpp = 0.5: 1.6 PSNR = 60.84: 55.69	PSNR, MSE and SSIM
[60]	<ul style="list-style-type: none"> <li>XOR encoding of the secret message</li> <li>User selection to hide a secret bit in one of the 4 LSBs</li> <li>Modified LSB</li> <li>Simple implementation</li> </ul>	<ul style="list-style-type: none"> <li>Multiple cover images possibly needed</li> <li>Steganalysis evaluation is missing</li> <li>Image structure not considered</li> <li>Not compared with similar techniques</li> </ul>	256x256 grey scale payload: 128x128 image Avg. PSNR = 43.455	MSE, PSNR
[61]	<ul style="list-style-type: none"> <li>To enhance security, use of multi-stage randomization, a lossless compression algorithm (DEFLATE algorithm), and AES encryption</li> <li>ABC algorithm to reduce embedding noise</li> <li>Tested using ROC curves of the WFLogSv steganalyser</li> </ul>	<ul style="list-style-type: none"> <li>AES key exchange overhead</li> <li>Not simple</li> <li>Time Complexity</li> <li>Image structure not considered</li> <li>Other Steganalysis techniques missing</li> </ul>	Images from UCID database 150x150 - 1080x1024 PSNR without ABC= 48.1:58.2 with ABC: enhance by magnitude of 3:6	PSNR, SSIM Euclidean norm testing ROC curves of the WFLogSv steganalyser
[62]	<ul style="list-style-type: none"> <li>Security is achieved by Compression, randomization, and encryption</li> <li>The image is compressed and XORed with a generated key</li> <li>A key based randomization to hide the secret message</li> <li>Encryption of the image using 3DES</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Image structure not considered</li> <li>Few tests</li> <li>Not compared with similar techniques</li> <li>Not typical steganography, encryption alike</li> </ul>	Color images: 256x256, 250x360 pixels Avg PSNR: 53.51	MSE, PSNR, and NC
[63]	<ul style="list-style-type: none"> <li>Utilizes compression, encryption (Bernoulli map), randomization using KT and HM.</li> <li>Fibonacci decomposition with the help of NSKA-LSB</li> <li>Maintains good imperceptibility.</li> </ul>	<ul style="list-style-type: none"> <li>Complex due to many stages</li> <li>Steganalysis evaluation is missing</li> <li>Image structure not considered</li> <li>Few tests</li> <li>Not compared with similar techniques</li> </ul>	512 x 512 gray images From USC-SIPI Embedding rate = 6.25, 12.5, 18.75 %, Avg. PSNR= 61.14, 66.58, 72.29	PSNR, SSIM, and BER

[64]	<ul style="list-style-type: none"> <li>Randomization with help of Duffing map and Circle map</li> <li>XOR Encryption of the secret message</li> <li>Chi Square test passed with payload of 4000 bits</li> <li>Good imperceptibility</li> <li>LSB replacement based</li> </ul>	<ul style="list-style-type: none"> <li>Only Chi-square steganalysis is used for evaluation with low payload</li> <li>Image structure not considered</li> <li>Key exchange overhead</li> </ul>	<p>Non-standard color images: 256x256, 512x512 Payload: 800:16,000 bits PSNR: 256x256 = 63.0: 76.56 512x512 = 69.1: 82.73</p>	<p>Randomness tests, MSE, PSNR and SSIM The Average Difference, Laplacian MSE, NAE, IQI</p>
[65]	<ul style="list-style-type: none"> <li>Secret message encryption and compression</li> <li>Randomization to select random pixels to embed the secret message</li> <li>Direct sequence spread spectrum technique is used in LSB-1 and LSB-2</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Image structure not considered</li> <li>Few tests</li> <li>Not compared with similar techniques</li> <li>Diffie-Hellman to exchange keys</li> </ul>	<p>jpg images payload: 50: 1000 characters PSNR 58.528: 71.596</p>	<p>PSNR, MSE</p>
[66]	<ul style="list-style-type: none"> <li>Regional adaptive with randomization embedding.</li> <li>Huffman compression and OTP-XOR encryption of Turkish secret message</li> <li>OTP generated using Mandelbrot sets with the LM.</li> <li>Only high entropy regions are considered</li> </ul>	<ul style="list-style-type: none"> <li>Only Chi-square steganalysis is used for evaluation</li> <li>Huffman table and parameter exchange overhead</li> <li>Relatively complicated</li> <li>Only LSB plane is analysed and considered</li> </ul>	<p>NASA&amp;SIPI grayscale images 512x512, Payload: 1: 93.5 KB PSNR= 61.9: 51.15</p>	<p>PSNR, BPP, SSIM UNIVERSAL IMAGE QUALITY INDEX (UIQI)</p>
[67]	<ul style="list-style-type: none"> <li>XOR encryption of the secret message with a random sequence of Bernoulli chaotic map function</li> <li>Randomization of channel and pixel selection</li> <li>Embedding is done in one of the fourth LSB of the pixel.</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Not robust due to Image structure not considered</li> <li>Low payloads used</li> </ul>	<p>RGB: 256x256, 720x576 Payload: 44: 500 characters PSNR: 52.12: 67.82</p>	<p>Statistical Metrics, MSE, PSNR, Max Absolute Squared Deviation, Ratio of the squared norm and CC</p>
[68]	<ul style="list-style-type: none"> <li>First security tier is the secret message compression and AES encryption</li> <li>Pixels randomization using Fisher-Yates Shuffle algorithm</li> <li>Resistant to the Chi-square</li> <li>Integrity check guaranteed using message CRC</li> <li>High capacity with good imperceptibility</li> </ul>	<ul style="list-style-type: none"> <li>Only used Chi-square steganalysis</li> <li>Image structure not considered</li> <li>Key exchange overhead</li> <li>Relatively complicated</li> </ul>	<p>512x512 RGB Payload: 1 : 256 KB PSNR: 40.083: 63.862 Max payload 315392 Bytes (Gzip)</p>	<p>MSE, PSNR, NCC, Average Difference, Maximum Difference, Laplacian MSE and Normalized Absolute Error</p>
[69]	<ul style="list-style-type: none"> <li>3DES encryption of the secret message,</li> <li>Randomization using mod function with secret seed.</li> <li>RSA for key exchange.</li> <li>LSB embedding</li> </ul>	<ul style="list-style-type: none"> <li>Key exchange overhead</li> <li>Image structure not considered</li> <li>Weak randomization as its not chaotic</li> <li>Steganalysis evaluation is missing</li> </ul>	<p>Payload: 12: 48 KB PSNR 53.3150: 52.8734</p>	<p>PSNR, SSIM, retrieval bit, error rate (RBER)</p>
[70]	<ul style="list-style-type: none"> <li>Pseudorandom vectors used for image encryption, scrambling and secret message encryption</li> <li>Embedding is Randomly achieved at Intermediate Significant Bit (ISB)</li> <li>High security due to encryption and randomizations</li> </ul>	<ul style="list-style-type: none"> <li>Complex</li> <li>Master key exchange overhead</li> <li>Image structure not considered</li> <li>Steganalysis evaluation is missing</li> <li>Moderate PSNR</li> </ul>	<p>512x512 standard images bpp=2 Avg PSNR= 39.11</p>	<p>PSNR, MSE, Normalized Absolute Error (NAE) and NCC.</p>
[71]	<ul style="list-style-type: none"> <li>RSA Encryption of the secret image</li> <li>Randomization using 2-D ACM</li> <li>Embedding using an inverted 2-bit LSB steganography</li> <li>Embedded in one channel (blue)</li> <li>High capacity</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Steganalysis evaluation is missing</li> <li>Time complexity</li> </ul>	<p>512x512 images Secret messages: RGB 64x64 &amp; Grayscale 128x128 Payload: 24,576:32,768 KB PSNR=57.25: 52.5</p>	<p>PSNR, MSE</p>
[72]	<ul style="list-style-type: none"> <li>XOR encryption of secret information with help of LM.</li> <li>Embedding LSB plane randomized</li> <li>Support image processed for information extraction</li> <li>Imperceptibility of the first image is ideal</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Steganalysis evaluation is missing</li> <li>Extra overhead due to using two images</li> <li>Key exchange overhead</li> </ul>	<p>128x128 pixels 1<sup>st</sup> Primary image= 50% data 2<sup>nd</sup> Support image=50% data PSNR of 1<sup>st</sup> image =inf PSNR of 2<sup>nd</sup> image= 53.24</p>	<p>PSNR, MSE</p>
[73]	<ul style="list-style-type: none"> <li>AES encryption of the secret message</li> <li>Randomization based on Bow-tie shape pattern</li> <li>LSB Embedding using SCC</li> <li>Stego image is further encrypted</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Steganalysis evaluation is missing</li> <li>Key exchange overhead</li> <li>Few tests</li> </ul>	<p>RGB 256x256, 512x512 PSNR= 39%, 49%</p>	<p>PSNR</p>



[74]	<ul style="list-style-type: none"> <li>The secret images separated into multiple parts</li> <li>Based on RGB planes with several combinations of separated red channel with multiple XOR encryption of the secret and the green and blue LSBs</li> <li>Randomly embedding in LSB of the green and the blue channels</li> </ul>	<ul style="list-style-type: none"> <li>High complexity due to using 3 secret images</li> <li>Image structure not considered</li> <li>Steganalysis evaluation is missing</li> <li>Key exchange overhead</li> <li>Few tests</li> </ul>	Cover images jpg 255x255x3 Secret images: .png LSB & LSB1 PSNR: 49.248 LSB1&LSB2 PSNR:44.999	PSNR, MSE
[75]	<ul style="list-style-type: none"> <li>AES encryption of the message</li> <li>Randomization of pixels using Modern Fisher-Yates Shuffle</li> <li>Embedding using LSB substitution</li> <li>Pixels sequence is encrypted and sent along with image</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Only tested against Chi-square steganalysis</li> <li>Pixel Locator Sequence exchange overhead</li> <li>Not compared to similar techniques</li> </ul>	RGB images 225x225, 512x512 Avg. PSNR =46.148	PSNR, MSE, Chi square
[76]	<ul style="list-style-type: none"> <li>Encrypting the secret message using Blowfish algorithm</li> <li>Randomization achieved by LCG algorithm</li> <li>Number of embedded bits is intensity based (2-6 bits)</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Only used Chi-square steganalysis</li> <li>Not compared to similar techniques</li> <li>Payload capacity is not mentioned in Chi square attack.</li> </ul>	256x256, USC-SIPI image database bpp: 2.00: 2.95 Avg PSNR = 47.286	MSE RMSE PSNR Chi-Square Attack
[77]	<ul style="list-style-type: none"> <li>The secret message is AES encrypted and the embedding positions are randomized using LM and Cat maps.</li> <li>1st &amp; 2nd bit planes are utilized</li> <li>Using accurate PSNR (weighted PSNR)</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Non-standard steganalysis techniques</li> <li>Not compared to similar techniques</li> <li>parameters exchange overhead.</li> </ul>	Medical images 256 x 256, 512x512 Payload 0.5 bpp. Avg PSNR= 50.89: 50.73 Avg wPSNR= 60.21: 69.84	PSNR, wPSNR, MSE, SSIM, Cross- correlation Coefficient, Entropy and Key sensitivity.

In [80], a color image of H×W size is decomposed into three images consisting of its RGB components at the bit-level. These images are then vertically combined to create one bit-level image (3H rows x 8W columns). Based on Chaotic SKTM, permutation is carried out at a bit level of the image. The initial values of the chaotic function are concluded based on a 128-bit key value, which is constructed from a combination of external user key and information extracted from the plain image. Eventually, the function is iterated 3Hx8W times, and the results are recorded and inverted to be used for permuting the image bits accordingly. A lightweight encryption scheme is presented in [81]. The raw image is converted to a 1D array and permuted using a random sequence produced by the LM. This sequence is transformed into a DNA sequence. Also, the LM is used to generate another random sequence that is likewise used to obtain another DNA sequence. The two sequences are added using DNA computation rules. In the final step, each pixel is XORed with its preceding pixel. In [82], the authors propose a compression and encryption method based on hyper-chaotic function, 2D compressed sensing, and DNA encoding. The aim of using a hyper-chaotic function instead of the 1D chaotic function is to increase the system key space, thereby improving system complexity and security. The cover gray image is compressed using the 2D compressed sensing technique. Fractional-order Chen hyper-chaotic system is employed to control DNA encoding and operation. The initial values of the Fractional-Order hyper-chaotic system are generated using the hash value of the original image. The DNA encoded image is enciphered using Arnold transformation to produce the encrypted image.

In [83] authors propose an encryption scheme that uses intertwining and ELMs. The primary point is to de-associate neighboring pixels by shuffling them. Next, the image is partitioned into blocks, and permutation-substitution operations are performed using an intertwining LM and ELM along with the cosine-based transformation. In addition, the image is rotated 90° anticlockwise. Finally, random order substitution is achieved by utilizing the random sequence generated using a

chaotic function. A novel high speed image encryption scheme based on 1-D cosine fractional chaotic map and image encryption scheme (DCF-IES) is proposed in [84], which is based on a new real 1-Dimensional Cosine Fractional (1-DCF) chaotic map. To increase encryption speed, permutation operation is excluded from the architecture design. Despite the absence of the permutation process, a substitution process with a high sensitivity to a plain image guarantees a high level of security. The chaotic function is first utilized to generate two sequences that act as system keys, wherein the keys are used to accomplish substitution. The process is achieved by performing an XOR operation as also addition and MOD functions between the key and raw pixels. This operation is iterated twice over image row values to ensure strong encryption. The output cipher is sensitive to minor changes in the value of the input pixels.

In [85], image scrambling-based encryption is presented. Scrambling is carried out based on a random sequence, which is generated using a formula of two inputs that act as a secret key. Then, the pixels' locations are rearranged utilizing the generated sequence. Permutation based encryption is suggested in [86]. In this method, the Linear Feedback Shift Register (LFSR) produces a PRN that is employed to generate two shuffled images. Permutation of the image rows creates the first one, while permutation of image columns forms the second image. Both images are XORed in the final step to create the encrypted image. The Chaotic Gravitational Search (CGS) concept for encryption is introduced in [87]. In this system, a binary gravitational search algorithm selects a random PRNG, thus starting an encryption key among three algorithms: Mersenne Twister (MT), SIMD-Oriented Fast Mersenne Twister (SFMT), and Combined Multiple Recursive (MRG) algorithms. Then, the Chaotic Gravitational Search Algorithm (CGSA) produces the initial value for the selected generator. The generated keystream is used to encrypt images by applying permutation alone or in combination with the substitution process.



Authors in [88] suggest transposition and substitution encryption-based techniques that utilize two pseudorandom generators: an altered version of the Sophie Germain Prime Generator (ASGPG) and Lehmer Random Number Generator (LRNG), which generate a group of random numbers. The first group is used to assign new values to image pixels by XORing the random numbers with image pixels: a substitution condition. The second group attains the transposition by swapping the positions of pixels. In [89], improved Baker map and LM are used to achieve image encryption. A two-dimensional Baker chaotic map is employed to control the chaotic LM parameters as well as the state variable. It is used to increase the randomness and unpredictability levels. Two random sequences are produced by the chaotic LM. The sequences are then exploited to perform image encryption by first shuffling the pixels, followed by substitution. Likewise, in [90] chaos-based encryption is proposed, which follows the permutation and substitution methodology to encrypt the original image. Clifford's chaotic system and LM are iterated for a particular value followed by a quantization process. Next, positions are shuffled, and grayscale substitution is performed as a final stage. Parameters of the Clifford system map or the attractor, act as encryption keys.

In [91], the authors propose a Hyper-Chaos (HC) based image encryption algorithm. They make use of a 5-D multi-wing hyper-chaotic system to resist cryptanalysis. It generates a chaotic sequence that is used first for pixel-level permutation and then for bit-level permutation. Up to this point, confusion is fulfilled. To achieve diffusion, the chaotic sequence generated earlier is XORed with the confusion step output. It is worth mentioning that the function's parameters are deduced from the plain image properties. In [92] presents a unified image encryption algorithm. This technique utilizes Substitution-Box (S-Box) to realize the diffusion concept.

Hence, a keyed-piecewise linear chaotic map creates a key stream sequence. This key is employed for diffusion operations that are based on a specific formula between this key value and image pixels. However, the intermediate encrypted image is 180° rotated and then scrambled before making the second diffusion. In this technique, the decryption process is identical to the encryption process. Table IV summarizes the related references for the image encryption methods.

### C. Region based Steganography

In the following paragraphs, some techniques will be presented, wherein steganography is carried out in certain areas of the cover image to primarily enhance security. Some techniques exploit only image edges, while others use edges and smooth areas. Image edges and boundaries are the areas in which the intensity value changes sharply within a short distance, while the smooth area is the area with low-intensity variations. In [18], edge pixels are detected and selected for embedding using the Canny edge detector. Huffman code is applied to the secret bits in the primary step for data compression. Then, the edge pixels are randomized, and the number of pixels intended for embedding is determined by coherent bit length L. Next, 2k correction is applied to achieve better imperceptibility. Edge detection incorporated with morphological dilation as part of the steganographic technique is suggested in [20]. In this method, the secret message is embedded in the image sharp regions, which are detected by the Canny edge operator and optimized by the morphological dilation operator. The Canny operator is applied to a modified version of the original image channels obtained by adding the 4 MSBs of RGB channels. Subsequently, a 3x3 dilation operator is utilized to identify reference pixels. The bits are inserted within the remaining LSB bits using the hybrid XOR technique, such that least possible alterations of edge pixels are guaranteed. This meets the high security demands.

TABLE IV. SUMMARY OF ENCRYPTIONS TECHNIQUES OF IMAGE ENCRYPTION TECHNIQUES

Ref	Encryption Concept
[78]	Confusion based encryption using Arnold Cat map and HM algorithm
[79]	Encryption is achieved by rotation, modified zigzag transformation, and enhanced LM output with XOR operation. It is a confusion and diffusion encryption.
[80]	Bit-level image Permutation using a chaotic skew tent function
[81]	Permutation using a chaotic LM in addition to DNA encoding operations
[82]	Arnold transformation encryption of DNA
[83]	Permutation-substitution encryption utilizing intertwining logistic, enhanced LM, and cosine-based transformation
[84]	Substitution by exploiting 1D-dimensional cosine fractional (1-DCF) chaotic map
[85]	Scrambling based encryption using random sequence based on user formula
[86]	Permutation based encryption using linear feedback shift registers along with XOR operation
[87]	Permutation only or with substitution by exploiting a Binary gravitational search algorithm, Mersenne twister, SIMD-oriented Fast Mersenne twister, and combined multiple recursive.
[88]	Transposition and substitution encryption based on Sophie Germain prime generator and Lehmer random number generator
[90]	Transposition and substitution encryption using an improved baker map and LM
[91]	Permutation - substitution encryption utilizing Clifford chaotic system and LM
[92]	Permutation - substitution encryption using a 5-D multi-wing hyper-chaotic system
[92]	Substitution - permutation encryption by employing a keyed-piecewise linear chaotic map

In [93], the secret data is hidden in the edges of the image using the LSB technique. The Canny edge detection algorithm is employed to identify image edges. The secret message is converted into a binary sequence and encrypted using the OTP encryption method. The encryption process is achieved by modulus addition of the secret bits with the corresponding OTP bits. Laplacian of Gaussian (LoG) detector is used in [94] alongside a chaotic function. The secret information is first encrypted by XORing it with a PRN generated by a chaotic LM. Then, the edges of the green and blue planes are identified using the LoG edge operator. Finally, 2-LSB of the green and blue edge planes are used for the embedding process. In [19], the author suggests using a hybrid edge detector and encryption to secure the steganographic technique. The Vernam cipher is applied to the secret message using a pseudo-random generated key that is generated using a nonlinear feedback shift register, Geffe Generator. This method uses a hybrid edge detector which combines the Sobel operator with Kirch operators. The LSB technique is used to hide secret message bits; here, three bits are embedded in the edge pixels while two bits are embedded in non-edge pixels.

In [95], an Adaptive Multi Bit-Planes image steganography using Block Data-Hiding (MPBDH) is proposed. First, the secret message is encrypted using the AES algorithm. Then, complex regions are chosen for embedding, based on a complexity threshold estimation and the number of bit planes. If the whole message cannot be embedded within the selected pixels, then parameter readjustment is used to compulsorily ensure that all bits are embedded. LSB and Hamming code-based algorithm is suggested in [96]. The cover image is

divided into blocks, and then edge detection is performed after zeroing all LSBs of the red channel pixels. The embedding is done based on the pixel's location. If the pixel is a non-edge pixel, standard LSB embedding is used for the RGB channels. Otherwise, LSB is performed for the three channels and the other two LSBs of the RG channels are used to embed the Hamming code. In [97], the complexity is based on the pixel variation among the central pixel and all neighboring pixels. The cover image is divided into small overlapping blocks (3x3). Then, a multidirectional high pass filter bank is used to find eight residual responses, which are then utilized to calculate the corresponding complexity using a proposed Complex Block Prior (CBP) criterion. The blocks are also sorted from high to low complexity, and the blocks with the same complexity level are grouped together. Finally, a single bit or multiple bits are embedded adaptively within the central pixel.

The Block-Wise Edge Adaptive Steganography Scheme (BEASS) method is suggested in [98]. It utilizes the edges obtained by using a fuzzy edge detector as well as the surrounding pixels to embed secret message bits. The cover image is divided into 64x64 blocks, and their corresponding standard deviation is calculated to estimate their local complexity. The blocks are sorted according to their standard deviation, and then the blocks are further divided into 3x3 blocks. Three message bits are hidden in edge pixels using the minimal mean squared error (MSE) that helps determine the embedding capacity of neighboring non-edge pixels within the block. Table V summarizes the related references about the region-based image steganography methods.

TABLE V. SUMMARY OF REGION-BASED STEGANOGRAPHY TECHNIQUES

Ref	Features and Pros	Cons	PSNR (dB)	Evaluations Metrics
[18]	<ul style="list-style-type: none"> <li>Secret message compressed using Huffman coding and randomly embedded in edge pixels (Canny edges)</li> <li>Coherent bit length L determines the number of embedding pixels</li> <li>2k correction maintains visual quality</li> </ul>	<ul style="list-style-type: none"> <li>Huffman Table must be exchanged</li> <li>Steganalysis evaluation is missing</li> <li>Steps add complexity</li> <li>Limited capacity</li> </ul>	512x512 gray-scale Payloads =35852:108074 bits Avg. PSNR= 61.9654	PSNR, Universal Image Quality Index (Q)
[19]	<ul style="list-style-type: none"> <li>Vernam cipher encryption of the secret message with a pseudo-random key to enhance security</li> <li>Efficient hybrid edge detector of Sobel and Kirch operators to improve capacity</li> <li>LSB adaptive embedding in Green &amp; Blue channels.</li> </ul>	<ul style="list-style-type: none"> <li>7 bits of 2 block of 3x3 pixels utilized as embedding indicator</li> <li>Steganalysis evaluation is missing</li> <li>Encoding complexity</li> </ul>	90x90 secret image 512x512 cover image Avg bpp=1.9605 Avg PSNR= 41.533	MSE, PSNR, bpp
[20]	<ul style="list-style-type: none"> <li>Canny edge detector with dilation operator to involve edge pixels and their neighbours to improve capacity</li> <li>Embedding using an improved XOR technique to improve security</li> <li>Robust against (RS) steganalysis</li> </ul>	<ul style="list-style-type: none"> <li>Relatively Low embedding rate</li> <li>Encoding complexity.</li> <li>Only RS steganalysis tested</li> </ul>	512x512 Greyscale and color images Avg bpp=1.25 Avg PSNR = 44	MSE, PSNR, SSIM, FSIM
[93]	<ul style="list-style-type: none"> <li>To add security, the secret message is OTP encrypted</li> <li>OTP key is obtained using random function</li> <li>LSB based in Canny edge pixels.</li> </ul>	<ul style="list-style-type: none"> <li>Handling of message key and host image edges</li> <li>Steganalysis evaluation is missing</li> <li>Low capacity</li> </ul>	512x512 greyscale images Payload: Up to 1KB PSNR for 1KB =69.1106	CC, PSNR, MSE
[94]	<ul style="list-style-type: none"> <li>LoG edge pixels of green and blue channels is used for embedding process</li> <li>Efficient low complexity XOR encryption of the message with chaotic logistic map sequence</li> </ul>	<ul style="list-style-type: none"> <li>Parameters exchange overhead</li> <li>Steganalysis evaluation is missing</li> <li>Relatively Low capacity as 2 channels are used</li> </ul>	512x512 RGB image bpp=1.72 PSNR= 46.1733	PSNR, NCC, Entropy, Number-of-changes-per-rate, and Unified-average changed-intensity.

[95]	<ul style="list-style-type: none"> <li>The secret message is AES encrypted and adaptively embedded in noisy regions</li> <li>Muti bit planes is utilized with block data-hiding</li> <li>Enhanced image visual quality</li> <li>Robust against visual attack and ensemble classifier</li> </ul>	<ul style="list-style-type: none"> <li>RSA key exchange overhead</li> <li>Other well-known steganalysis are not tested</li> <li>Complexity is based on the bit planes not value of pixels</li> <li>Ensemble classifier test for low bpp</li> </ul>	<p>512x512 gray images bpp=0.4, PSNR= 56.64, wPSNR= 71.96</p> <p>bpp=1.50, PSNR=48.08 wPSNR=63.20</p>	PSNR, wPSNR, SSIM, Visual attack, Ensemble classifier
[96]	<ul style="list-style-type: none"> <li>Adaptive embedding based on LSB and Hamming code.</li> <li>Non-edge pixel use LSB embedding</li> <li>Canny edge pixel to embed secret bits and Hamming code</li> <li>Imperceptibility improved with adaptive embedding</li> </ul>	<ul style="list-style-type: none"> <li>Steganalysis evaluation is missing</li> <li>Few tests</li> <li>Capacity affected by Hamming code</li> <li>Cleared red LSBs affects the visual quality</li> </ul>	<p>RGB 512x512, 512x384 from USC-SIPI, UCID-Image Database Payload: 9424:30224bits PSNR: 63.397 :68.429</p>	PSNR, MSE
[97]	<ul style="list-style-type: none"> <li>A content-adaptive steganography method based on identifying the local texture complexity.</li> <li>Complexity based on pixel variation with respect to all neighbours using multi-directional High Pass Filter bank</li> <li>The maximum of the pixel differences in a pixel block determines number of embedding bits</li> <li>Embedding using LSBMR or multibit XOR</li> </ul>	<ul style="list-style-type: none"> <li>Too local complexity estimation since small blocks size are utilized</li> <li>Other steganalysis tests not tested</li> <li>Relatively complex</li> <li>Parameter handling</li> </ul>	<p>512x512 greyscale SIPI, BOWS2 and BOSSbase dataset Max capacity= 249,729: 549,051 (0.95: 2.09 bpp) PSNR= 44.16:56.23 wPSNR=63.88: 75.87</p>	Capacity, PSNR, WPSNR and SSIM SPAM STEGANALYSIS
[98]	<ul style="list-style-type: none"> <li>Block-wise Edge Adaptive Steganography Scheme (BEASS)</li> <li>Dynamic local complexity measure of Standard Deviation is utilized (image subblocks containing edges are selected)</li> <li>high payload with minimal distortion embedding utilizing the minimal Mean Square Error</li> <li>Robust against major attacks</li> </ul>	<ul style="list-style-type: none"> <li>Standard deviation as a complex measure is not accurate for big blocks as it does not take into account the spatial arrangement of pixels</li> <li>wPSNR measure is more accurate in such cases</li> <li>Low embedding capacity</li> <li>High complexity</li> </ul>	<p>512x512 greyscale images from BOSSbase database bpp= 0.3 : 1 PSNR (0.3 bpp) =70.54: 74.66 PSNR (~1 bpp) = 61.28: 65.78</p>	PSNR, KL-Divergence, SSIM, Average Difference, NAE, Execution time, Kurtosis, Skewness, Histogram analysis, RS attacks, and feature based universal steganalyzer

#### D. Bit-Plane System

The following LSB steganography techniques use the concept of virtual bit-plane. Higher plane systems are exploited instead of using an 8-bit plane to hide secret data. In these systems, the Zeckendorf criterion needs to be satisfied in order to embed the secret information that can be extracted later. "Every positive integer can be represented uniquely as the sum of one or more non-consecutive distinct Fibonacci numbers" [99]. Hence, the number representation is considered valid if no consecutive ones appear in the sequence.

In the scheme presented in [99], secret data is embedded in different bit-planes rather than using the regular binary bit planes. It is based on the Lucas Number system that uses 11 numbers for representations. Hence, the Lucas sequence is utilized for image bit plane representations, which uses 11 bits instead of 8 bits for representing the pixel's intensity. Embedding is achieved in the second bit-plane, which yields deterioration by  $\pm 1$  in the stego image. Blue and green channels of the RGB color image are used for data embedding, while red is used as an indicator. As mentioned, embedding should comply with the extended Zeckendorf theorem for handling redundant representation. In [100], the method represents the cover image using the Fibonacci sequence. The cover image in this situation is represented in 12-bit planes. The secret message to be embedded is encrypted using a symmetric cipher with the help of a chaotic LM to generate the encryption key. Then, the generated key is XORed with secret bits and embedded in the second LSB.

Authors in [101] suggest improving the Fibonacci data hiding technique by utilizing Catalan numbers. A certain set of Fibonacci numbers and a certain set of Catalan numbers are combined to create a new number set that complies with

Zeckendorf's theorem. As a result, 15 virtual bit-planes are obtained, which is three more than the number of bit-planes produced by the Fibonacci method. Authors in [102] propose two embedding techniques by utilizing two different number systems. The first embedding scheme is based on a prime decomposition of pixel value into 15 virtual bit-planes. In contrast, the second is based on natural number decomposition, which yields 23 virtual bit-planes. In these techniques, the secret message can be embedded in higher bit-planes without introducing noticeable distortion. In [103], a new method based on a specific representation is used to decompose pixel intensity values into 16 virtual bit-planes. This scheme necessitates that the sum of all bit-planes must be less than the highest pixel intensity value, which in this case is  $2^8-1$ . For the embedding process, a cover pixel is randomly selected using PRNG, then decomposed, and a particular virtual-bit plane is chosen. To represent numbers that have multiple representations, the one with high lexicographically representation is selected. In addition, if a pixel value post embedding cannot be represented in the system, it is excluded, as the embedded information cannot be extracted. The author in [104] proposes a steganographic technique based on a new pixel value decomposition. This scheme uses a set of decomposition weights that decompose the cover image into 10 bit-planes. The first five LSBs' weights increase slightly while growing exponentially for the rest. The secret message bits are embedded in one or more LSB positions. Embedding is only done for modified pixels with a valid representation in the system. Moreover, in several cases, numbers have more than one representation in the system. Hence, the one with the lowest lexicographical representation is a valid number. Table VI summarizes the references related to bit-plane based methods.

TABLE VI. SUMMARY OF BIT-PLANE BASED STEGANOGRAPHY TECHNIQUES

Ref	Features and Pros	Cons	PSNR (dB)	Evaluations Metrics
[99]	<ul style="list-style-type: none"> <li>Using Lucas sequence to represent pixel's intensity</li> <li>Yields deterioration by <math>\pm 1</math> in the stego image.</li> <li>Reduces visual distortion effects.</li> <li>Robust against geometrical, statistical and structural attacks</li> </ul>	<ul style="list-style-type: none"> <li>Low capacity than standard LSB steganography</li> <li>Produce lower quality stego image</li> <li>Image structure not considered</li> <li>More complex than binary representation</li> </ul>	512x512, 394x600, 768x512, 200x200 RGB USC-SIPI & Kodak bpp=10%:100% PSNR=57.27:47:34	MSE, PSNR, SSIM histogram differences, image, Chi-square attack, structural attacks and RS attack
[100]	<ul style="list-style-type: none"> <li>Cover image represented using Fibonacci sequence</li> <li>XOR encryption of LM sequence with secret message</li> <li>Embedding in the 2nd bit plane</li> <li>Simple and effective encryption using the XOR operation</li> </ul>	<ul style="list-style-type: none"> <li>Some pixels escaped</li> <li>Image structure not considered</li> <li>Steganalysis attacks missing</li> <li>Computation overhead</li> <li>Parameters exchange overhead</li> </ul>	512x512 greyscale images from CVG-UGR Database bpp=0.3, PSNR = 54.21 bpp=0.9, PSNR = 41.04 Avg PSNR :49.97	ER, MSE, PSNR Robustness tests Bit error rate BER rate-distortion curve
[101]	<ul style="list-style-type: none"> <li>Number set composed of union of a certain set of Fibonacci numbers and a certain set of Catalan numbers</li> <li>15 virtual bit-planes obtained</li> <li>Robust against statistical and geometrical attacks</li> </ul>	<ul style="list-style-type: none"> <li>Some pixels escaped (affects capacity)</li> <li>Image structure not considered</li> <li>Steganalysis attacks missing</li> <li>Computation overhead</li> </ul>	Greyscale images Payloads: 1000:2500 bits PSNR= 67.03: 71.45	MSE, PSNR
[102]	<ul style="list-style-type: none"> <li>Cover image can be represented using prime sequence (15 bits), or using natural number sequence (23 bits)</li> <li>Secret message can be embedded in higher bit-planes without introducing distortion.</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Steganalysis attacks missing</li> <li>Computation overhead</li> <li>Low visual quality for higher bit planes</li> </ul>	Greyscale images (Natural, prime) PSNR(bit plane): 0 <sup>th</sup> = 48, 48, 1 <sup>st</sup> = 43, 43, 7 <sup>th</sup> = 30, 24	Worst case Mean Square Error (WMS) PSNR, Histogram
[103]	<ul style="list-style-type: none"> <li>Pixels randomly selected and decomposed into 16 bit-planes.</li> <li>A particular bit plane is chosen</li> <li>Produces less distortion</li> </ul>	<ul style="list-style-type: none"> <li>Some pixels cannot be used for embedding</li> <li>Capacity is affected by unusable pixels</li> <li>Image structure not considered</li> <li>Steganalysis attacks missing</li> </ul>	512 x 512 PSNR: 1 <sup>st</sup> LSB= 52, 2 <sup>nd</sup> LSB= 50, 7 <sup>th</sup> LSB= 37, 8 <sup>th</sup> LSB= 34	Payload capacity, PSNR
[104]	<ul style="list-style-type: none"> <li>Cover image is decomposed into 10 virtual bit-planes</li> <li>The first 5 LSB weight increases slightly</li> <li>Embedding in one or more LSBs positions (valid pixels)</li> <li>Robust against statistical</li> </ul>	<ul style="list-style-type: none"> <li>Not every pixel is valid after embedding</li> <li>Capacity is affected by unusable pixels</li> <li>Image structure not considered</li> <li>Steganalysis attacks missing</li> <li>Computation overhead</li> </ul>	512x512 jpg images Embedding using: 0 <sup>th</sup> ,1 <sup>st</sup> , 2 <sup>nd</sup> ,3 <sup>rd</sup> ,4 <sup>th</sup> bit PSNR: 39.41: 49.02	MSE, PSNR, SSIM

### E. Pixel Indicator Techniques

In indicator-based data embedding schemes, the channels are divided into indicator and data channels. The indicator channel determines the data channel for data hiding, based on certain sequences for better security. In [16], the two least significant bits of one channel are used as an indicator of the presence of secret data in the other two data channels. The indicator channel is chosen based a sequence created from R, G, and B, that is, RGB, RBG, GBR, GRB, BRG, and BGR. The length of the secret message is used as an indicator selection criterion to enhance security. In addition, hiding data in channels considers the pixel's intensity.

In [1], the 7<sup>th</sup> bit of a pixel and the 7<sup>th</sup> bit of the pixel value +1 are concluded. A comparison between those values and two bits from the secret message is conducted to seek a matching. In the case of a mismatch, the difference is calculated and then added to the pixel value. At this point, the embedding process is completed for this pixel. Eventually, the embedding process alters the pixel value by +2 or -2. The aim of designing this algorithm is to implement robust and secure steganography. In [25], a variant version of PIT is presented. This technique uses indicator channel criteria to determine the data channel order, based on the combinations of the MSB in the RGB channel. The first step is to obtain the message length, which is then

stored in the first 8 bytes of the first row. Then, embedding is started from the first 8 bytes of the second row, and the indicator channel selection criteria is utilized to determine the order of the data channel. The selection criteria are based on the message length and the type of the parity bit used to create a shuffled order of RGB channels. Also, the number of bits to be embedded in each channel is specified.

The study [105] suggests a PIT based technique to achieve high capacity. Here, the binary secret message is divided into four parts and the cover image. The two LSB of the first eight bytes of the red channel of the image are used to store the message length. The order of the cover image parts is stored in the two least significant bits of the four first pixels in the blue channel. Next, each pixel is evaluated for the ability to embed using the red channel's three MSBs. The three bits represent the RGB ability: the presence of zero means no embedding has taken place in that channel. Then, the number of zeros in the four MSBs of the candidate channel is counted to determine the number of secret bits to be hidden. The method proposed in [106] utilizes the red channels as an indicator to hide the secret message in the fifth and sixth bits of either the green or the blue channels of the cover image. The count of ones in the red channel determines which channel is currently in use. If the count is even, the green channel is used to embed the secret data; otherwise, the blue is used. A similar technique is found

in [107] in which the green channel is used as an indicator. If the count of the number of ones in the green channel is even, the red channel is used. Otherwise, the blue one is used. Utilizing two bits for embedding process of each pixel leads to reasonable payload capacity but enhances its security. Table VII summarizes the references related to PIT based techniques.

*F. Steganographic Techniques Based on Combination of Different Concepts*

In this section, several techniques are seen to apply different concepts to achieve secure steganography. In the scheme proposed in [108], Huffman coding is applied to the secret message to reduce its size. Then, based on the location (x, y) of the current pixel, either a bitwise XNOR operation or Fibonacci algorithm is applied to embed the secret message. If x is less than y, the XNOR operation is employed to embed the secret bits in the green or blue channels, and the red channel is used as an indicator. If y is greater than x, the Fibonacci algorithm is applied to embed secret bits in the second LSB of the Fibonacci virtual green bit plane. Otherwise, the pixel is skipped. In [109] the author suggests a steganography technique based on control bit and chaotic bit stream. A chaotic LM is used to generate a chaotic bit stream. Then, this stream is XORed with the LSB of the cover image pixels to create a control bit matching with the corresponding secret message bit. Therefore, the embedding process may change the LSB value or be kept intact based on specific criteria. A technique based on Adaptive Directional Pixel Value Differencing (ADPVD) is suggested in [110]. The aim is to enhance embedding capacity

and security. The method starts by evaluating the PVD embedding capacity by traversing three directions: the horizontal, vertical, and diagonal directional edges. That is accomplished after partitioning the original image into two-pixel non-overlapping blocks. The highest capacity rate is calculated for each color channel, and then the appropriate direction is selected.

In [111], the authors suggest a steganography technique based on variant expansion and modulus function. The purpose is to improve embedding capacity as well as the security of the stego image. The cover image is divided into non-overlapping blocks of two pixels. The proposed method considers multiple directions for each color channel and adaptively selects the appropriate embedding direction that achieves the highest embedding capacity. Instead of only considering positive differences, this method selects positive and negative difference values to hide secret data. In [112], the authors present a steganographic method for an RGB image based on the PVD technique. As in most PVD based techniques, the cover image is partitioned into sequential non-overlapping blocks of two pixels. Then, two-color channels combinations are created: red and green color components for the first combination, and green and blue color components for the second. Next, the secret data is embedded in each block using the PVD technique and then examined and readjusted to obtain the modified three-color combination. This operation utilizes a particular threshold to control the embedding capacity of each block in order to minimize distortion.

TABLE VII. SUMMARY OF PIT BASED STEGANOGRAPHY TECHNIQUES

Ref	Features and Pros	Cons	Evaluations	Metrics
[1]	<ul style="list-style-type: none"> <li>The embedding is based on the indicator bit, the 7th bit of a pixel value p and p+1</li> <li>Robust and secure steganography</li> <li>Simple implementation</li> <li>The embedding process alters the pixel value by +2 or -2.</li> </ul>	<ul style="list-style-type: none"> <li>Lack of steganalysis.</li> <li>Subject to statistical steganalysis</li> <li>All image regions are considered affects security and imperceptibility</li> <li>Low capacity</li> </ul>	256x256 from USC-SIPI-ID dataset. Payload: 2: 10 KB PSNR: 55.39: 48.39 bpp=0.031: 0.16	PSNR, MSE, Histogram
[16]	<ul style="list-style-type: none"> <li>The indicator channel selection is secret message length dependant to enhance security</li> <li>Produces low visual distortion</li> <li>Hiding process takes into account the pixel's intensity</li> <li>Standard PIT algorithm uses 2-bits LSB's</li> </ul>	<ul style="list-style-type: none"> <li>It uses a fixed number of bits per channel that could cause noticeable distortion</li> <li>Uses fixed embedding sequence</li> <li>Image structure not considered</li> <li>Steganalysis evaluation is missing</li> </ul>	512x384 BMP image 2: 8KB, 256x256 avg PSNR= 43.65: 52.81	PSNR, Histogram, Mean, standard deviations
[25]	<ul style="list-style-type: none"> <li>Indicator channel selected based on the message length</li> <li>Data channel is selected according to 3LSBs of indicator channel</li> <li>Improved security due to using indicator with multi-mode indicators with adaptive channel embedding</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Steganalysis attacks missing</li> <li>Limited capacity due pixels escaping</li> <li></li> </ul>	RGB images Payloads: 1Kb, 2Kb, 4Kb Avg. PSNR:64.45, 62.45, 60.45	PSNR, MSE
[105]	<ul style="list-style-type: none"> <li>It uses 3 MSB of red channel as an indicator</li> <li>Number of zero bits in MSB determines storage capacity</li> <li>To enhance security, input image divided to 4 regions and each part of secret message will store in this region.</li> </ul>	<ul style="list-style-type: none"> <li>Some pixels are used to store control bits</li> <li>Image structure not considered</li> <li>Steganalysis evaluation is missing</li> <li>Subject to statistical and geometrical attacks</li> </ul>	RGB with different sizes 2000 character 2.144122 bpp (avg) avg PSNR 60:57	Histogram, Mean, standard deviations, PSNR
[106]	<ul style="list-style-type: none"> <li>Uses 5th &amp; 6th LSBs to enhance security since attacker focus on LSB bits for secret data extraction</li> <li>Number of ones in the indicator channel determines the data channel</li> <li>2 bits of the other channels are used as data bits.</li> <li>Secret message bits are XORed with predefined secret key to increase security</li> </ul>	<ul style="list-style-type: none"> <li>All image contents are considered</li> <li>Steganalysis evaluation is missing</li> <li>Subject to structural and geometrical attacks</li> <li>Low payload capacity</li> </ul>	RGB with different sizes PSNR (512X512) = 54.65 Max payload =2 bpp	PSNR Histogram Mean values

A steganographic method based on an LM function combined with LSB and PVD to improve security is suggested in [21]. A random key is generated using a chaotic LM that is employed to pick two pixels randomly at a time. In addition, the key value is utilized along with the MOD function to operate either with 3-LSB substitution or PVD, to embed the secret information. In [113], the author claims a novel steganographic approach known as Clustering Modification Directions (CMDs). In this scheme, instead of focusing only on the embedding location clusters of the texture area, clustering of the direction modifications is considered as well. The purpose is to obscure statistical features to resist steganalysis.  $\pm 1$  LSB embedding approach is considered in this situation. The cover image is segmented into several sub-images as well as the secret message. After embedding the first message portion, the costs of the adjacent segments are updated to cluster the embedding direction. Each time embedding occurs, the costs are updated. A variable-length group of bits substitution based scheme is presented in [114]. In this scheme, embedding for a Group of Bits' Substitution (GBS) is done by replacing a group of bits in a pixel with another group of bits of the same message length. The scheme is designed to work in two variations: 1-bit GBS and 2-bit GBS, which hide 1-bit and 2-bits, respectively. The choice is based on certain predefined conditions. Image imperceptibility and security are improved since most of the pixel values remain unchanged.

The authors in [115] suggest LSB based steganography with Optical Character Recognition (OCR). The concept is based on using a secret message in the form of characters within an image. Character-level features are extracted from the secret image and then embedded into a cover image using the standard LSB. The OCR model has been developed and trained to extract character features. The security perspective of this technique is that, even if the attacker extracts the embedded bits, he still needs to know the OCR model in order to recover the original message. In [116], the authors propose a new method by combining the Right-Most Digit Replacement (RMDR) with an Adaptive Least Significant Bit (ALSB). The cover image is divided into lower texture and higher texture regions. Accordingly, either RMDR or ALSB is chosen to embed the secret message based on RMD rather than bits. RMDR is employed to embed secret bits in the lower texture regions, whereas ALSB is used in high texture regions.

In [117], the RGB cover image is cropped into a predefined number of crops with certain secret coordinates. This number is used to divide the secret text message accordingly. Each part of the message is then embedded using standard LSB into a certain cropped part using a secret sequence. Embedding is

achieved using the 3-3-2 sequence. Finally, stego crops are assembled to create the stego image. The coordinates of cropped parts are considered as the key and agreed upon between the two parties. The approach presented in [118] uses two images: a reference image and a cover image. The reference image is divided into N blocks, wherein every block is assigned a unique code. The secret message is also divided into N-bits blocks that are encoded using the block codes obtained earlier. If there is no match between the secret block and the block codes, some LSBs of the reference image need to be altered. Information such as the starting block and traversing direction is incorporated into a secret key, which is then encrypted using the RSA algorithm. Finally, the encoded bit sequence is embedded into the cover image using any LSB technique.

Utilizing bit plane indexes, authors in [119] suggest a secure steganography technique. In this scheme, the secret message is embedded in multiple image bit planes to enhance security without sacrificing capacity payload. It is based on manipulating bit planes indexes. Only the two LSB bits are employed for this purpose. The cover image is initially preprocessed such that the first two bits are not be equal. If the first LSB bit equals the first secret bit, the index is recorded. If they mismatch, the second LSB plane is recorded. In the next turn, the recorded index is in reverse order, for example, if it previously recorded zero, it is one the next time and alteration to LSB is done accordingly. Hence, the final index stream fluctuates between zero and one. In [120], a different perspective is developed to achieve image steganography. Instead of modifying separate image pixels, which causes random noise in the image, this technique changes the image's color palette. All pixels of the same color are transformed into the same color. Therefore, this method achieves a higher user perception. Utilizing quad-trees, authors in [29] present a steganographic method in luminance ( $L^*$  channel) and chrominance ( $a^*$  and  $b^*$  channels) ( $L^*a^*b^*$ ) color space. This approach utilizes a quad-tree segmentation process to partition the spatial domain of the cover image into high correlation and low correlation adaptive size blocks. Embedding is done in the high frequency regions of the DCT of the highly correlated cover image blocks. To improve stego quality,  $L^*a^*b^*$  color space is utilized. A high quality stego image is guaranteed along with better security, since the embedding takes place only in the high frequency regions that produce minimum image degradation. The performance of this method is affected by the correlation of the image, wherein a highly correlated image is preferred. Table VIII summarizes the related references.

TABLE VIII. SUMMARY OF STEGANOGRAPHIC TECHNIQUES BASED ON DIFFERENT CONCEPTS

Ref	Features and Pros	Cons	PSNR (dB)	Evaluations metrics
[21]	<ul style="list-style-type: none"> <li>High capacity and Security by combining LSB&amp;PVD with LM to randomly select two consecutive pixels</li> <li>Using either LSB or PVD based on mod function and LM</li> <li>3 bits embedded in case of LSB</li> </ul>	<ul style="list-style-type: none"> <li>Lack of steganalysis.</li> <li>Low visual quality.</li> <li>All image regions are considered affects security and imperceptibility</li> </ul>	512x512 greyscale Payloads: bpp=2.26: 2.37 Avg PSNR: 38.7925	PSNR, Histogram analysis
[29]	<ul style="list-style-type: none"> <li>Quad-tree utilized to obtain High &amp; low correlations adaptive-size blocks</li> <li>Embedding only in high frequency regions</li> </ul>	<ul style="list-style-type: none"> <li>The performance is affected by the correlation of the image (highly correlated image is preferred)</li> </ul>	512 x 512 color images with variety of correlations Capacity 76%-90%	SSIM, Combined Capacity Quality Effective-ness



	<ul style="list-style-type: none"> <li>DCT of chrominance channels (a*b*)</li> <li>Hence high-quality and better security is guaranteed</li> <li>Robust against low-density attacks</li> </ul>	<ul style="list-style-type: none"> <li>Moderate PSNR</li> <li>Payload capacity not mentioned in the steganalysis</li> </ul>	Avg PSNR: 37.317	(CCQE). Attacks: filtering, geometric, and compression attacks.
[108]	<ul style="list-style-type: none"> <li>Hybrid bit planes (Fibonacci) with XNOR operation</li> <li>Huffman coding to compress the secret message.</li> <li>Effective simple encryption offers high security</li> <li>High imperceptibility</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Steganalysis attacks missing</li> <li>Computation overhead</li> <li>Huffman table exchange overhead</li> </ul>	RGB 512x512 images Payloads: 8MB & 16KB PSNR: 65.153:74.192	PSNR, MSE, Embedding capacity, Histogram
[109]	<ul style="list-style-type: none"> <li>XORing LSB with chaotic bitstream to produce control bit</li> <li>Embedding based on comparison of LSB with Control bit</li> <li>Simple implementation</li> <li>Secure against brute force attack</li> </ul>	<ul style="list-style-type: none"> <li>System parameters exchange overhead</li> <li>Image structure not considered</li> <li>Steganalysis attacks missing</li> <li>Subject to statistical steganalysis</li> </ul>	300x300, 512x512, 1024x1024 greyscale images Payloads: 512: 8192 bytes PSNR= 51.96: 64.82	Correlation coefficient, entropy, PSNR, and Image Fidelity
[110]	<ul style="list-style-type: none"> <li>Blocks of two non-overlapping pixels</li> <li>Adaptively selects the direction for each color channel</li> <li>Simple implementation.</li> <li>Enhancement of embedding capacity and security</li> </ul>	<ul style="list-style-type: none"> <li>Image structure not considered</li> <li>Steganalysis attacks missing</li> <li>Moderate visual quality</li> <li>Three direction calculation - overhead</li> </ul>	512x512 bpp =1.65 (greyscale) PSNR=46.71  bpp = 1.63 (RGB) PSNR=51.59	Capacity, PSNR, histogram analysis
[111]	<ul style="list-style-type: none"> <li>Based on variant expansion and modulus function</li> <li>Adaptive embedding direction with positive and negative differences are considered</li> <li>Simple implementation with enhanced capacity and imperceptibility</li> </ul>	<ul style="list-style-type: none"> <li>Overhead of parameters exchange</li> <li>All image regions are considered</li> <li>Steganalysis attacks missing</li> <li>Moderate capacity</li> </ul>	512x512 RGB from SIPI  Highest PSNR= 52.216 Vertical & bpp=1.573 Highest capacity: Diagonal bpp=1.609	MSE, NPCR, embedding capacity, NPCR, UACI, and pixel difference histogram analysis
[112]	<ul style="list-style-type: none"> <li>RGB-PVD based scheme.</li> <li>PVD of the two overlapping channel combination of (R, G) and (G, B) with readjustment of the RGB components</li> <li>Capacity is improved due to overlapping blocks</li> </ul>	<ul style="list-style-type: none"> <li>Low visual quality (Low PSNR)</li> <li>No steganalysis evaluation</li> <li>Sequential embedding and all image regions are considered affects security and imperceptibility</li> </ul>	512x512 RGB images: bpp=2.53 PSNR= 32.79	PSNR, MSE, Payload capacity
[113]	<ul style="list-style-type: none"> <li>Modifications are considered along with clustering the directions (+ or -) of embedding modification by updating the cost</li> <li>Robust against high-dimensional features and ensemble classifiers</li> <li>Can be used together with schemes with additive distortion functions, such as HILL, S-UNIWARD, WOW</li> </ul>	<ul style="list-style-type: none"> <li>High complexity</li> <li>Works with sub images</li> <li>The costs of pixels within each sub-image are dynamically adjusted</li> </ul>	512x512 gray-scale images from BOSSBase image database.	Testing Classification error Steganalytic performance (maxSRMd2) Steganalytic performance (tSRM)
[114]	<ul style="list-style-type: none"> <li>A variable-length group of bits substitution-based scheme with two variations (1-bit &amp; 2-bits)</li> <li>Image imperceptibility and security are improved since the majority of pixel values remain unchanged</li> </ul>	<ul style="list-style-type: none"> <li>Lack of steganalysis.</li> <li>Subject to statistical steganalysis</li> <li>All image regions are considered affects imperceptibility</li> <li>Moderate capacity</li> </ul>	512x512 RGB images 1 bit: Payloads= 1 bpp PSNR=51.64 2 bits: Payloads=2 bpp PSNR= 49.762	PSNR, hiding capacity, image quality index, and pixel difference histograms
[115]	<ul style="list-style-type: none"> <li>Enhanced security since character features of text in secret images are used as secret message</li> <li>Need of a trained OCR model.</li> <li>standard LSB.</li> <li>Efficient in training time and accuracy (SMO classifier)</li> </ul>	<ul style="list-style-type: none"> <li>All image regions are considered (affects imperceptibility)</li> <li>Computationally expensive</li> <li>Overhead of classifier training and testing</li> <li>Preprocessing steps overhead</li> <li>Character-Feature table handling</li> </ul>	RGB Steganalysis Dataset. Payloads: 128x128 grey images. PSNR: 51.107 (1 bpp) 43.094 (2 bpp) 36.444 (3 bpp)	PSNR, MSE, SSIM
[116]	<ul style="list-style-type: none"> <li>Combining RMDR with ALSB</li> <li>The RMDR &amp; ALSB offer high embedding capacity and maintain a good imperceptibility and Security</li> <li>Texture complexity utilized to use either RMDR or ALSB</li> <li>Robust against statistical steganalysis.</li> </ul>	<ul style="list-style-type: none"> <li>Low block size used to determine texture level.</li> <li>SPAM + ensemble classifier can successfully steganalyze for a higher embedding rate</li> <li>Not tested against structural detectors</li> <li>Moderate PSNR</li> </ul>	512x512, 256x256, 1024x1024 from UCID, USC-SIPI bpp = 3.052 PSNR= 39.00	PSNR, Q, RS-analysis, pixel difference histogram analysis, and SPAM features under ensemble classifier steganalysis

[117]	<ul style="list-style-type: none"> <li>• Uses 3-3-2 sequence and cropping cover image into k parts and the secret message is divided into k parts</li> <li>• Embedding using 3-3-2 sequence</li> <li>• Security is related to number of parts, coordinates, and sequence pattern</li> </ul>	<ul style="list-style-type: none"> <li>• Image structure not considered</li> <li>• Steganalysis evaluation is missing</li> <li>• Subject to statistical and structural steganalysis</li> <li>• Fixed embedding sequence</li> </ul>	512x512 RGB images PSNR: 62.5332	PSNR, MSE
[118]	<ul style="list-style-type: none"> <li>• Message encoding using two images divided into k blocks.</li> <li>• Secret message encoded using reference image and then embedded in the LSB</li> <li>• Secret key encrypted using RSA involves: starting block, traversing direction, etc</li> </ul>	<ul style="list-style-type: none"> <li>• Image structure not considered</li> <li>• Steganalysis evaluation is missing</li> <li>• Subject to statistical and structural steganalysis</li> <li>• Two images needed</li> <li>• Key exchange overhead</li> </ul>	256x256 Payload= 2000 bits Avg. PSNR = 71.48  Payload= 16000 bits Avg. PSNR = 62.36	PSNR, MSE, Histogram
[119]	<ul style="list-style-type: none"> <li>• Manipulates bit-planes indexes to enhance security.</li> <li>• 2 LSB should be in the form 01,10. The cover image is pre-processed accordingly and the vector of indices to be sent</li> <li>• Robust against PoV, WS steganalysis</li> </ul>	<ul style="list-style-type: none"> <li>• Handling of the vector of indices</li> <li>• All image contents are considered</li> <li>• Modern steganalysis can attack</li> <li>• Not robust against MLSB-WS steganalyser when bpp=1</li> </ul>	512 x 512 Greyscale Payload: 20%: 100% PSNR: ~47 for bpp=1	PSNR, PoV, WS steganalysis, MLSB-WS steganalysis
[120]	<ul style="list-style-type: none"> <li>• Changes the color palette</li> <li>• All pixels of the same color are changed to the same color</li> <li>• Achieves a higher user perception.</li> <li>• Allows resistance to analysis of adjacent pixel colors</li> </ul>	<ul style="list-style-type: none"> <li>• Its capacity is very dependent on a color palette</li> <li>• Not resistant to color palette analysis and standard palette images</li> <li>• Need to test over modern Steganalysis</li> </ul>	512 x 512 bpp = 0.35: 1.37 PSNR: 52.74:58.10	PSNR, SSIM, EC

## VI. OBSERVATIONS, DISCUSSION, AND RECOMMENDATIONS

### A. Observations

- Chaotic based randomness: even though chaotic based LSB steganography achieves higher security, the payload capacity attained is low, and there exists low robustness against statistical and geometric attacks.
- Secret message encryption-based approach: this concept provides higher security, but the complexity is high, especially while using substitution-permutation encryption.
- Image encryption: using standard encryption techniques, multilevel encryption techniques, and chaotic based techniques provides good security. However, the overall system overhead is high.
- Virtual multi-bit plane-based steganography: this paradigm achieves better payload capacity and higher security as the possibility of randomness is greater. Nonetheless, the secret data can deteriorate if there is a slight stego image change by attackers. It is particularly vulnerable to non-statistical steganalysis (geometrical attacks) such as rotation, scaling, and cropping.
- Region based steganography: these techniques achieve good robustness and security, but the embedding capacity in general is low.

### B. Discussion

Hiding secret information inside a cover image without introducing suspicious artefacts is the main objective of image steganography. In addition, high security, good imperceptibility, and high embedding rate are desirable and challengeable goals. Researchers have been working on enhancing the performance of steganographic algorithms in terms of achieving high security, high imperceptibility, and high payload capacity. Yet, the optimum goal has not been reached since the challenging criteria oppositely affect each

other. When the main consideration is security, the technique should hide the presence of embedded data inside the cover image from the attacker's attention. In addition, it should obscurely hide the data so that attackers cannot identify the original secret message even if they detect its presence. Several concepts have recently been utilized to achieve high security in image steganography.

For securing steganographic techniques, the concept employed most widely is encryption, which has been used to add a layer of security. Encryption can be attained utilizing standard encryption techniques such as AES, 3DES, and RSA along with secret keys to enhance the overall system security. On the other hand, user-defined encryption algorithms are also utilized via the concepts of permutation only, substitution only, or both. The level of security can also be boosted much by embedding the secret data in non-sequential order, that is, by using random sequences to scatter the secret bits all over the cover image. Existing chaotic functions are famous for producing random numbers that can be exploited to create random sequences. Further, some researchers rely on varied concepts to generate such randomness. Pixel channels indicator is another paradigm that has been used to indicate the presence or absence of secret information and identifies the color channel being used.

The visual aspects of an image are also utilized to achieve a level of security, since the image is composed of smooth regions and non-smooth regions also known as low frequency and high frequency regions. Embedding data in a smooth area can raise distortion levels; this breaches the confidentiality of secret data. On the other hand, exploiting the non-smooth regions and edges as embedding locations does not leave evidence of the existence of secret data. Employment of number systems to create virtual bit planes is another means of hiding the secret information without creating noticeable distortion as well as of hiding pixels' relations. Such attributes overcome the security limitations of the standard spatial domain techniques. Frequency domain steganography is another approach that has been followed to guarantee the

security of steganography by choosing appropriate locations to embed secret data. This technique avoids manipulating pixels directly and instead uses transform procedures, thereby leading to good imperceptibility. However, the embedding capacity is limited and the computational cost is higher.

### C. Recommendations

The recommendations of this study are as follows:

- Combining edge-based steganography with randomness-based concepts to achieve higher security approaches that resist statistical steganalysis;
- Utilizing the existing encryption methods to add an extra layer of security;
- Applying the adaptiveness concept by combining multiple hiding techniques based on some image attributes or user-defined criteria (techniques such as quad tree search are useful to segregate the cover image into various segments with different attributes);
- Instead of utilizing the entire image to embed the secret data, hiding data in particular regions known as the Region of Interest (ROI), which resists statistical attacks by breaking the statistics relations of adjacent pixels;
- Employing the optimization concept to enhance the security of chaotic based steganography (machine learning techniques are an appropriate method to achieve such a goal);
- Drawing more attention to images in the YCBCR color system, since it has received less attention in this context; and
- Considering 3D for embedding secret data, as very few attempts have been made in this domain.

## VII. CONCLUSION

Image steganography is used to hide secret information inside a cover image. It is frequently used to guarantee confidentiality while sending information over an untrusted network. A comprehensive review of image steganography in the spatial domain was carried out utilizing recent research mainly through IEEE Explore, ScienceDirect, Springer Link, and other databases. Most methods utilize LSB based steganography in the spatial domain and its variants due to its simplicity and effectiveness. In addition, PVD, EMD, PIT have been employed as well. In this work, a review of image steganography in the spatial domain in general and, more precisely, of the security aspect, led to its classification into multiple categories. These categories are as follows: randomization based, encryption based, randomization and encryption based steganographic techniques, image encryption, region-based steganography, multiple bit-planes based, pixel indicator techniques, and other steganographic techniques based on combinations of different concepts. At the end of this review, some discussion of the gaps and the future scope of the above-mentioned concepts has been included. In addition, future recommendations for new and current researchers interested in this field are provided.

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# Automated Type Identification and Size Measurement for Low-Voltage Metering Box Based on RGB-Depth Image

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**Abstract**—The low-voltage metering box is a critical piece of equipment in the power supply system. The automated inspection of metering boxes is important in their production, transportation, installation, operation and maintenance. In this work, an automated type identification and size measurement method for low-voltage metering boxes based on RGB-D images is proposed. The critical components, including the door shell and window, connection terminal block, and metering compartment in the cabinet, are segmented first using the Mask-RCNN network. Then the proposed Sub-Region Closer-Neighbor algorithm is used to estimate the number of connection terminal blocks. Combined with the number of metering compartments, the type of metering box is classified. To refine the borders of the metering box components, an edge correction algorithm based on the Depth Difference (Dep-D) Constraint is presented. Finally, the automated size measurement is implemented based on the proposed Equal-Region Averaging algorithm. The experimental results show that the accuracies of the automated type identification and size measurement of the low-voltage metering box reach more than 92%.

**Keywords**—Low-voltage metering box; RGB-D image processing; automated size detection; automated type detection; inspection automation

## I. INTRODUCTION

The low-voltage metering box is an important piece of electrical equipment in power systems. It is responsible for measuring and monitoring the electrical energy consumption of end-users, which are ordinary residents, factories or enterprises [1-2]. It plays a pivotal role in ensuring that the power supply in a building is well regulated and efficiently distributed.

The automated inspection of low-voltage metering boxes is important in their production, transportation, installation, operation and maintenance [3-4]. The type identification and structural size inspection are of significance for the safety and the long-term use of the low-voltage metering boxes [5-6]. The type and size inspection refers to the process of examining the structure, physical shape and size of critical components in a metering box [7-8]. The structure and size of these components should be consistent with the relevant standards and regulations to ensure the proper functioning of the metering boxes. The conforming structure and size are prerequisites for a reasonable, safe and reliable layout of components of the metering boxes. The inappropriate type and size may lead to

equipment damage or electrocution accidents, which can reduce the service life of the metering boxes. The type and structural size inspection is essential to ensure the safe and accurate operation of the low-voltage metering boxes and improve the reliability of electrical systems.

The inspection is typically carried out by a qualified technician in accordance with established procedures and guidelines. The technician should check the exterior and interior of the low-voltage metering box, including the appearance, key components, markings, and size measurement, which is labor-intensive and time-consuming. The automated inspection is urgent for a low-voltage metering box [9-12]. To a certain extent, it can improve the management efficiency and extend its service life.

Machine vision and other computer technologies make the automation inspection of metering boxes possible. Wang et al. [13] designed an intelligent detection management system for the low-voltage metering cabinets to optimize the inspection process and improve the detection efficiency. Shen et al. [14] analyzed the failure mechanism of the metering boxes to further improve their production process. Xu et al. [15] and Weng et al. [16] introduced image-based intelligent monitoring for the low-voltage metering cabinets to guard against theft and facility damage. However, there has been little research about the automatic type identification and size measurement of the low-voltage metering boxes.

To improve the efficiency of industrial production, there have been some studies on the size measurement of workpieces based on image processing and recognition technology. Three common approaches for size measurement are the monocular vision method, the binocular vision method and the structured light method, which are described as follows. (1) The monocular vision method is a commonly used method that uses a single camera to capture a workpiece image and combined with prior knowledge to compute the actual size of the workpiece [17]. Li et al. [18] proposed an axial dimension detection method for a corrugated compensator based on the image recognition. Chen et al. [19] introduced the Canny edge detection and contour feature extraction algorithm to identify the outer diameter and wall thickness of pipes. Cheng et al. [20] applied the camera calibration to measure the key size of injection-molded products. Yu et al. [21] took the actual height as a reference to calculate the sizes of key parts of the

human body. (2) The binocular vision method uses two images which are acquired from different angles, and the three-dimensional spatial location information of the object can be obtained based on the parallax principle. Xue et al. [22] used the Kinect sensors to identify the size and orientation of square box objects, which can be used in mobile robots handling. Liu et al. [23] achieved an on-site size measurement of large forgings based on binocular stereo-vision and forging scene geometry constraints. (3) The principle of the structured light method for size measurement is optical triangulation [24]. The surface of the object modulates the structured light, and the modulated light is captured by a charge-coupled device (CCD), which forms a two-dimensional distorted image [24]. The 3D coordinates and contour information of the designated point could be obtained based on the distorted image and the location of the modulated light bars.

The automated measurement of the workpiece size based on machine vision generally consists of two steps. The first step is to extract an edge or edge feature points of the workpiece via image processing. Then the two-dimensional coordinates are mapped into 3D space by modeling or calculation to obtain the actual size of the workpiece. Different workpieces have different shapes and physical characteristics. Thus, the size measurement method should be designed based on the characteristics of the captured images. The workpiece size measurement approaches mentioned above almost all focused on the measurement of a single small part. It is not applicable for the external and internal size measurement of the low-voltage metering box.

The low-voltage metering boxes with direct connections are classified into four types: single-phase single-meter metering boxes, single-phase multi-meter metering boxes, three-phase single-meter metering boxes, and three-phase multi-meter metering boxes [25]. The phase of a metering box is determined by the number of connection terminal blocks. For a single-phase metering box, the number of connection terminal blocks is four while it is eight for a three-phase metering box. The meter of a metering box is determined by the number of the metering compartments. The accurate automated type identification of the metering boxes remains a difficult problem, due to the illumination, occlusion, and other problems. In particular, the baffle plate in front of the connection terminal blocks significantly affected the detection accuracy.

In this work, an automated type identification and size measurement method for low-voltage metering boxes based on RGB-D (red, green, blue, and depth) images is proposed. The critical components, including the door shell and window, metering compartment, and connection terminal block in the cabinet, are segmented first using the Mask-RCNN network. Then the proposed Sub-Region Closer-Neighbor algorithm is used to estimate the number of connection terminal blocks. Combined with the number of metering compartments, the type of the metering box is classified. To refine the border of the metering box components, the edge correction algorithm based on the Depth Difference (Dep-D) Constraint is presented. Finally, the automated size measurement is implemented based on the proposed Equal-Region Averaging algorithm.

The main contributions of this work are summarized as follows:

- The automated type identification and size measurement method for the low-voltage metering boxes is proposed, based on RGB-D image processing techniques.
- The Sub-Region Closer-Neighbour algorithm for the number estimation of connection terminal blocks is proposed. Based on the calculated number of connection terminal blocks and metering compartment, the type of a metering box is identified.
- For the automatically segmented contour of critical components, the edge correction algorithm is proposed based on the proposed Depth Difference (Dep-D) Constraint in the depth channel. Then, the automated size measurement is implemented based on the proposed Equal-Region Averaging algorithm.

The rest of this paper is organized as follows. Section II introduces the proposed automated type identification and size measurement algorithm for low-voltage metering boxes. Section III describes the dataset and the experimental results. Finally, the conclusions are presented in Section IV.

## II. PROPOSED AUTOMATED TYPE IDENTIFICATION AND SIZE MEASUREMENT ALGORITHM FOR LOW-VOLTAGE METERING BOXES

The low-voltage metering box is a critical component of numerous electrical systems, functioning to guarantee the secure and effective distribution of electrical power [26]. Specifically, this device is utilized to measure and monitor electrical energy consumption within residential, commercial, or industrial settings.

A low-voltage metering box includes two parts: the door shell and the metering cabinet. In the door shell, there are door windows. In the metering cabinet, there are incoming compartment, metering compartment, outgoing compartment, mounting plate, watt-hour meter plug, plug interference fit, plug clearance fit, connection terminal block, and wire. Specially, the sizes of three critical components are essential in the inspection of the low-voltage metering box, which are door shell, door window and metering compartment. The structure of a low-voltage metering box is illustrated in Fig. 1.

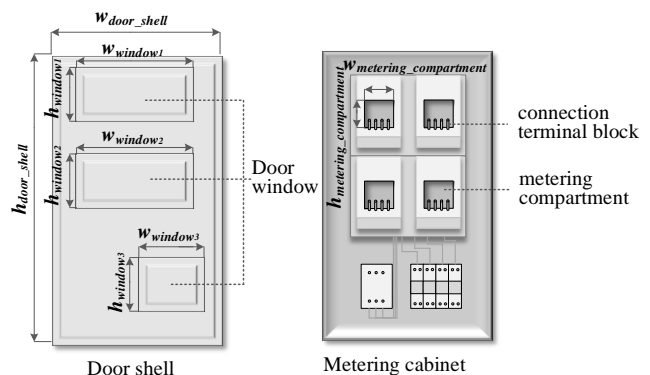


Fig. 1. Structure of a low-voltage metering box.

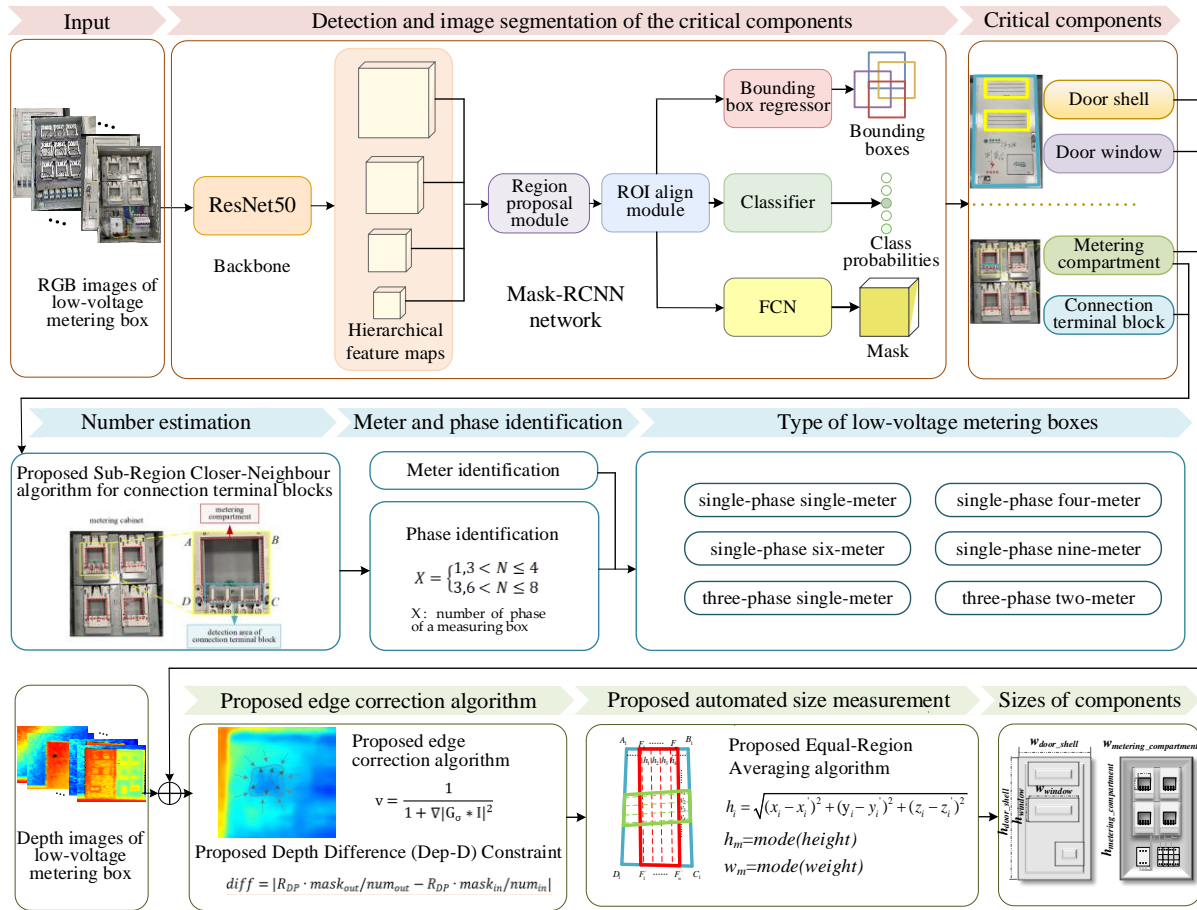


Fig. 2. Flow chart of automated type identification and size measurement for low-voltage metering boxes based on RGB-D images.

The appearance and structure inspection are important in the production, transportation, installation, operation and maintenance of low-voltage metering boxes. The automated inspection could enhance the efficiency of industries, and save labor forces.

In this work, a system for the automated type identification and size measurement of the low-voltage metering boxes is proposed. The overall process flowchart of the system algorithm is shown in Fig. 2.

The critical components of low-voltage metering boxes are detected and segmented by using Mask-RCNN network [27]. The numbers of metering compartments and connection terminal blocks are detected automatically based on the proposed methods. Then according to the phase and number of meters, the type of low-voltage metering boxes is identified. For the segmented contour of the door shell, door window, and metering compartment, the edge correction algorithm is presented to refine the border of the components in the depth images. The Equal-Region Averaging algorithm is proposed to measure the size of these components in the metering boxes.

#### A. Detection and Image Segmentation of the Critical Components

The automated detection and segmentation of the critical components of the metering boxes in the RGB images is the foundation for the automated type identification and size

measurement. By combining the detection results and segmented masks, the numbers of metering compartments and connection terminal blocks in the cabinet can be calculated, which are key for the classification of various types of low-voltage metering boxes.

The size inspection of the critical components is the basis for the production, transportation, installation, and maintenance of the metering boxes. All the parts must comply with the requirements in the design drawings and the relative specifications and standards. By combining the detection and segmentation results with the depth information, the sizes of the critical components can be calculated.

Mask-RCNN is a powerful object detection and instance segmentation network. It extends the multi-task network structure based on Faster R-CNN, which, in addition to learning bounding boxes and class labels in a multi-task fashion, adds a third branch for predicting object masks. This method combines the advantages of both object detection and semantic segmentation, achieving accurate and detailed object location and precise segmentation in complex scenes. The Mask-RCNN architecture consists of a backbone convolutional neural network, a region proposal network used to generate object region proposals, and a network branch for predicting object masks. The architecture of the Mask-RCNN network is illustrated in Fig. 3.

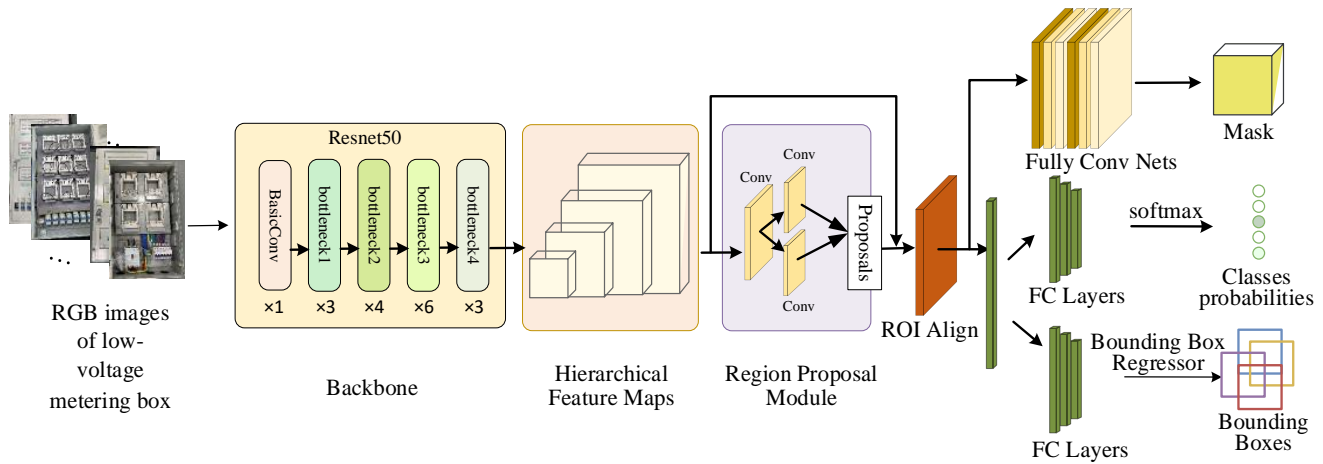


Fig. 3. The architecture of the Mask-RCNN network.

The backbone network is utilized for hierarchical feature extraction from images, while the region proposal network is employed for object detection and generation of candidate regions. The extraction of candidate regions is essentially bounding box regression. For an external bounding box  $G$  of the target, its four vertex coordinates are denoted by  $(G_x, G_y, G_w, G_h)$ . For the proposed initial rectangular region  $P$ , its four vertices are represented by  $(P_x, P_y, P_w, P_h)$ . Obtaining the target bounding box means finding a mapping  $f$  based on the given  $(P_x, P_y, P_w, P_h)$ . Given a set of parameters  $W$  learned through a network for the given input feature vector  $X$ , it can be mapped to the target feature vector  $Y$ , i.e.,  $Y \approx WX$ , that is:

$$f(P_x, P_y, P_w, P_h) = (\hat{G}_x, \hat{G}_y, \hat{G}_w, \hat{G}_h) \quad (1)$$

$$(\hat{G}_x, \hat{G}_y, \hat{G}_w, \hat{G}_h) \approx (G_x, G_y, G_w, G_h) \quad (2)$$

where the  $(\hat{G}_x, \hat{G}_y, \hat{G}_w, \hat{G}_h)$  is derived by the translations and scale transformations depicted in (5) and (6).

The goal of bounding box regression learning is to solve the four transformations  $t = (t_x, t_y, t_w, t_h)$ , where  $(t_x, t_y)$  represents the translation transformation and  $(t_w, t_h)$  represents the scale scaling. The formulas are shown in (3) and (4).

$$t_x = P_w d_x(P), t_y = P_h d_y(P) \quad (3)$$

$$t_w = \exp d_w(P), t_h = \exp d_h(P) \quad (4)$$

$$\begin{aligned} \hat{G}_x &= t_x + P_x \\ \hat{G}_y &= t_y + P_y \end{aligned} \quad (5)$$

$$\begin{aligned} \hat{G}_w &= P_w t_w \\ \hat{G}_h &= P_h t_h \end{aligned} \quad (6)$$

Based on the above formulas, it can be concluded that the objective function for bounding box regression is:

$$d_*(P) = w_*^T \delta(P) \quad (7)$$

where  $*$  =  $(x, y, w, h)$  and  $\delta(P)$  is the input target parameter,  $w_*$  is the parameter to be determined, and  $d_*(P)$  is the predicted value. By introducing the loss function

$$loss = \sum_{i=1}^N (t_*^i - w_*^T \delta(P^i))^2 \quad (8)$$

the optimization objective of the function is:

$$w_* = \arg \min_{w_*} (t_*^i - w_*^T \delta(P^i))^2 + \lambda \|w_*\|^2 \quad (9)$$

By following the aforementioned bounding box regression process, the desired target bounding boxes are obtained. Mask-RCNN has high detection and segmentation accuracies and generalization abilities, making it suitable for object detection and instance segmentation tasks in complex scenes.

### B. Automated Type Identification Algorithm for the Low-voltage Metering Boxes

The type of low-voltage metering boxes can be determined by the number of connection terminal blocks and metering compartments. In this section, the number of connection terminal blocks is estimated by using the proposed Sub-Region Closer-Neighbor algorithm. Then, the number of metering compartments is added, and the type of a metering box can be determined.

1) *Proposed Sub-Region Closer-Neighbor algorithm for the number estimation of connection terminal blocks:* The single-phase metering box is typically connected to a live line and a neutral line in order to measure the amount of electricity flowing into a building or property. For each meter in the metering cabinet, there are two connection terminal blocks for the incoming and outgoing of live lines, and another two connection terminal blocks for the incoming and outgoing of neutral lines. Therefore, there are four connection terminal blocks in a single-phase low-voltage metering box.

Three-phase meter boxes are connected by two live wires and one neutral wire [28]. Inside a three-phase metering box, a single electric meter requires six terminal connection blocks for the live wires to enter and exit and two terminal connection

blocks for the neutral wire to enter and exit, so the number of terminal connection blocks for a single electric meter inside a three-phase metering box is eight.

Due to the complex structure of the metering boxes, as well as the influence of lighting and shooting angle, there are differences in brightness and shading of the connection terminal blocks on the image. This leads to errors in the automated segmentation algorithm. Moreover, the occlusion of wire or baffle plate in front of the connection terminal blocks will result in incomplete or miss segmentation.

In this paper, a quantity estimation algorithm for connection terminal blocks is proposed, to determine whether the metering box is single-phase or three-phase. The connection terminal blocks are located below the metering compartment, as shown in Fig. 4. Fig. 4 shows the inner surface of a low-voltage measuring box, the red dashed box shows the metering compartment region segmented based on the Mask-RCNN network. The four corners of each metering compartment are labeled as A, B, C and D. The connection terminal block region is defined as a quadrilateral I, with a length of  $\max(L_{AB}, L_{CD})$  and a width of  $\max(\frac{1}{2}L_{BC}, \frac{1}{2}L_{AD})$ , which is symmetric with respect to the corner C and corner D connection line.

In the defined detection region, if there are connection terminal blocks inside, the number of connected domains is calculated, and set to N.

With the number of phase of a low-voltage measuring box denoted as X, the phase discrimination of the low-voltage metering box is shown as follows:

$$X = \begin{cases} 1, 3 & 3 < N \leq 4 \\ 3, 6 & 6 < N \leq 8 \end{cases} \quad (10)$$

When the average number of connection terminal blocks in a metering box is close to four, this low-voltage metering box is a single-phase metering box; when the average number of low-voltage metering box is close to eight, the low-voltage measuring box is a three-phase metering box.

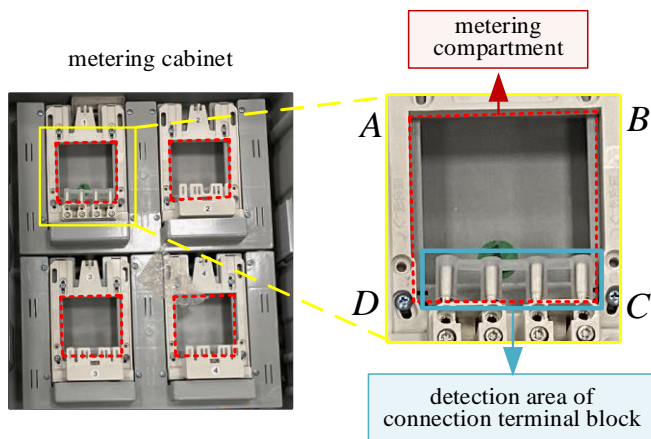


Fig. 4. Schematic diagram of connection terminal block detection region.

Under an occlusive situation, the connection terminal blocks might be incompletely segmented. However, the proposed number estimation algorithm could still detect the

number of the connection terminal blocks, and determine the phase of the metering box.

2) *Number estimation of metering compartment*: Based on the segmented results of the metering compartments, the number of metering compartments is estimated by counting the number of metering compartment regions. The metering compartment might be incompletely segmented. Under this situation, the count in the region is still taken. The number of metering compartments is set as  $M, M=1, 2, \dots, k$ .

### C. Edge Correction Algorithm Based on the Depth Difference (Dep-D) Constraint

Due to the influences of factors such as the shooting angle, illumination and shooting time of the depth camera, there may be errors in the edge of  $R_0$ . To correct the edge of  $R_0$  and reduce the impact on the accuracy of subsequent size measurement, an edge correction algorithm based on the depth difference constraint is proposed. The algorithm pseudocode is as follows:

<b>Algorithm 1</b> Edge correction algorithm based on the Dep-D Constraint	
<b>Input:</b>	
1.	$I(x, y)$ : The depth image $R_{DP}$ .
2.	$E_0(x, y)$ : The edge of $R_0$ .
<b>Output:</b>	
3.	$E_{out}(x, y)$ : The corrected edge of $R_0$ .
4.	$C_i(x, y) \leftarrow E_0(x, y)$ // The initial contour
5.	<b>repeat</b>
6.	$C_i.normal \leftarrow \text{normalize}(C_i(x, y))$ // The direction of contour movement
7.	$v \leftarrow 1/(1 + \nabla G_\sigma * I ^2)$ // The speed of contour movement
8.	$C_i(x, y) \leftarrow \text{movement}(C_i, C_i.normal, v)$ // Move the contour in the specified direction and speed
9.	$mask_{out}, mask_{in}, num_{out}, num_{in} \leftarrow \text{template}(C_i)$ // Establish templates based on the shape and size of $C_i$
10.	$diff_i \leftarrow  I \cdot mask_{out}/num_{out} - I \cdot mask_{in}/num_{in} $ // The constraint condition
11.	$diff.append(diff_i)$ // Store the results of each loop into an array
12.	<b>until</b> $diff_i = \max(diff)$

1) *Steps of the proposed edge correction algorithm*: The steps of the proposed edge correction algorithm are as follows:

Step 1: Set the edge of  $R_0$  ( $E_0$ ) as the initial contour.

Step 2: Move each point on the contour to make it closer to the true edge. To improve the correction speed, the direction of contour movement is the normal direction of the contour curve where the contour is located. The speed of contour movement is controlled by the depth gradient corresponding to the point, which is calculated as follows:

$$v = \frac{1}{1 + \nabla|G_\sigma * I|^2} \quad (11)$$

where  $v$  is the calculated speed of contour movement,  $G_\sigma$  represents the Gaussian kernel, which smooths the image, and  $I$  denotes the depth image  $R_{DP}$ . If the gradient is small, it indicates that the point is far from the real edge, and the motion speed is increased; otherwise, the motion speed is decreased.



Step 3: After all points in the contour are changed, the constraint condition for the contour is calculated. Steps 2 and step 3 are repeated until the constraint conditions are met.

2) *Constraint condition based on the proposed outer and inner templates*: In this work, two structure templates are proposed to build the constraint condition. The two structure templates are illustrated in Fig. 5.

Because of the hollow region in the middle of the metering compartment where the electricity meter is located, there is a significant depth difference inside and outside the edge of the metering compartment. As shown in Fig. 5, an outer template  $mask_{out}$  and an inner template  $mask_{in}$  are introduced to determine whether the current contour is the edge of the measuring box. The size and the shape of  $mask_{out}$  and  $mask_{in}$  are consistent with the current contour. As shown in Fig. 5, in the  $mask_{out}$ , the outermost two layers of the outer template are all assigned the value of 1, and the values of the remaining layers are all set to 0. In the  $mask_{in}$ , the outermost two layers of the outer template are all assigned values of 0, and the values of the remaining layers are all set to 1. The two structure templates with the metering compartments in depth image  $R_{DP}$  are combined, and the distance difference between the edge and the interior of the bounding box in the depth camera can be calculated. The distance difference can be expressed as follows:

$$diff = \left| I \cdot \frac{mask_{out}}{num_{out}} - I \cdot \frac{mask_{in}}{num_{in}} \right| \quad (12)$$

where  $num_{out}$  and  $num_{in}$  represent the number of elements with values of 1 in the  $mask_{out}$  and  $mask_{in}$ , respectively.

When the contour moves to the true edge, due to the difference in the depth values between the inner and outer edges, the  $diff$  value will reach its maximum value (the red point in Fig. 6). In this work, when the  $diff$  starts to decrease, it is considered to meet the constraint condition and the iterations stop. The contour obtained in this iteration is the corrected edge.

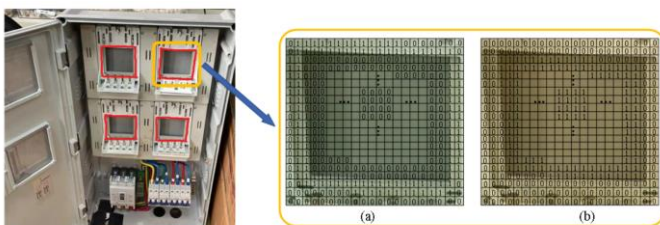


Fig. 5. The proposed structure templates: (a) outer template and (b) inner template

#### D. Automated Size Measurement based on the Proposed Equal-Region Averaging Algorithm

Due to the errors caused by the infrared pattern projected by the depth camera during the imaging process, as well as the

errors caused by the stereo matching algorithm, some pixels' depth information is missing or deviating in the depth image [29]. To obtain more accurate depth-channel information and realize automated size measurement, the Equal-Region Averaging algorithm is proposed in this work. The steps are as follows:

Step 1: Calculate the bounding box of the segmented region. The segmented components are the door shell, window and metering compartment.

Step 2: Obtain the four corners of the bounding box. Set  $a_i$  ( $i=1,2,3,4$ ) as the distance parameters between each corner and all the points on the segmented region.

Step 3: Define four pseudo-corners as the points on the segmented contour, which have the minimal distances to their corresponding corners. The pseudo-corners cut the contour into four segments.

Step 4: For each segment, find the midpoint of each segment, and take the midpoint as the center to obtain a detection area with a length of one-quarter of the side length. In Fig. 7, the red box line represents the length detection range of the door shell, window or metering compartment. And the green box line represents the width detection range of the component.

In the defined detection region, the corresponding pixel points on the opposite sides are connected. The length of each line can be calculated as:

$$h_i = \sqrt{(x_i - x'_i)^2 + (y_i - y'_i)^2 + (z_i - z'_i)^2} \quad (13)$$

where the 3D coordinate values of the corresponding pixel pair are  $F_i(x_i, y_i, z_i)$  and  $F'_i(x'_i, y'_i, z'_i)$ .

The vector of the heights is:

$$height = [h_1, h_2, h_3, \dots, h_i] \quad (14)$$

and the vector of widths is:

$$width = [w_1, w_2, w_3, \dots, w_i] \quad (15)$$

The mode of these two vectors is calculated, and the values  $h_m$  and  $w_m$  are the height and weight of the component.

$$h_m = mode(height), w_m = mode(width) \quad (16)$$

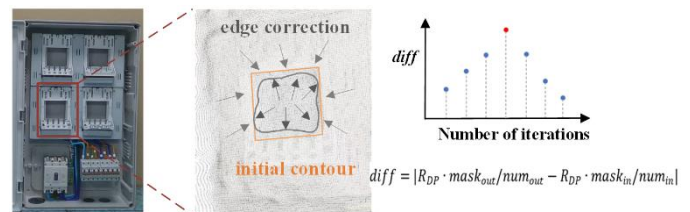


Fig. 6. The proposed edge correction algorithm based on the Depth Difference (Dep-D) Constraint

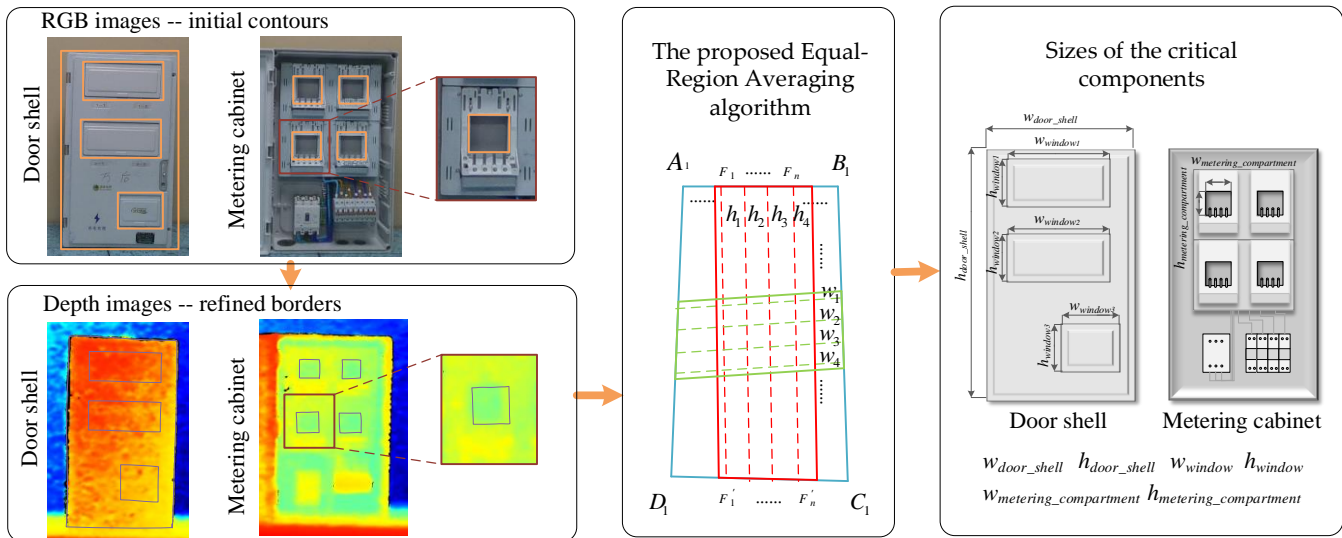


Fig. 7. Schematic diagram of size measurement region of door shell, window and metering compartment.

### III. EXPERIMENTAL RESULTS AND ANALYSIS

In this work, an automated type identification and size measurement method is proposed for the low-voltage metering boxes, which are among the most critical pieces of equipment in a power system.

#### A. RGB-D Image Data of Low-voltage Metering Boxes

Six types of low-voltage metering boxes are collected in this work, namely single-phase single-meter, single-phase four-meter, single-phase six-meter, single-phase nine-meter, three-phase single-meter, and three-phase two-meter low-voltage metering boxes. Table I shows the diagrams of the outer shell and the inner surfaces of these six types of low-voltage metering boxes.

The RGB-D images are captured using the Intel RealSense D415 depth cameras developed by Intel Corporation. The image resolution is 1280\*720. A total of 732 images are collected as experimental data.

#### B. Experimental Results of Type Identification for Low-voltage Metering Box

In the RGB channel, the metering compartment and connection terminal block are segmented by using the Mask-RCNN network first. Then, the number of connection terminal blocks is estimated by using the proposed Sub-Region Closer-Neighbor algorithm. Combined with the depth information, the contours of the metering compartments are re-fined. The number of metering compartments is estimated, by counting the connected do-main of metering compartment regions. Finally, the type of low-voltage metering box is identified by using the number of metering compartments and connection terminal blocks.

1) *Experimental results of type identification for low-voltage metering box:* In this work, six types of low-voltage metering boxes are classified. Table II shows the detection accuracies for these six types of low-voltage metering boxes.

From Table II, it can be seen that average detection accuracies of the proposed type identification method for the low-voltage metering boxes reach up to 94.8%. The detection accuracies for six types of low-voltage metering box range from 92.3% to 96.8%.

TABLE I. SIX TYPES OF LOW-VOLTAGE METERING BOXES

Single-phase single-meter		Single-phase four-meter	
Outer shell	Cabinet	Outer shell	Cabinet
Single-phase six-meter		Single-phase nine-meter	
Outer shell	Cabinet	Outer shell	Cabinet
Three-phase single-meter		Three-phase two-meter	
Outer shell	Cabinet	Outer shell	Cabinet

TABLE II. DETECTION ACCURACIES OF DIFFERENT TYPES OF LOW-VOLTAGE METERING BOXES

Type	Detection accuracy	Average accuracy
Single-phase single-meter	92.3%	94.8%
Single-phase four-meter	96.8%	
Single-phase six-meter	93.6%	
Single-phase nine-meter	95.7%	
Three-phase single-meter	92.5%	
Three-phase two-meter	93.1%	

The recognition accuracies of single-phase single-meter and single-phase nine-meter metering boxes are lower than those of the other types, mainly due to the misdetection of the number of connection terminal blocks. The counting accuracy of the connection terminal blocks is reduced due to illumination, occlusion, and other problems. In particular, the baffle plate in front of the connection terminal blocks significantly affects the segmentation accuracy. In this work, the Sub-Region Closer-Neighbor algorithm is proposed to reduce the influence of occlusion. The proposed method could increase the recognition accuracy even if the connection terminal blocks are incompletely segmented. Moreover, even if part of the connection terminal block is misdetected, the proposed method could still reduce the detection error, by inducing the (8). The distance between the detected number and the standard number (4 or 8) is calculated. The final number of connection terminal blocks is the number with the smallest distance from the standard number. If the connection terminal blocks are fully occluded, misjudgment of the phase could occur.

2) *Experimental results of critical components segmentation and number detection method:* To identify the types of low-voltage metering boxes, the critical components in the metering box are segmented first. Then, the Sub-Region Closer-Neighbor algorithm is proposed to estimate the number of terminal blocks. The defined Depth Difference (Dep-D) Constraint is used in the edge correction algorithm, to refine the contour of the metering compartments. The number of metering compartments is estimated based on the segmentation results. Table III lists the results of the automated segmentation and counting methods for metering compartments and connection terminal blocks.

As shown in Table III, the Intersection over Union (IoU) values for the segmentation of the connection terminal block, rang from 75.5% to 89.6%.

The precision of segmentation for the connection terminal blocks is affected by many factors. The color of the connection terminal block is gray, which is close to color of the metering cabinet panel. The location of connection terminal block is below the metering compartment. Most of the time, there is a baffle plate set in front of the connection terminal block, in order to protect the wires. The connection terminal block could only be seen in the gap of plate stripes. Sometimes, the wires can occlude the connection terminal block as well. Fig. 8 illustrates the situations which affect the detection accuracy of connection terminal blocks.

TABLE III. RESULTS OF AUTOMATED SEGMENTATION AND COUNTING METHODS FOR CONNECTION TERMINAL BLOCK AND METERING COMPARTMENT

Type of metering box	Component	IoU	Number counting	Type identification
Single-phase single-meter	CTB	78.6%	94.7%	92.3%
	MC	93.3%	100%	
Single-phase four-meter	CTB	75.5%	88.9%	96.8%
	MC	90.2%	99.5%	
Single-phase six-meter	CTB	80.5%	90.5%	93.6%
	MC	94.5%	99.7%	
Single-phase nine-meter	CTB	83.6%	90.0%	95.7%
	MC	90.6%	98.7%	
Three-phase single-meter	CTB	86.4%	93.8%	92.5%
	MC	90.6%	98.6%	
Three-phase two-meter	CTB	89.6%	90.6%	93.1%
	MC	94.9%	97.5%	

Component CTB: Connection Terminal Block, Component MC: Metering Compartment

Due to the occlusion, illumination, and shooting angle, the connection terminal blocks could be mis-segmented, or incompletely segmented. Although the IoU of the segmentation of the connection terminal block is lower than 89.6%, the accuracy of the number counting ranges from 88.9% to 94.7%, for the proposed Sub-Region Closer-Neighbor algorithm.

The segmentation of the metering compartments is implemented by Mask-RCNN network in the RGB images. The shape and structure features of the metering compartment are identical in the metering cabinet. Sometimes, occlusion or incomplete image acquisition occur due to the different shooting angles. These will influence the segmentation accuracy. In spite of these influences, the number counting accuracy of the metering compartment is still above 97.5%. In the number counting algorithm, as long as the object is classified as the metering compartment, the number of metering compartments is counted. This will reduce the influence of occlusion. Based on the critical component segmentation and number counting, the type of metering box is identified. The detection accuracy is above 92.3%.

### C. Experimental Results of Automated Size Measurement for Low-voltage Metering Box

The size and structural design of the low-voltage metering boxes should fully consider the layout of the components and the functional requirements of the appearance.

According to Enterprise Standard Q/GDW 11008-2013 "Technical Specification for Low-Voltage Metering Box" [23], released by the State Grid Electric Power Co., Ltd., the component sizes of the low-voltage metering boxes should meet the enterprise standard, and the size errors should be within a certain range. Size inspection is required over the whole life of the metering box, including the manufacture, transportation, on-site installation, and daily usage.

1) *Quantitative metrics for size measurement:* In this work, an automated size measurement method is presented, to automatically detect the size of the door shell, door window, and metering compartment in the cabinet.



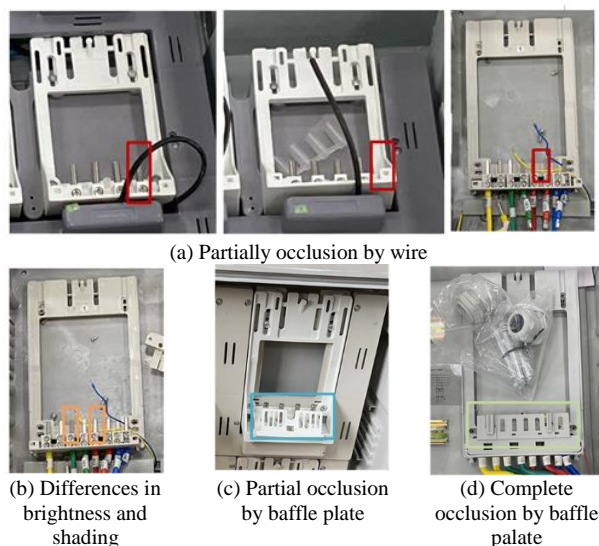


Fig. 8. The situations which affect the detection accuracy of connection terminal blocks.

The critical components are segmented by using the Mask-RCNN network in the RGB images. The edge correction algorithm based on the Depth Difference (Dep-D) Constraint is proposed in this work. The refinement algorithm uses the information in the depth-channel. Based on the refined contours of the components, the size is measured based on the proposed Equal-Region Averaging algorithm.

The precision of the proposed size measurement algorithm is indicated by the following metric:

$$p = \begin{cases} \text{ture}, & \text{error} < \alpha \\ \text{false}, & \text{error} \geq \alpha \end{cases} \quad (17)$$

If the average calculation error is within  $\alpha$ , then this measurement result is correct.

2) *Experimental results for size measurement:* In the Enterprise Standard Q/GDW 11008-2013 "Technical Specification for Low-Voltage Metering Box", it is stipulated that the size error of the metering box shell should not exceed 5mm. This work set the  $\alpha$  as 5mm, 4mm, 3mm, and 2mm. The experimental results are shown in Table IV.

As shown in Table IV, the accuracy of the size measurement is 92.6%, when  $\alpha$  is set to 5mm. When the  $\alpha$  is set to 2mm, the detection accuracy is still above 85%.

In this work, three critical components need to be measured, which are the door shell, door window, and the metering compartment in the cabinet. The regions of these components are segmented in the RGB images using the Mask-RCNN network.

For the Intel Real Sense depth camera, the RGB image is aligned with that in the depth image. The spatial location information of the object is acquired in the depth channel. The Intel RealSense D415 camera is used to capture depth data by projecting an infrared laser pattern onto the scene, and measuring how it is reflected back to the camera's sensors.

TABLE IV. RESULTS OF AUTOMATED SIZE MEASUREMENT FOR THE CRITICAL COMPONENTS OF LOW-VOLTAGE METERING BOX (%)

Type of metering box	Component	Measuring Accuracy			
		$\alpha_1$	$\alpha_2$	$\alpha_3$	$\alpha_4$
Single-phase single-meter	DS	94.3	93.5	90.6	90.3
	DW	90.1	88.4	86.4	85.1
	MC	94.3	91.5	89.6	87.3
Single-phase four-meter	DS	93.2	92.7	91.2	90.9
	DW	93.7	92.3	91.9	91.2
	MC	91.4	91.5	90.3	89.4
Single-phase six-meter	DS	95.2	92.5	90.6	89.5
	DW	94.2	92.7	91.3	89.4
	MC	90.5	89.3	88.5	87.5
Single-phase nine-meter	DS	94.3	92.5	91.6	90.1
	DW	92.2	91.8	89.3	87.6
	MC	95.3	92.3	90.5	88.1
Three-phase single-meter	DS	93.3	91.5	89.6	88.3
	DW	93.4	91.5	89.3	85.6
	MC	94.8	92.5	92.5	86.7
Three-phase two-meter	DS	93.6	92.5	91.8	89.9
	DW	91.5	90.3	89.1	88.3
	MC	93.1	92.5	90.2	89.5
Average measuring accuracy:		92.6% ( $\alpha_1=5\text{mm}$ )	91.8% ( $\alpha_1=4\text{mm}$ )	90.4% ( $\alpha_1=3\text{mm}$ )	87.5% ( $\alpha_1=2\text{mm}$ )

Component DS: Door Shell, Component DW: Door Window, Component MC: Metering Compartment

The segmented contours in the RGB images are used as the initial borders in the depth images. Then, the proposed edge correction algorithm based on the Depth Difference (Dep-D) Constraint is applied. This border refinement algorithm considers the depth difference between the outside and inside of the border. The actual contour is estimated after iteration, by balancing the gradient on the border.

#### D. Comparison with State-of-the-art Methods

In this work, a method is proposed to classify six types of low-voltage metering boxes. In this section, the proposed method is compared with state-of-the-art methods: the VGG [30], YOLO [31-32], EfficientDet [33], and ResNet [34-35] networks.

The VGG network comprises of different variants of convolutional neural networks, stacking multiple convolutional layers with small-sized convolution filters along with max-pooling layers [30]. The YOLO network uses a single convolutional neural network to predict both object class probabilities and bounding boxes directly from full images in one go [32]. The EfficientDet network applies a compound scaling approach to optimize both model architecture and input resolution [33]. The ResNet network solves the problem of vanishing gradients in the deep neural networks by using residual connections that allow the network to pass information directly from the input to the output [34]. All of these above networks have been widely used on various image classification tasks. Table V shows the comparison results.

TABLE V. RESULTS OF AUTOMATED IDENTIFICATION OF SIX TYPES OF LOW-VOLTAGE METERING BOXES (%)

Type of metering box	VGG [30]	YOLO [31-32]	EfficientDet [33]	ResNet [34-35]	Ours
Single-phase single-meter	73.4	69.3	75.2	80.4%	<b>92.3</b>
Single-phase four-meter	81.4	89.2	83.2	90.2%	<b>96.8</b>
Single-phase six-meter	80.5	85.2	79.3	82.9%	<b>93.6</b>
Single-phase nine-meter	85.7	90.1	89.2	91.4%	<b>95.7</b>
Three-phase single-meter	71.5	73.5	78.9	75.2%	<b>92.5</b>
Three-phase two-meter	87.4	86.4	92.5	84.5	<b>93.1</b>

As shown in Table V, our proposed type identification method achieves the highest classification accuracy. The classification accuracies for six types of low-voltage metering box are above 92.3%.

The state-of-the-art networks achieve the classification accuracies ranging from 69.3% to 92.5%. For these networks, the metering box images with labels are input to the networks, to implement a six-type multi-class classification task. The dataset tested in this work includes a total of 732 images, which could lead to overfitting, where the model becomes too specialized to the training data.

Although the metering compartments are notable features in the images, the type of the metering boxes need to be decided by the number of metering compartments and connection terminal blocks at the same time. The detection of connection terminal blocks is more difficult, due to their shapes, sizes, colors and locations. The misdetection of connection terminal blocks could lead to the wrong classification of metering box types.

Our proposed method considers many factors in the type identification task. The proposed Sub-Region Closer-Neighbor algorithm could count the number of connection terminal blocks in scenarios with complex illumination and occlusion.

#### IV. CONCLUSIONS

The low-voltage metering box is one of the most crucial pieces of equipment in a power system network. In this work, a metering box identification system based on the computer vision techniques is studied to realize automated detection of the appearances and structures of metering boxes. An automated type identification and size measurement method for the low-voltage metering box is proposed.

The following are the main steps of this proposed method. The critical components, including the door shell and window, connection terminal block, and metering compartment in the cabinet, are segmented first using the Mask-RCNN network. Then the proposed Sub-Region Closer-Neighbor algorithm is used to estimate the number of connection terminal blocks. Combined with the number of metering compartments, the type of metering box is classified. To refine the borders of the metering box components, an edge correction algorithm based on the Depth Difference (Dep-D) Constraint is presented.

Finally, the automated size measurement is implemented based on the proposed Equal-Region Averaging algorithm.

The primary contributions of this study are as follows. Firstly, the proposed Sub-Region Closer-Neighbor algorithm enables a more precise estimation of the number of connection terminal blocks, which is an essential parameter for the type identification of a metering box. This results in higher classification accuracies when compared to existing deep learning methods [30-35]. Secondly, to obtain more accurate size measurements, an edge correction algorithm is proposed. Then the automated size measurement is implemented based on the proposed Equal-Region Averaging algorithm.

There are two primary challenges in this study. The first is the occlusion of the connection terminal block, which leads to incorrect classification of the metering box type. The second challenge is the limitations of the depth camera, which introduces errors in size measurement. While this study proposes solutions to overcome these challenges, there is a need for further work to enhance detection and measurement accuracy.

One drawback of this article is that it involves numerous calculation steps, making the calculations complicated. Furthermore, in order to capture both segmentation and depth information, the system requires the processing of both RGB and depth images. In future research, it may be worthwhile to explore algorithms that can accomplish automated inspection using depth-images exclusively.

In the future, the improvement of automation level is a development trend in the power system industry. Compared with manual inspection, which can be time-consuming and labor-intensive, the integration of artificial intelligence technology in this field can significantly reduce costs, enhance overall efficiency and optimize resource utilization.

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# Data-driven Decision Making in Higher Education Institutions: State-of-play

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**Abstract**—The paper highlights the importance of using data-driven decision-making tools in Higher Education Institutions (HEIs) to improve academic performance and support sustainable development. HEIs must utilize data analytics tools, including educational data mining, learning analytics, and business intelligence, to extract insights and knowledge from educational data. These tools can help HEIs' leadership monitor and improve student enrolment campaigns, track student performance, evaluate academic staff, and make data-driven decisions. Although decision support systems have many advantages, they are still underutilized in HEIs, leaving field for further research and implementation. To address this, the authors summarize the benefits of applying data-driven decision approaches in HEIs and review various frameworks and methodologies, such as a course recommendation system and an academic prediction model, to aid educational decision-making. These tools articulate pedagogical theories, frameworks, and educational phenomena to establish mainstay significant components of learning to enable the scheming of superior learning systems. The tools can be utilized by the placement agencies or companies to find out their probable trainees/recruitees. They can help students in course selection, and educational management in being more efficient and effective.

**Keywords**—Business intelligence; data analytics tools; decision-making framework; decision-making support systems

## I. INTRODUCTION

Assuring the high quality of the offered educational services is among the main goals of all higher education institutions (HEIs). Nowadays, many HEIs receive funding according to the number of students and the research activity. This necessitates continuous monitoring of the activities and management decisions that guarantee quality education of the educational services provided in HEIs [1-2]. HEIs' management bodies must make daily decisions to follow the institutions' strategies and achieve the set goals. This management context in higher education requires adequate and reliable support for making management decisions [1]. Higher education management is progressively realizing the priority of accurate and available information that endorses both basic operations and long-term strategic planning [3]. For this reason, many modern universities are searching for ways to improve their traditional management processes and solve the challenges linked to them.

Recently, HEIs have become increasingly dependent on data collection, storage, and processing [4]. Contemporary HEIs use software systems to automate their activities, e.g.

student information systems, learning management systems, human resource systems, scientific activity reporting systems, and have rich data sets from external systems (registers, databases with scientific information, etc.) that can support management decisions to improve ongoing processes. The collected data has no real value if HEIs' leadership does not realize the strategic significance of the data and does not extract information from the data to make data-driven decisions.

It is very difficult for HEIs' leaderships to find the accordant information required for the decision-making when there is a plethora of systems [3]. Data collection and analysis require human resources involvement and manual perusing of ceaseless data streams. In addition, the presented data does not provide information about the HEI's current state of play and should be analysed again any time when HEI's manager needs up-to-date data. This leads to the increasing interest of HEIs' leadership in using collected and analyzed data to support decision-making [5-6]. They are trying to apply new strategies and solutions for extracting data from software systems and turning it into knowledge that supports ongoing processes' optimization, management and improvement in all major areas [2, 7-9] and can be used to inform strategic decisions at all organizational levels.

The last requires investments in appropriate technologies which support all management processes [10], e.g. incl. semantic and linked-data technologies, Educational data mining, Learning analytics and Academic analytics, Business intelligence [11]. Data analysis tools allow automatic data extraction, analysis and classification from different systems [12]. They allow HEIs' leadership to track and analyse trends and KPI performance through intuitive dashboards [13-14] presenting summarized information in graphical form (charts, tables and measurement graphs [15]) and find hidden patterns in the data, trends or anomalies [16]. The resulting information helps HEIs' leadership manage the institution more effectively, measure the impact of their initiatives, make strategic decisions for improving the ongoing processes [17-18], and collect evidence for informed decision-making. By leveraging such tools, HEIs stakeholders can gain insight and monitor progress over time on almost all aspects of HEIs activities, such as student performance, enrollment trends, academic productivity, career development, cost management, regulatory compliance, research activity, collect data on ongoing educational and research processes and take measures for improvement. By using software solutions to support the decision-making

process HEIs managers can offer alternative solutions [19], minimize the risk and negative impact of errors [2, 4, 20-21], increase the validity of the management decisions taken [22] and contribute to achieving sustainable development of HEIs, save time in discovering relevant information for decision-making and funds to pay experts to extract relevant information and give better insight and control over operations. Implementing and using decision-making systems in higher education reduce the cost and time needed to outline problems, complications or obstacles in higher education systems and make the best decisions [23-25]. Implementing and using decision-making systems in higher education reduce the cost and time required to outline problems and find the most appropriate solutions to distinguish complications or impediments of higher educational systems.

The integrated software system that will support academic decision-makers to make timely and right solutions is a significant step in implementing new educational policies. Implementing analytical tools to support management decision-making is a long process that often does not run smoothly. In implementing such tools, HEIs face several technological challenges and challenges related to privacy and ethical and responsible use of data [26]. Furthermore, large datasets do not necessarily guarantee better decisions [26]. The implementation process usually goes through six steps (justification, planning, business analysis, design, construction, and deployment [27]). During this process, a thorough study of the ongoing processes has to be done [11, 28], incl. the selection of appropriate data for processing, selection of solutions for data extraction and visualization, implementation of data warehouses, integration of relevant data sources, etc. In addition, HEIs leaders should consider how they can use data analytics most effectively, address privacy and security issues, how data strategies can aid informed decision-making. At the end of this process, they have to integrate analytic tools as part of the HEI decision-making structure, which demands institutional strategic planning and resource allocation to reflect its rising relevance in supporting the institution's mission. The successful admission of a data-based decision-making culture in HEI requires trained staff, technologies for data integration, data management systems, and tools for reporting, analysis, and data visualization [26].

The paper highlights the importance of using data-driven decision-making tools in HEIs to improve academic performance and support sustainable development. It also focuses on how these educational data mining tools play a major role in the holistic improvement of learners and thus aids a paradigm shift from traditional to data-driven decision making by the HEIs. Section II summarizes the benefits of applying data-driven decision approaches in HEIs. Section III reviews developed tools that support HEIs leadership in decision-making. The Section IV summarizes the approaches used. Section V outlines the limitations of the paper and opportunities for future research in the field.

## II. APPLICATION AREAS AND BENEFITS

Many studies have been conducted globally on the benefits of applying data analysis and management decision-making tools to improve processes for organizing and conducting

student candidate campaigns, student training, academic staff development, effective resource allocation, etc.

HEIs' leadership can apply data analytics tools to optimize the student enrollment process. Data analytics tools allow them to monitor and evaluate current campaign performance versus previous periods, detect enrollment trends [29], identify actions related to student attraction and recruitment [30] and allocate resources for marketing campaigns. Modern analytical tools help the HEIs' managers to monitor the current candidate enrolment campaign and make informed decisions to optimize and improve the process of recruiting students, conduct a targeted marketing campaign based on data on the interest of prospective students in previous years and improving strategies for attracting suitable students and managing the enrollment process for future campaigns. Detailed analysis shows how well the institution is performing, and HEIs' leadership can use the results to identify key trends that could affect the overall success of HEIs' admissions.

Data analytic tools deepen the awareness of HEIs' managers of students' success rates and allow them to track trends over time [31]. The governing bodies have access to aggregate data for students' achievements, which allows them to monitor students' progress [24], identify at-risk students [24, 32] and predict graduation rate [33-34]. They can use this summarized information to identify the reasons for low graduation rates, develop intervention plans [32, 35-37], and improve students' completion rate [38-40]. Tools allow managers to identify the most effective and desired programs [33], to take measures to increase the quality of learning resources and training [41-43].

Data analytic tools can support HEIs' leadership in monitoring research activity and making informed decisions to stimulate it based on the summarized data from university systems, online libraries and databases. HEIs' leadership and people who are responsible for monitoring research activity can make comparisons between the achievements of teachers (e.g. published books and articles, citations, research grants and awards) at different levels (university, faculty, department) over different periods and based on the results to give recommendations to scientists to improve their research activities.

Data analysis and decision support tools make it easier for universities to deal with one of the most frequent obstacles continuously faced in the decision-making process – the selection of human resources. This process is significant for any HEI and determines its future stability and development. HEIs' managers can apply the tools to identify and differentiate candidates' personal and professional qualities [10] and to predict their advancement and performance determined for different occupations and hierarchy levels [10]. Based on generated reports on the structure of the academic staff and the free hours in separate units, the governing bodies can make informed decisions about announcing competitions for the development of the academic staff. Such tools help managers to improve the selection process [40, 45] and evaluate teachers' work, to select the most appropriate teacher for a new course based on course content and academic staff qualifications [10]. In addition, HEIs' leadership can make decisions to stimulate

teachers to update curricula, learning resource and change teaching methods [46-48] and thus, to provide students with a better learning environment and enhance the quality of training [34].

Data analytics tools enable HEIs' managers to create and distribute various reports, incl. HEIs' annual performance reports with meaningful summarized historical data. Such annual reports assist managers to answer tactical questions for making data-driven decisions across all departments and divisions [31, 49-50] and determine whether measures are effective and sustainable.

HEIs' leadership can analyze and manage big data to provide transparency in management, predict future outcomes and identify potential problems [31]. In addition, HEIs' leadership can use data analytics tools to make the data-driven decision for cost reduction [40] and allocate resources more efficiently [43, 46-47, 50], meet the desire for accountability for internal and external stakeholders [51] and policymaking [52].

Data analytics tools allow stakeholders to conduct extensive education analysis and share findings across HEIs. From this point of view, HEIs' managers can use data analysis tools to monitor and improve the performance indicators and create a competitive strategy to increase the HEI rank among competing institutions [53].

HEIs' leaders understand that implementation of data-driven decision support tools can significantly transform how they work, enabling new ways to increase student enrolment, improve the quality of educational services, and increase the productivity of teachers and researchers. The proof of this is the large number of successful examples of implementing data-based decision-making solutions in various aspects of HEIs' activities. HEIs' leadership is applying data analytics tools to identify at-risk students and reduce drop-out rate [3, 54-59], provide better feedback [60], identify effective teaching strategies [32], track student engagement and predict student success [32, 56, 61-63], improve student success and graduation rate [61, 64-68], improve HEI evaluation results [61], outline realistic targets to strategically tackle inefficiencies and solve declining student enrolment problems [56]. There are also examples of successful experiments for using data analysis tools to help HEIs' leadership make data-driven decisions on quality assurance, improving institutional processes and student achievement, and reducing drop-outs [69-72].

### III. APPROACHES AND TOOLS

Today, HEIs use decision-making support systems to deal with various challenges, but their use is still partially implemented. According to Mora [1] there is still potential to utilize them at HEIs and corresponding knowledge gaps need to be studied further. The results of a study conducted [84] show that HEIs in developed countries are ready to deal with globalization and take steps towards implementing digital solutions to improve university processes.

Mansmann and Scholl [73] have presented a methodological approach that enables the assessment of educational capacity and the planning of its distribution and

usage. They have also developed a decision support system that allows simulation and evaluation of different proposals and scenarios based on this approach. The system is designed to integrate input data from various sources into an autonomous data warehouse, extract meaningful details and dependencies from the data, and present them to decision-makers in an appropriate format. By utilizing this system, policymakers can expedite planning procedures, gain deeper insights into the data and the methodology, and ultimately improve academic administration efficiency.

Bresfelean and Ghisoiu [7] propose a system supporting decision-making about teaching, research, curricula, examination materials and procedures. The system has three main modules – Students, Teaching and Research. The modules extract and process data from university systems and databases, including a research activity management system, a library system, administrative systems (financial, accounting, etc.), management of school records application, web-based grade book, fee management application, distance education portal, e-mail, research management application, periodic academic quality assessments, research and teaching staff evaluations, surveys of PhD students and graduates, etc. The results from the data processing can be used for quality assessment, analysing the organization's practices, and making decisions on management issues.

According to Olsson [74], business intelligence tools are of great use for managing a HEI. The GLIS tool informs top-level governing bodies about the annual planning and reporting process. It also can be used by governing bodies at different levels for handling the admissions process, planning student intake, subsequent analysis of educational programs and bibliometric analysis of publications data.

Şuşnea [4] develops an intelligent support system for decision-making which increases the efficiency of academic processes. The system includes three integrated sub-systems: a sub-system for data management necessary for training the models (data on graduates, students, academic and non-academic staff, faculties, financial resources, educational resources, and e-learning), a sub-system for generating and managing models based on data from the data management sub-system and data extraction through data mining techniques and analytical tools, and user interface. The system provides users with access to data from many sources and the ability to choose a data aggregation level. In addition, it assists the decision-makers in monitoring, modelling and predicting the quality of higher education and contributes to knowledge transfers and collaboration between institutions interested in quality assurance.

Denley [75-77] created a system which suggests what sequence of courses a student should take to enhance his/her success. The Degree Compass system is based on an algorithm which instead of taking the student's choices and preferences, relies on grade and enrollment data. After retrieving all records of student attributes, enrollment choices and grades received, the system ranks the courses based on the chance of successful completion. Furthermore, the algorithm uses the same approach to design a pattern (i.e. the sequence of courses) and predict student's assessment in each course. A straightforward

web-based interface, that gives students access to the ranking results, indicates the intensity of recommendation for different course combinations by designating stars (1 to 5). The algorithm that evaluates the courses also reflects on the decisions that students have already made, particularly about their major and prior exams. By analyzing huge datasets to produce predictions about the courses that are most likely to promote student success, the MyFuture add-on module offers details on degree paths and the transition between the HEI and the workforce.

Sarker [78] explored the applicability of the Linked Data technique to promote student retention, progress, and graduation. Two experiments were conducted with the developed academic prediction model – to predict the probability of students being at risk of dropping out and to predict students' academic performance/grades by using readily available data from internal institutional sources/data repositories and external open data sources.

In their work, Fulantelli [79] introduces a framework for mobile learning that facilitates educational decision-making by considering the connections between different types of interactions that occur during mobile learning activities and the relevant pedagogical tasks for each activity. To demonstrate how the framework may be used in mobile learning contexts, they produced a case study.

Lei et al. [80] propose a decision-making framework for educational institutions that aims to improve educational decisions and quality through following student development. The framework contains a student development system, educational data mining, and a decision process. Based on extracted data on student development, the framework supports decision-making to promote it.

Karlstad University invests in business intelligence solutions to help governing bodies find concerning financial, human resource and educational matters. The KULI tool [81] has sections for presenting pre-made and customized information presentations. The pre-made presentation allows monitoring of the budget based on historical economic data, planning of the recruitment process based on the age distribution among the staff data, and supporting the capacity planning process (number of classrooms, number of teachers) based on the data for study programmes and courses. The Custom Information Presentation module allows users to process and adapt data to extract the personalized information they seek.

Cadme and Piedra [82] use a Linked Data technique to explore scientific activity and help universities incorporate scattered teacher-researcher production into the network, form scientific networks, discover potential priority areas where legislators can help formulate science and technology policies.

Indrayani and Pardiyono [83] developed a system that helps future students to choose a HEI based on criteria from a service quality model. The system generates an ultimate decision according to a number of criteria (reliability, responsiveness, assurance, empathy, and tangibles) by using an analytical hierarchy process. Such a process has been used in developing

other decision-support systems for educational environments [84].

Komleva et al. [85] developed a decision support system that automates the data collection process from conducted surveys. The system architecture allows working with different fine-grained data sets, which is a prerequisite for the constant development of the system.

Piri et al. [86] use visual information to support the decision-making process. They form the KPIs through structured interviews with 30 people in management positions in the HEI. After analyzing the results, they organized 85 KPIs in the digital dashboard. The developed system has a three-layer architecture – user interface, business layer and database layer. The dashboard utilizes a combined dataset from the learning management, e-learning, accounting and research information systems. The dashboard allows executives to apply filters to view different results and charts. Visualized information helps academic managers identify trends, strengths and weaknesses and make decisions as quickly as possible. In this way, they can improve the quality of all university services, track the university's performance in national and international rankings and conduct advertising campaigns to attract students and PhD students.

Chitpin [87] proposes an Objective Knowledge Growth Framework (OKGF) that helps managers make more effective decisions in solving practice problems. The OKGF framework can improve institutional performance and increase student achievement.

Alisan and Serin [88] propose a decision support system that maintains the quality and positioning of departments and courses offered. This system works in three steps – collecting Internet data by using web scraping methods, converting it into meaningful and processable information using natural language processing methods, and ranking the alternatives using multi-criteria decision-making methods. The suggested system provides useful information to various stakeholders – universities, teachers and students. The qualities of the proposed decision support system in terms of application and reliability are demonstrated by conducting information extraction experiments on computer engineering job postings and university course content in Turkey.

Ashour [44] offers an educational ontology that governing bodies can follow when selecting the most appropriate and qualified teacher for a new course. The ontology summarizes the long steps of mapping course content and faculty member profiles. In a subsequent study, Ashour [10] proposed a solution to support the selection process through the Linked data. They apply the technique to generate a link between university semantic data and research data from online libraries. The Linked Data generation methodology has three steps – initialization (selection of local data source and university ontology, selection of external data source, specification of the linked data set), innovation (identification of restrictions and writing of linkage rules), validation (publication and evaluation). The proposed solution is tested at King Abdulaziz University.

Tadić, Marasović, and Jerković [87] have created a fuzzy multi-criteria decision support model for appointing research and teaching staff in HEIs, which is based on the technique for order preference by similarity to ideal solution (TOPSIS). The model uses both quantitative and qualitative selection criteria, as well as the competencies of experts, in a hierarchically structured manner. The authors have successfully applied this model to the selection of teaching and research staff in higher education institutions in Croatia.

Prasetyo [2] designed a decision support system for determining the HEI's resource need. The system comprises three sub-systems for managing model, data and user interface. The system manages the model base that stores the mathematical model (sessions, estimates of the number of new students, financial income, financial expenses, educational and student operational costs) and result values. By altering the data for the number of lecturers, classrooms, students and guest lecturers, the simulation's outcome value may be determined. Simulation models help management identify problems and use the results to support decision-making.

Makki et al. [90] proposed an admission/decision support system for capacity planning based on a framework for student enrollment and HEI admission.

Du [91] used a decision support system to improve the curriculum. The system uses mobile learning technologies to analyze students' feedback at the end of training. The resulting dataset is used as input to the fuzzy logic system for analysis. The experimental results indicate that the mobile learning technology combined with the fuzzy logic system offers a more effective approach for decision-making analysis related to curriculum optimization for both students and teachers.

To address the challenges of European mobility programs that seek to involve students with multidisciplinary competencies, Teixeira, Alves, Mariz & Almeida [92] have developed a decision support system for selecting students for short-term Erasmus+ mobility. The researchers utilized an analytic hierarchy process based on a four-layer model that collects information about the specifics of each project and student profile and promotes greater inclusion and homogenization of project teams. They tested the proposed system with 6 test scenarios, and the results demonstrate that the proposed model can be applied with various selection criteria among students and consider their hard and soft skills. The system can support decision-making to build project teams where students' knowledge is aligned with the technical skills required to complete the projects.

Gaftandzhieva, Doneva and Bliznakov [93] propose software tool for monitoring the career designed for different stakeholder groups (faculty staff, members of quality committees, head of departments, top and middle management) having a role in stimulating career paths in academy. The AcadStaffAnalyst tool allows them to monitor the career development of the faculty staff based on the 68 quantitative indicators divided into 7 groups (Acquisition of scientific degrees, Occupying scientific positions, Occupying management positions, Publishing activity, Projects activity, Activity in scientific events, Gender gap) and make data-informed decisions to stimulate career paths, ensure equal

access to options for career growth, set priorities and adjust them when the situation allows it. The tool can generate self-assessment reports with data for the faculty staff for the need of accreditation procedures. Indicator values are obtained by extracting and processing data from human resource systems, academic staff development systems, and research reporting system.

To help university decision-makers make decisions to increase retention rate and improve student success rate Gaftandzhieva, Doneva and Bliznakov [94] offer a tool for monitoring student success from. The StudAnalyst tool allows programme managers, deans and rector to monitor 42 quantitative indicators divided into 3 groups (Student success during the training, Student success in graduation, Gender gap) and generate reports for each indicator with retrieved values when s/he wants to see the current situation in the faculty/university depending on its user role. The tool can also generate such reports automatically following the predetermined schedule and store them in its repository. Reports contain summarized data visualized in tables and diagrams and help users to perform various analyses and make data-informed decisions.

#### IV. DISCUSSION

Studies cited in this paper show that data-driven decision-making tools can improve decision-making in HEIs. HEIs are complex organizations with multiple stakeholders, making decision-making a challenging task. By using data-driven decision-making tools, HEIs can make more informed decisions leading to better performance, higher student achievement, and increased competitiveness of departments and courses offered.

One of the approaches proposed to support decision-making is using decision-support systems. Such systems can collect data from various sources, analyse the data, and present the results in a meaningful format to different stakeholders. The studies by Alisan and Serin [88] and Prasetyo [2] proposed decision support systems for capacity planning and determining the need for higher education resources, respectively. These systems can help management identify problems in operating systems and use the results to support decision-making.

Another approach proposed is the use of fuzzy multi-criteria decision support models. The study by Tadić et al. [89] developed a fuzzy multi-criteria decision support model for research and faculty staff in HEIs' appointments based on the technique for order preference by similarity to the ideal solution (TOPSIS). The model uses hierarchically structured quantitative and qualitative selection criteria and the competencies of the experts. The proposed model, which refers to a specific set of rules and procedures, has been implemented for the purpose of choosing faculty members who will be involved in both teaching and research activities in Croatia. This process likely involved analysing various factors such as educational qualifications, research experience, and other relevant criteria in order to make informed decisions about the candidates most suitable for the job.

The studies by Ashour et al. [10, 44] proposed educational ontology and linked data techniques to support the process for selecting the most appropriate and qualified teacher for a new course. The ontology summarizes the long steps of mapping course content and faculty member profiles, while the linked data technique generates a link between university semantic data and research data from online libraries.

Finally, the study by Du [91] used a data-driven decision support system to improve the course curriculum. The system uses mobile learning technologies to analyze students' feedback at the end of training. The dataset of student responses is set as input to the fuzzy logic system to perform the analysis. The results of experiments showed that mobile learning technology with the fuzzy logic system offers improved decision-making analysis for curriculum optimization for the student and teachers.

In conclusion, the studies reviewed in this article demonstrate the potential of data-driven tools to support decision-making in HEIs. By using these tools, HEIs can make more informed decisions leading to better performance, higher student achievement, and increased competitiveness of departments and courses offered. Further research is needed to determine the most effective tools and approaches for supporting decision-making in HEIs.

Table I presents a summary of the reviewed tools. The "Data Sources" column contains a brief description of the source types, as mentioned in the references. The "Users" column refers to the intended audience for each tool. The "Purpose" column provides a concise statement of what problem the tool is designed to solve.

TABLE I. SUMMARY OF THE RELEVANT TOOLS

Authors & References	Data Sources	Users	Purpose
Mora et al. (2017) [1]	Various data sources	Higher education institutions' (HEIs) managers and decision-makers	Provide open opportunities to apply decision-making support systems in HEIs
Mansmann & Scholl (2007) [73]	Autonomous data warehouse, different sources	HEIs' policymakers and decision-makers	Assess educational capacity and plan distribution and utilization
Bresfelean & Ghisoiu (2010) [7]	University systems and databases	HEIs' management staff	Support decision-making about teaching, research, curricula, examination materials and procedures
Olsson et al. (2012) [74]	GLIS tool	Top-level governing bodies at HEIs	Inform about annual planning and reporting processes, handle admissions processes, plan student intake, balance student load, analyse educational programs, and bibliometric analysis of publication data
Şuşnea (2013) [4]	Alumni, students, academic and non-academic staff, faculties, financial and educational resources, e-learning	HEIs' senior management, students, and teachers	Provide a scientific base for decision-making, increase the efficiency of academic processes, and improve the quality of higher education at national and international levels
Denley (2012-2014) [75-77]	Grade and enrollment data	Higher education students	Suggest the best patterns of courses to maximize student success, and predict grades obtained in each exam
Sarker (2014) [78]	Internal institutional and external open data sources	First-year university students and HEIs's management staff	Promote student retention, progress, and graduation
Fulantelli et al. (2015) [79]	Mobile learning interaction types	Educational decision-makers and policymakers	Aid educational decision-making
Gaftandzhieva et al., 2023 [93]	Human resources systems, academic staff development systems, research reporting system	Stakeholder groups (faculty staff, members of quality committees, head of departments, deans and vice-deans, rector and vice-rector) having a role in stimulating career paths in academy	Make data-informed decisions to stimulate career paths, ensure equal access to options for career growth
Gaftandzhieva et al., 2023 [94]	Student Information system	Programme managers, deans and rector	Monitoring student success in a timely manner

## V. CONCLUSIONS

HEIs are complex organizations that require effective decision-making to improve performance and increase competitiveness. This article reviewed several studies that proposed data-driven tools for supporting decision-making in HEIs. The studies proposed decision-support systems, fuzzy multi-criteria decision-support models, educational ontology, linked data techniques, and mobile learning technologies to analyse student feedback.

The studies showed that data-driven decision-making tools are able to support decision-making in HEIs. These tools can help management identify problems in operating systems and use the results to support decision-making. The studies also demonstrated that HEIs' leaders could use different approaches to support decision-making, incl. decision support systems, fuzzy multi-criteria decision support models, educational ontology, linked data techniques, and mobile learning technologies.



Overall, the studies reviewed in this article highlight the importance of data-driven decision-making in HEIs. By using these tools, HEIs can make more informed decisions leading to better performance, higher student achievements, and increased competitiveness of departments and courses offered.

The cited works highlight that data-driven decision-making methods can support decision-making in HEIs. However, HEIs need to consider certain limitations when applying these methods. One limitation is the lack of quality data. Much data collected in HEIs can be inconsistent, incomplete, or unavailable. Therefore, it is significant to ensure HEIs collect relevant and reliable data. Another limitation is the difficulty in identifying the right questions to research. To successfully apply data-driven decision-making methods, it is significant to identify the right questions for research. This requires knowledge of the decision-making process and specific challenges that HEIs face.

Data-driven decision-making methods have many areas of application, including analysis of student feedback, monitoring of student success, identification of trends in course selection, and optimization of resource management. They also help the companies in the campus placement and help all the stakeholders of the education system at one go. Despite their wide application in various fields, these methods should be adapted to the specific HEI's needs.

Given the limitations and application areas, further research is needed to determine which tools and approaches are most effective in supporting decision-making in HEIs.

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# Semi-Dense U-Net: A Novel U-Net Architecture for Face Detection

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**Abstract**—Face detection and localization has been a major field of study in facial analysis and computer vision. Several convolutional neural network-based architectures have been proposed in the literature such as cascaded approach, single-stage and two-stage architectures. Using image segmentation based technique for object/face detection and recognition have been an alternative approach recently being employed. In this paper, we propose detection of faces by using U-net segmentation architectures. Motivated from DenseNet, a variant of U-net, called Semi-Dense U-Net, is designed in order to improve the binary masks generated by the segmentation model and further post-processed to detect faces. The proposed U-Net model have been trained and tested on FDDB, Wider face and Open Image dataset and compared with state-of-the-art algorithms. We could successfully achieve dice coefficient of 95.68% and average precision of 91.60% on a set of test data from OpenImage dataset.

**Keywords**—Semi-Dense U-Net; face detection; segmentation; U-Net

## I. INTRODUCTION

Face detection deals with the localization of face in a given image. At the outset, detection process takes an input image containing one or more faces, applies a detection and localization model and produces a confidence score and a set of bounding-box parameters containing the coordinates of the face and its dimension. Face detection being the first phase in face analysis, the detected face is subjected to facial analysis process for machine learning and computer vision applications. Over decades, several algorithms have been proposed using a variety of approaches to detect faces in the image for diverse applications addressing uncontrolled illumination, scale variance, rotation in plane, occlusion, low quality image, large and tiny faces, masked faces, faces with makeup etc. These algorithms are designed to address a subset of these issues but no algorithm can address all the issues.

A variety of face detection techniques for computer vision applications can be found in the literature. Several new techniques and approaches have been explored at a great extent in the literature, each approach trying at its maximum

to address a selected subset of the issues in face detection using the available dataset. Over time, the complexity of the face dataset has widened considerably covering very high- and low-resolution images and with facial features that has laid challenges in achieving good detection rate and further promoting development of new algorithms to address the issues. Early work on face detection dates back to 1992 in [1], that used artificial neural networks. However due to the limited computational and storage resources, it did not gain considerable attention. In contrast to traditional algorithms, capability of convolutional neural networks (CNN) to learn features from its input has led to a number of recent advancements in the field of face detection using CNN. With improved computing power through GPU and now TPU's, there is more scope for research promoting construction of complex models for AI based applications. CNN architectures have made it possible today to learn complex features from large and complex datasets. Several novel architectures such as AlexNet [2], VGGNet [3], GoogLeNet [4], ResNet [5], DenseNet [6], DarkNet [7] and its variants have been used as backbone network for feature extraction. This has improved the performance of face detection frameworks over time.

Figure 1 shows a face detection process used in our work. The input color image of any scale is subjected to preprocessing, that scales down the input image to a standard size of 256×256 or 512×512. In our work, three U-Net architecture variants are used, each trained with three standard datasets. The outcome of feature extraction is a binary feature map/mask representing the segmented image, as shown in the figure. As the network output does not always produce a very fine and sharp segments, it is further refined to generate sharp rectangular regions suitable for detection of bounding box in the final step.

The remainder of the paper is organized in the following manner. Section II presents some of the prominent face detection architectures, U-net segmentation architectures and its variants used for various applications, Section III presents the proposed architectures, Section IV highlights on implementation details with the experimental results and Section V summarizes with conclusion.

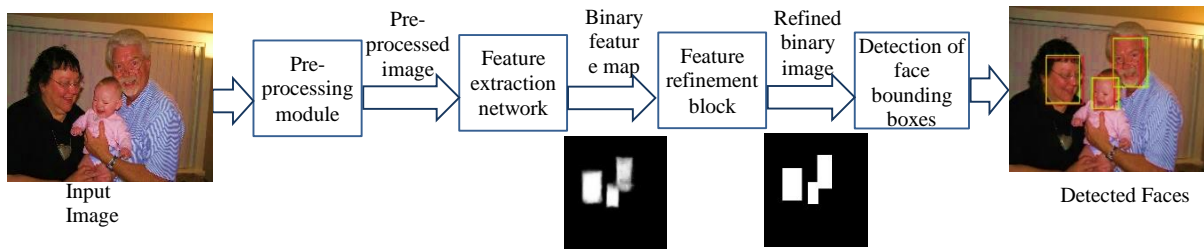


Fig. 1. General model of proposed face detection architecture. The first binary image (at bottom) is the model output and second is output of post-processing module.

## II. RELATED WORK

CNN segmentation architectures are being used for several applications, such as, for medical images [8][9], object and instance segmentation such as Mask-RCNN [10], video object segmentation [11] to name a few. It however has been used to segment the entire region of the object and can be extended to recognition applications. U-Net [8] is one such neural network architecture designed for biomedical image segmentation. Its U-shaped network consists of an encoder CNN that gradually reduces the spatial size of the input image while increasing the number of feature maps to retains high-level contextual information and a decoder section that reconstruct the segmentation map by gradually increasing the spatial size of the features and concatenating them with the corresponding features from the encoder part using skip connections for precise localization information. The study [12] proposed a simplified UNet architecture for medical image segmentation. UNet++ [9] is a U-Net based architecture using nested and dense skip connections designed to improve the accuracy of medical image segmentation. It improved U-Net by adding skip pathways that connect the two sub-networks and uses deep supervision. The deep supervision module enables the model to operate in an accurate mode, where the outputs from all segmentation branches are averaged; and fast mode that selects the final segmentation map from the segmentation branches. This choice determines the extent of model pruning and speed gain. Motivated by DenseNet architecture [6], Li et al. [13] proposed H-denseunet segmentation architecture for liver and liver tumor segmentation. The study [10] is another such approach to detect faces using a segmentation architecture. Using improved Mask R-CNN, Lin et al. proposed G-Mask [14] for detection and segmentation of face that incorporates both into one framework. It used ResNet-101 for feature extraction, RPN to generate RoIs, and fully convolutional network to generate binary mask. A most recent work on U-Net can be found in [15] that segments lungs in the chest radiography images. With several recent segmentation architectures and its improvements thereof, we find them being applied in a diverse domain meaningfully able to elaborate on the semantic aspects of the problem domain to the solution space. Each architecture has tried to extract and extend the prominent features of the base architecture and inherit prominent features of other architectures to address the drawbacks in the base architectures. In this paper, our proposed architecture inherits the features of U-Net, DenseNet and ResNet to build an improved segmentation architecture that produces more accurate segmentation output and successfully applied it on a face detection problem. The

outputs observed are on par with some of the standard convolutional face detection architectures.

## III. PROPOSED ARCHITECTURES

U-Net based segmentation architectures have been widely used on medical images for disease detection and localization. In this paper, U-Net architecture is used as a base to develop an improved U-Net architecture to improve the accuracy of the binary mask generated that will be postprocessed to detect faces. Here, we use three U-Net based architectures for face detection application. The details of the architectures used are as follows:

### A. Using U-net

Our experiment uses U-Net architecture comprising of six blocks at encoder with two convolutional layers in each with the kernel size of 3, same padding, he\_normal kernel initializer, relu activation, max pooling of size 2 and a dropout of 0.2. Input to the architecture is a single channel image of dimension 512, with the corresponding training output being its binary image with masks at the face regions. Size of the feature map converges at the encoder generating 512 feature maps of size 16 and decoder upsamples it to a single binary feature map image of size 512 generating a segmented binary image for the given input. The segmented regions represent the faces predicted. The prediction may not have always a clear and sharp edge. These variations are addressed by a post-processing module that refines the prediction of segmented regions. Bounding box is then computed over the refined image.

### B. Using VGG16-Unet

Transfer learning today speeds up the training time by using pre-trained weights of a backbone network. This is experimented by using a pre-trained VGG-16 backbone network at the encoder side of U-net, configured with ImageNet dataset weights. The weights at the encoder side were configured to be non-trainable and the decoder part to be trained with the input dataset. The network is expected to learn faster as the encoder is already in possession of valuable weights. The model takes a colored image of size 512 and produces a binary segmented image of same size. As mentioned in the above model, the output is further refining using a post-processing module to improve the segmented regions. Bounding box is then computed over the refined image.

### C. Using Semi-Dense U-Net

In a general CNN, each layer produces a set of features and is forwarded to the next layer for deep feature extraction. ResNets [5] introduced a concept of skip-connections where an output can bypass the normal flow of non-linear transformations with an identity function and get combined with a layer down the network. With transition function  $H_l$  for the  $l^{th}$  layer, we can represent the result of skipped layer as:

$$x_l = H_l(x_{l-1}) + x_{l-1} \quad (1)$$

U-Net uses this skip-connection to connect between encoder and decoder. The research [6] further improved it by adding a dense connectivity between layers where each layer will be learning features from its all-previous layers. Hence the transition function will have feature maps  $x_0, \dots, x_{l-1}$ , as input. This can be formulated as

$$x_l = H_l([x_0, x_1, \dots, x_{l-1}]) \quad (2)$$

This generates a strong feature map through which each layer will be encapsulating low- to high-level feature. This architecture is referred as DenseNets. Motivated from ResNets and DenseNets, a modified U-net architecture is proposed by adding skip-connections at the encoder side that connect to layers within the encoder and dense connections at the decoder side with links from various layers at the encoder side scaled down at respective levels at the decoder side, and we name it *Semi-Dense U-Net*. Our proposed architecture uses seven blocks at the encoder side and six blocks at the decoder,

as shown in Fig. 2. Feature maps are increased progressively from 16 at the first block, B1, to 512 at the seventh block, B7.

1) *Layer structure*: Each layer is built using two convolution layers with kernel size of three, same padding, he\_normal kernel initializer with relu activation, batch normalization, max pooling of size two and a dropout of 0.2. At the encoder side, the normalized output at layer  $l$  is concatenated with feature map from layer  $l - 1$  followed by max pooling. At the decoder side, output of the dense feature scale module is a  $512 \times 512$  color image scaled down to  $8 \times 8$  with 256 channels followed by decoder network up-sampling the features back to single channel of size  $512 \times 512$ . In U-Net and VGG16-Unet model, dropout of layers B1, B2, B10, B11 is 0.1, B3, B4, B8, B9 is 0.2 and B5, B6, B7 is 0.3. Semi-Dense U-Net uses dropout of 0.1 at layers B1, B2, B12, B13 and 0.2 at all others.

2) *Dense feature scaling module*: Dense feature scaling module scales down feature maps of each upper layer to 16 feature maps using max pooling. Hence, at layer  $l$ , we get  $(l - 1) \times 16$  feature vectors. This will be later concatenated with the feature maps generated at level  $l$  along with the up-sampled feature map from level  $l + 1$  at the decoder side. More semantic information are obtained from the feature maps at deeper layers [16]. Our feature map progressively encapsulates high to low range features as we go deeper. Hence, semantic information from the dense features is extracted by using a  $1 \times 1$  convolution layer and is normalized.

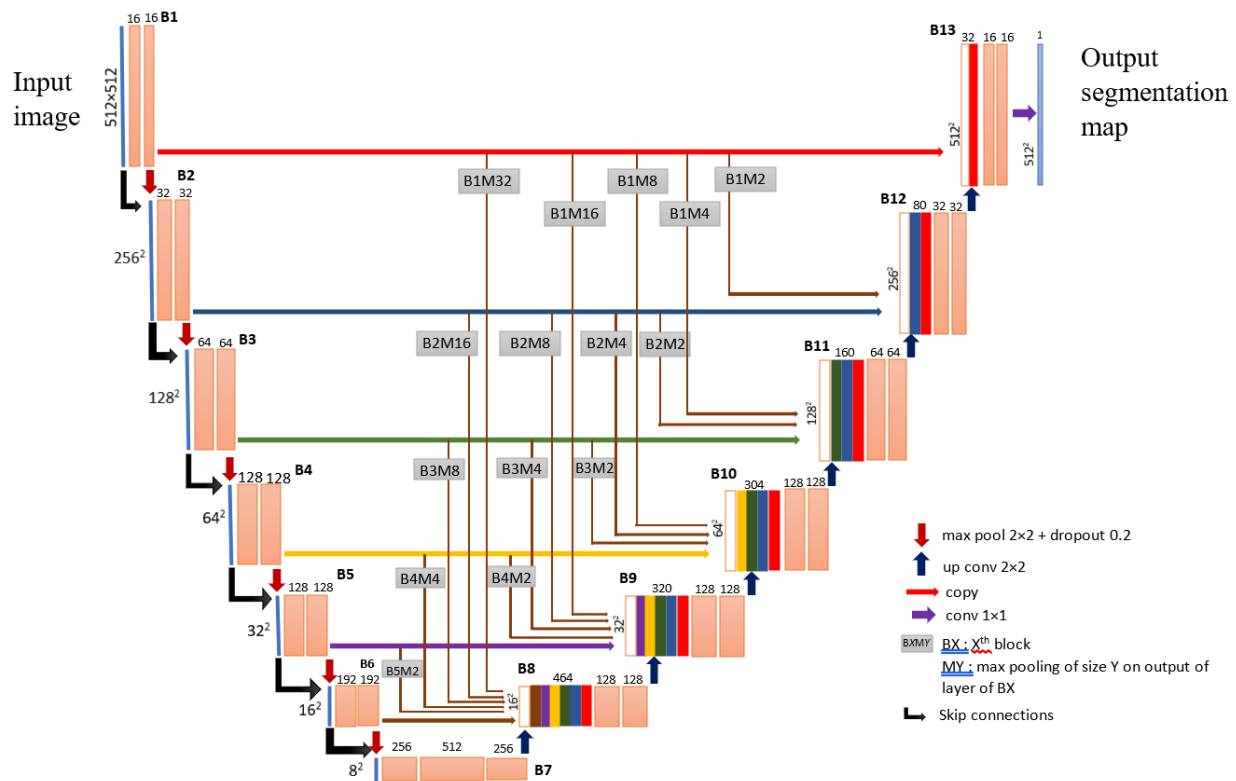


Fig. 2. Semi-Dense U-Net architecture. Each pink block represents multi-channel feature map and colored blocks at the decoder, the feature maps scaled down from upper layers using BXMY module.



3) *Growth rate*: At the encoder, if the function  $H_l$  at layer  $l$  produces  $k$  feature maps, it follows that layer  $l$  has input feature-maps from layer  $(l - 1)$  and  $(l - 2)$ , where  $l \geq 0$  and  $l = -1$  representing channels from the input vector. This can be visualized in Fig. 3. It can also be observed from the Fig. 2 that block 4 and 5 carries forward a constant number of 128 feature vectors. This effectively controls the expanding parameters of the network. At the decoder side, feature maps of encoder are scaled and squeezed to a fixed number of 16 feature maps at each level, as discussed above. By limiting it to a constant value, the number of parameters of the network can be kept small. Hence, if a layer  $l$  generates  $k$  feature maps, the decoder concatenates  $2k + 16(l - 1)$  feature maps at each layer.

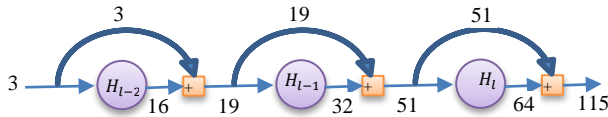


Fig. 3. Growth rate at the encoder side of the network.

#### D. Post-processing Module

Output of the network is an image that may contain traces of black within white predicted regions (Fig. 4 (a)). The network does not always generate a clear rectangular region. Further, there can be certain regions in the output with light traces of white pixels that are in fact false predictions. Hence the output image certainly should be subjected to post-processing to refine the predictions and eliminate false predictions. This module uses image enhancement techniques to produce a clear and sharp image, as shown in Fig. 4 (b), suitable for computing the bounding box of the predicted regions.

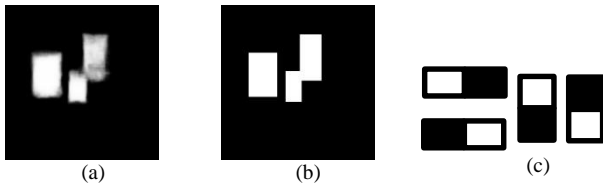


Fig. 4. Post-processing result. a) Model output b) Post-processing output c) Haar-like edge features.

Refinement has been experimented using two approaches: thresholding and grid-based region growing approach. With thresholding, image is first enhanced using Otsu threshold and further refined using opening morphological operation with kernel of  $3 \times 2$ px. Image is further contoured to extract boundaries of the segments. Overlapped segments are further processed to extract distinct rectangular regions out of the segmented regions and their bounding boxes. The post-processed result is shown in Fig. 4(b).

In the grid-based region growing approach, the image of  $512 \times 512$  is divided into grid of size  $4 \times 4$ . Intensity of the grid

is evaluated using  $G_{i,j} = \frac{1}{16 I_{max}} \sum I_{p,q}$ , where  $I_{max}$  is the maximum intensity of the image,  $I_{p,q}$  is the  $p, q^{th}$  pixel intensity of grid cell  $G_{i,j}$ . Based on the value of  $G_{i,j}$ , the cell is initially classified as, full-white (FW), full-black (FB) or fuzzy (FZ). Cells with  $G_{i,j} \geq 70$  are labeled as FW and  $G_{i,j} \leq 30$  are labelled as FB. Remaining are considered as fuzzy cells. FZ are further processed base on adjacency positions and haar-like features [17]–[19] to relabel them as FB/FW. Haar-like edge features (Fig. 4 (c)) are analyzed in each cell. Based on the pixel intensity proportion in the adjacent bands and its adjacency to the FW/FB, cells are labelled as FW or FB. This is then followed by contouring, extraction of boundaries and bounding box, as discussed for thresholding approach.

#### IV. EXPERIMENTS

The model is trained using TensorFlow deep learning API's on a Nvidia Tesla P100-PCIE (12 GB) GPU. For the U-net architecture, the image is initially converted to grayscale before feeding into the network. Inputs to the other two networks are color images. Feature refinement module partially uses OpenCV library for image enhancement and morphological operations. Image is preprocessed by scaling down to  $512 \times 512$ .

##### A. Training Datasets

Each model is trained and tested on Fddb, Wider face and OpenImage dataset. Fddb dataset contains 5,171 faces in 2,845 images. As Fddb dataset represents faces using ellipses, our models are trained to generate elliptical segments, as shown in Fig. 5. The post processing module extracts the elliptical regions coordinates, angle, major and minor axis. Model is tested using 10-fold cross validation and accuracies averaged. Wider face dataset contains faces with a high degree of variability in scale, pose and occlusion with images organized based on 61 event classes. Dataset randomly select 40%/10%/50% data as training, validation and testing. It contains 3,93,703 annotated faces in 32,203 images. We have used 12,880 training images to train our model and 3,226 validation images to test our model. Faces are classified as easy, medium and hard based on the face size of less than 50px, 50px to 300px and above 300px respectively. OpenImage-v6 face dataset contains 3,44,043 annotated images with 10,60,312 faces. It is classified into 3,31,627 training images (1,037,710 faces), 3,124 validation images (5,594 faces) and 9,292 test images (17,008 faces). Due to hardware resource limitations, we use 10,000 annotated training images as our dataset with 80%:20% for training and validation/testing. Model is trained to produce rectangular segments for the detected faces in OpenImage and Wider face datasets as provided in the dataset.

All models have been trained for 150 epochs with early stopping where validation loss is monitored with the patience of 10.

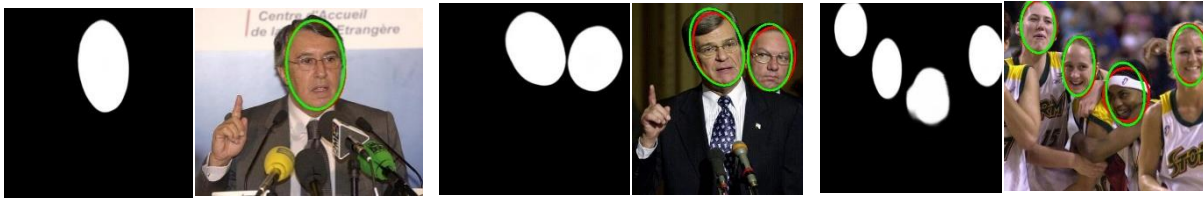


Fig. 5. Predicted binary mask image by the model and its corresponding image with face ellipses. Green ellipse represents ground truth and red represents prediction by the model for samples from Fddb dataset.

**B. Model Hyperparameters**

Model has been trained with adam optimizer with a constant learning rate of 0.001. Each layer is appended with batch normalization (BN) to optimize the segmentation accuracy. All the convolutional layers have been configured with relu activation function, he\_normal kernel initializer and sigmoid function at the last layer. Models have been trained with binary cross-entropy loss function for 150 epochs and batch size of 16 for U-Net and 8 for VGG16-UNet and Semi-Dense U-Net architectures. U-Net model used contains 7.7M parameters and VGG16-unet contains a total of 25.8M parameters with 11.3M trainable parameters. The proposed Semi-Dense U-Net, is optimized with only 5.8M parameters.

**C. Effect of Batch Normalization**

Models have been experimented with and without BN. Fig. 6 shows the results on two sample images drawn from wider face dataset. Fig. 6 (a) and 6(d) are the model output without BN whereas 6(b) and 6(e) are with BN. With BN, we can observe a comparatively better and sharper approximation than without BN. Further we can observe certain cloudy region at the rightmost side of the image in 6(a) leading to false positives. With BN, such regions have been eliminated in 6(b). In 6(d), it can be observed that leftmost two segments are not sufficiently predicted as a facial region, leading to false

negative. With BN, we get a better approximation of the region that is suitable to come under true positive even with an iou of 80%. Hence, BN has normalized the covariate values of the dataset and has given a better prediction accuracy. Fig. 6(c) and 6(f) show the original image with face bounding boxes obtained with BN.

**D. Evaluation on Datasets**

Table I tabulates the training and validation accuracy of the three models on Fddb, Wider face and OpenImage datasets. The accuracies observed are on par with the standard datasets. We can observe that Semi-Dense U-Net comparatively gives better accuracy than the other two. The accuracies mentioned in the table for Fddb dataset are the average accuracy over 10-fold cross validation. Fig. 7 to Fig. 9 show training and validation accuracy curves of U-Net, VGG16-UNet and Semi-Dense U-Net model on all three datasets. Training accuracy curves on Wider face dataset are projected for easy, medium and hard samples. In wider face dataset, the performance is found to fluctuate frequently for hard faces. This can be possibly due to the tiny faces in the samples. Most of the time, tiny faces are part of crowd images. Wider face dataset contains several classes of images that has crowded people. Often such faces are blur in nature, making it hard to extract detailed features.

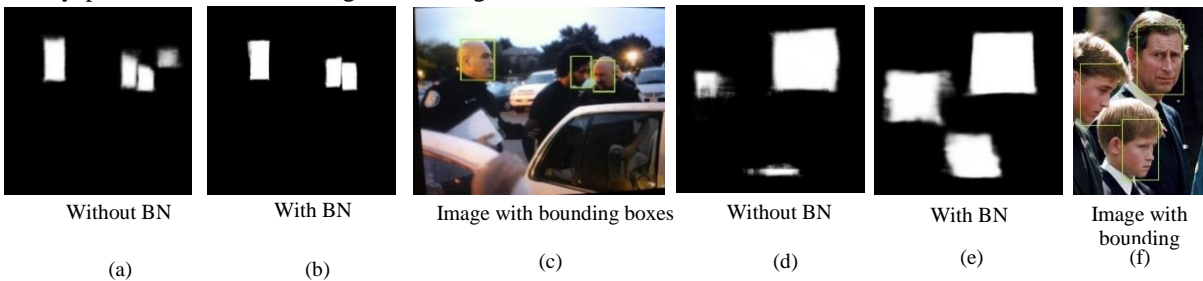


Fig. 6. Sample images projecting effect of introducing batch normalization at the end of each layer. (a), (c) without BN; (b), (e) with BN; (c), (f) Original image with face bounding box using outcome with BN.

TABLE I. TRAINING AND VALIDATION ACCURACIES OF Fddb, WIDER FACE AND OPENIMAGE DATASET

	Fddb Dataset (Accuracy in %)		Wider Face Dataset (Accuracy in %)						Open Image dataset (Accuracy in %)	
			Easy		Medium		Hard			
	Train	Val	Train	Val	Train	Val	Train	Val	Train	Val
U-net	98.22	96.83	99.68	99.35	99.44	98.88	99.00	96.75	98.52	96.72
VGG16-UNet	98.37	96.92	99.58	99.28	98.97	98.71	99.78	96.36	99.64	96.74
Semi-Dense U-Net	98.54	96.98	99.73	99.37	99.72	98.90	99.32	96.70	99.40	96.97

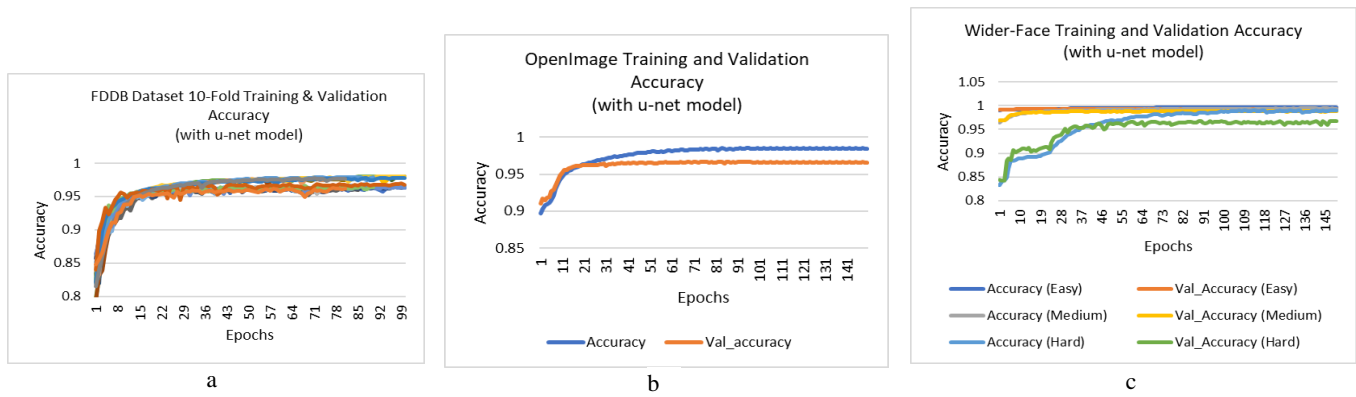


Fig. 7. Training and validation accuracy of U-Net Model on a) FDDB dataset b) OpenImage datasets c) Wider face dataset.

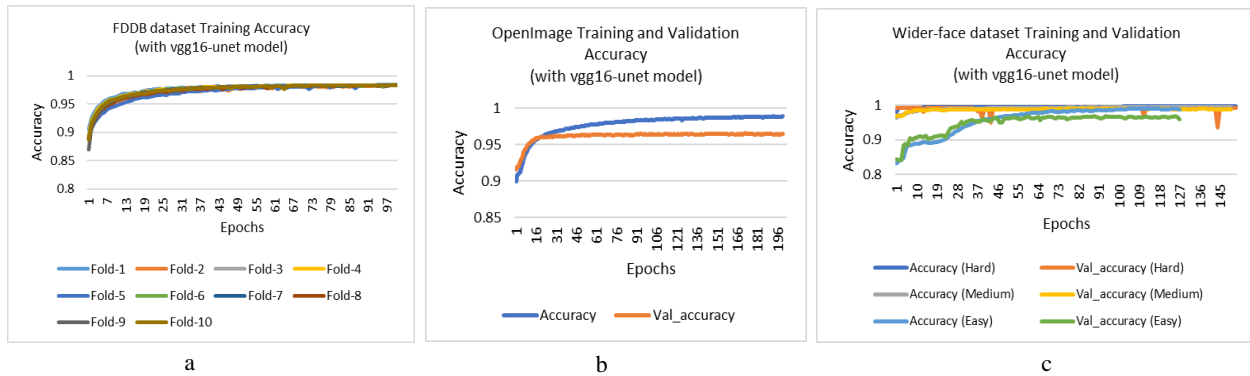


Fig. 8. Training and validation accuracy of VGG16-UNet Model on a) FDDB dataset b) OpenImage datasets c) Wider face dataset.

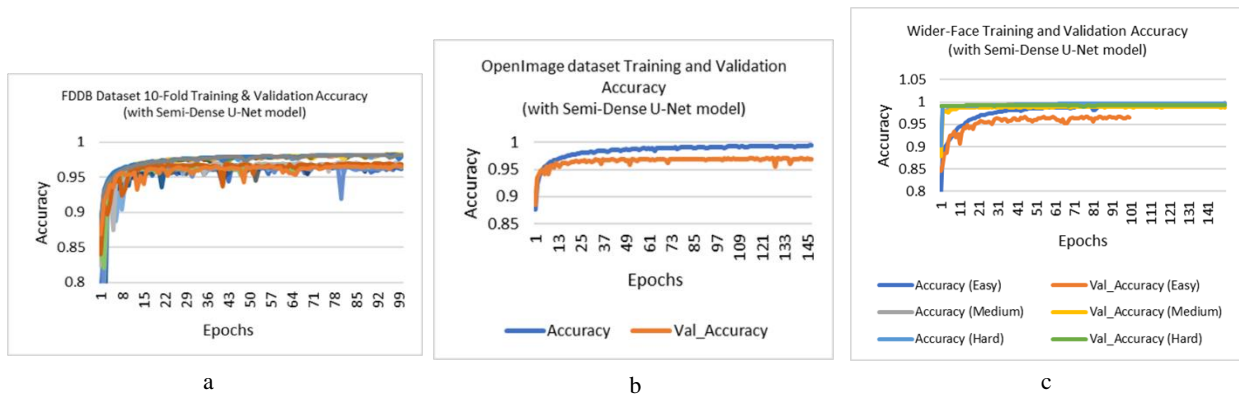


Fig. 9. Training and validation accuracy of Semi-Dense U-Net Model on a) FDDB dataset b) OpenImage datasets c) Wider face dataset.

### E. Results and Discussion

The core architecture used in this paper is based on U-Net and as discussed earlier, it is a segmentation architecture that produces image segments for regions of interest with matched features. The image segments are first extracted in post-processing module and then bounding boxes or elliptical parameters are formulated. Commonly used metrics for evaluating the performance of the segmented images are Jaccard coefficient to measures similarity between finite sample sets and is represented as  $J(A, B) = \frac{|A \cap B|}{|A \cup B|}$  indicating the ratio of intersection over union, and dice coefficient  $DC = \frac{2TP}{2TP+FP+FN}$ , a parameter to measure the test accuracy, were

TP, FP and FN represents true positive, false positive and false negative respectively and is commonly called as  $F_1$  score. Metrics precision, recall and  $F_1$  scores are computed at IoU of 0.4. Further we compare our performance with state-of-the-art face detection algorithms. Table II shows precision, recall and  $F_1$  score of the various models on the three standard datasets.

Table III tabulates the average precision of the models on FDDB and OpenImage dataset at iou's 0.4, 0.6 and 0.8. The results tabulated for FDDB are average of 10-fold cross validation. It can be observed that, at AP@40 U-Net achieves 86.5%, vgg16-unet achieves 52.8% and Semi-Dense U-Net achieves 98.97%. In contrast to the standard MTCNN that produced AP of 98.8%, Semi-Dense U-Net performed better

than MTCNN for AP@40. At higher iou, the performance of Semi-Dense U-Net is comparatively less than MTCNN but is observed to be on par with MTCNN. Comparing the performance of Semi-Dense U-Net with U-Net and vgg16-unet, U-Net and Semi-Dense U-Net performs much better than vgg16-unet. On the contrary, Semi-Dense U-Net performs much better due to better feature learning from skip and dense connections. A similar instance can be observed with OpenImage dataset where performance of Semi-Dense U-Net is on par with MTCNN and better than U-Net and VGG16-Unet. Table IV shows the average precision of the models on Wider face dataset. Comparing the results of easy, medium and hard, the proposed model performs well for easy and medium datasets but observed to perform very poorly on hard dataset. It was observed from the predictions that the model under performs for accurate prediction of tiny faces but manages to predict faces greater than 50px. A similar result can be seen in U-Net and vgg16-unet. A deeper analysis of the prediction reveals that the output of the Semi-Dense U-Net model is able to accurately predict frontal face of medium and large size and lightly blur faces but accuracy of predicting

heavily blur and occluded faces are not as expected. This has led to the degradation of the performance at various stages. Comparing the results of easy and medium, we observe model to perform better on medium than easy. The reason is due to the limited number of large faces (>300px) in the dataset compared to the medium size face samples. Hence, the model possibly had far a smaller number of images to extract diverse large size features to accurately tune the model parameters. The performance is expected to improve by training the model with a greater number of large sized face samples. Table V projects performance of state-of-the-art CNN algorithms for face detections on wider face dataset. Comparing the results of U-Net and Semi-Dense, we can infer from the results that the performance is close to each other but Semi-Dense U-Net performs better than U-Net. This is due to the better feature learning from the previous layers and better representation of the binary mask features at the model output. This enabled accurate detection of facial regions and its corresponding bounding box during post-processing at various scales making it an improvement of standard U-Net architecture.

TABLE II. PRECISION, RECALL AND F1 SCORE OF THE THREE MODELS

	FDDB dataset			OpenImage dataset			Wider face (Easy)			Wider face (Medium)			Wider face (Hard)		
	P %	R %	F <sub>1</sub>	P %	R %	F <sub>1</sub>	P %	R %	F <sub>1</sub>	P %	R %	F <sub>1</sub>	P %	R %	F <sub>1</sub>
U-Net	84.13	78.25	81.09	94.24	89.22	91.66	60.40	83.56	70.12	90.47	72.93	80.76	70.64	27.24	39.31
VGG-16 U-Net	48.67	63.88	55.25	78.78	83.08	80.88	46.60	84.38	60.04	83.86	70.30	76.48	47.91	28.65	35.86
Semi-Dense U-Net	89.94	82.52	85.60	97.92	93.72	95.68	86.67	89.04	87.84	92.25	69.64	79.37	58.10	33.57	42.55

TABLE III. TABULATION OF MODEL PERFORMANCE ON FDDB AND OPENIMAGE DATASET

Model used	FDDB			OpenImage		
	iou@0.4	iou@0.6	iou@0.8	iou@0.4	iou@0.6	iou@0.8
MTCNN	0.9884	0.9688	0.9077	0.9175	0.8845	0.8278
U-Net	0.8653	0.7697	0.3504	0.8226	0.7270	0.3077
VGG-16 U-Net	0.5285	0.3553	0.1058	0.6664	0.4932	0.1436
Semi-Dense U-Net (proposed)	0.9897	0.9578	0.8846	0.9160	0.8633	0.7173

TABLE IV. TABULATION OF MODEL PERFORMANCE ON WIDER FACE DATASET (EASY, MEDIUM AND HARD)

Model used	Easy			Medium			Hard		
	iou@0.4	iou@0.6	iou@0.8	iou@0.4	iou@0.6	iou@0.8	iou@0.4	iou@0.6	iou@0.8
U-Net	0.4477	0.3666	0.2223	0.6667	0.5855	0.1679	0.1973	0.0952	0.0009
Vgg-16 U-Net	0.3494	0.2854	0.1527	0.5802	0.4278	0.0522	0.1482	0.0639	0.0017
Semi-Dense U-Net (proposed)	0.8320	0.7920	0.5538	0.7963	0.7118	0.2972	0.2018	0.0838	0.0009

TABLE V. PERFORMANCE OF STATE-OF-THE-ART FACE DETECTION METHODS ON WIDER FACE DATASET

Method	Easy	Medium	Hard
Faceness [20]	0.713	0.664	0.424
ScaleFace [21]	0.821	0.818	0.701
MTCNN [22]	0.851	0.820	0.607
G-Mask [14]	0.902	0.854	0.662



Table VI (a) and (b) shows the model output for all three models and (c), (d), its corresponding detected faces for two samples drawn from Fddb dataset. We use elliptical annotations as used by the dataset. It can be inferred from the “Predictor Output” column that segments generated by U-Net are blur in nature and fails to detect some faces accurately leading to false negatives. On the other hand, VGG16-unet generates a sharper representation but fails to predict a face in (b) of the predictor output. Further, the rightmost segment of (b) has incomplete face regions. In the “Detection Results” column, face circled green are ground truth annotations and the one in red are detection by the model for the respective images in Predictor Output column. Comparatively, Semi-Dense U-Net is observed to have better accuracy in terms of prediction of face regions as well as sharpness of the segments. Several samples are observed to possess cloudy regions in the predicted image at several places in the U-Net and VGG16-Unet but are eliminated in the Semi-Dense U-net architecture.

In Table VI (e) to (h) and Table VII we observe similar outcomes for samples from OpenImage and Wider face dataset respectively. Semi-Dense U-net produces better segmentation results compared to the other two. By producing better and sharper segmented results, we can reduce the time of post-processing as it will eliminate the need for image enhancement to predict the bounding boxes. It can easily be computed over the predicted image. This proportionately will increase the overall detection speed. The average prediction time is observed to be approximately 30ms per image and post processing time is approximately 15ms. At this performance, we will be able to process around 22.22 images per second. By improving the prediction accuracy, the need for complex post-processing can be eliminated, thereby improving the computation time per image. While the prediction time is independent of the number of faces, postprocessing time varies based on the number of faces detected in the binary mask image.

TABLE VI. OUTPUT OF SAMPLE IMAGES FROM (A) TO (D) Fddb DATASET, (E) TO (H) OPENIMAGE DATASET. (A), (B), (E), (F) ARE MODEL OUTPUT. (C), (D), (G), (H) ARE ORIGINAL IMAGES WITH PREDICTIONS IN RED ELLIPSES/BOUNDING BOXES AND GROUND TRUTH IN GREEN ELLIPSES/BOUNDING BOXES

Model	Predictor Output		Detection Results		Predictor Output		Detection Results	
Unet								
VGG16-Unet								
Semi-Dense U-Net (proposed)								
	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>

TABLE VII. OUTPUT OF SAMPLE IMAGES FROM WIDER FACE DATASET. (A), (B) ARE MODEL OUTPUT. (C), (D) ARE ORIGINAL IMAGES WITH PREDICTIONS IN RED ELLIPSES/BOUNDING BOXES AND GROUND TRUTH IN GREEN ELLIPSES/BOUNDING BOXES

Model	Predictor Output		Detection Results	
Unet				
Vgg16-unet				
Semi-Dense unet (proposed)				
	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>

## V. CONCLUSION

Segmentation architectures are gradually increasing in numbers as does its applications. Performance of the architecture is still of concern even today. In this paper, we proposed to improve standard U-Net segmentation architecture commonly used in medical image segmentation and applied it to face segmentation and human faces detection. Our proposed architecture, Semi-Dense U-Net, produces improved results compared to standard U-Net architecture. Here, feature learning is improved by introducing skip connections and dense connections at various levels. While it produced considerably good prediction results for medium and large face, the model may not be suitable for application with tiny face detection requirements. In the future work, the architecture will be further improved to detect tiny faces and will be fine-tuned to predict occluded and heavily blur faces.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

## AUTHORS' CONTRIBUTIONS

Conceptualization, methodology, training and validation, writing original draft preparation and editing, Ganesh Pai; writing review and editing, supervision, Sharmila Kumari M.

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# End to End Text to Speech Synthesis for Malay Language using Tacotron and Tacotron 2

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**Abstract**—Text-to-speech (TTS) technology is becoming increasingly popular in various fields such as education and business. However, the advancement of TTS technology for Malay language is slower compared to other language especially English language. The rise of artificial intelligence (AI) technology has sparked TTS technology into a new dimension. An end-to-end (E2E) TTS system that generates speech directly from text input is one of the latest AI technologies for TTS and implementing this E2E method into Malay language will help to expand the TTS technology for Malay language. This study involves the development and comparison of two end-to-end TTS models for the Malay language, namely Tacotron and Tacotron 2. Both models were trained using a Malay corpus consisting of text and speech and evaluated the synthesized speech using Mean Opinion Scores (MOS) for naturalness and intelligibility. The results show that Tacotron outperformed Tacotron 2 in terms of naturalness and intelligibility, with both models falling short of human speech quality. Improving TTS technology for Malay can encourage its use in a wider range of contexts.

**Keywords**—Text to speech; end-to-end TTS; Tacotron; Tacotron 2; Malay language; artificial intelligence; mean opinion score (MOS); naturalness; intelligibility

## I. INTRODUCTION

Text-to-speech (TTS) or speech synthesis technology has been under development for decades, with the goal of making a system that can turn text input into natural, expressive, and understandable human speech. Early TTS systems were built using rule-based methods, where the algorithms responsible for transforming text into speech were based on a set of linguistic rules and heuristics. As TTS research moved forward, concatenative synthesis [1][2][3] became a popular method. In this method, small pieces of speech segments were put together to make a complete sequence of speeches. Even concatenative synthesis methods worked better but requires a complex pipeline and requiring significant resources and manpower. Additionally, the synthesized audios often suffer from glitches or instability in prosody and pronunciation, leading to an unnatural sound compared to human speech. [4].

Study by [3] stated that, another traditional and yet proven way to use TTS technology is to use the Statistical Parametric Synthesis (SPSS) model to generate speech. SPSS uses less data than the concatenative model, but the sound is not natural. An example of a SPSS model is the Hidden Markov Model (HMM). With huge developments in artificial intelligence, the Deep Neural Network (DNN) method has been introduced in TTS. DNN is an improved method compared to SPSS but requires huge datasets [5]. DNN is a neural network with

multiple hidden layers; learns by mapping text and speech and then predicting the spectral parameters that define the speech signal, such as frequency and spectrum, and then generating speech from the text input.

The end-to-end TTS systems were eventually developed as researchers started to use artificial neural networks to model the complexities of human speech. By learning to generate speech directly from text inputs, these systems did away with the need for explicit rule-based systems and separate processing stages. A groundbreaking advancement in the field of end-to-end TTS came with the introduction of the Tacotron model, which was introduced in 2017 by [6].

Tacotron [6] and Tacotron 2 [7] are two Deep Neural Networks that use an end-to-end pipeline. Both use a sequence-to-sequence model, which eliminates the need for a complex feature extraction or alignment process in TTS compared with traditional TTS. Generally, both models employ an encoder-decoder architecture in which the encoder network processes the text input and generates a compact representation, while the decoder network generates the speech signal from the encoded representation. Both models can generate high-quality speech with natural prosody and intonation with a simple signal processing.

This paper focuses on implementation of end-to-end TTS for Malay language. The Malay language, a member of the Austronesian family, is one of the many languages spoken globally. [8]. The Malay language is widely use in Southeast Asia, particularly in Malaysia, Indonesia, Singapore, Brunei, and some other countries in the region. Approximately, 250 million individuals are estimated to be speakers of this language [9]. The basic writing system in Malay is based on the Rumi script and uses the Latin alphabet. Malay language consists of 26 Latin letters [5] and 25 phonemes [9]. The Malay language has a long history and has evolved over time because of its exposure to various languages and cultures. Today, Malay language plays an important role, especially in Malaysia, and it is used in a variety of contexts, such as education, government, media, and everyday communication. As a result, progress in TTS research using Malay language plays an important role in preserving Malay as a lingua franca language in Southeast Asia.

Numerous studies focusing on Tacotron and Tacotron 2 models for TTS applications have been carried out, predominantly targeting languages like English [6][7], Chinese [10], Spanish, Korean, Japanese, Mongolian [11], and Myanmar [12][13]. Yet, the exploration of these two models

for Malay language TTS applications remains relatively limited. Previous TTS research for the Malay language has not employed an end-to-end methodology.

This study pioneers the implementation of Tacotron and Tacotron 2 in an end-to-end TTS model for the Malay language, aiming to compare their performance in naturalness and intelligibility, extending beyond traditional confines to harness their potent capabilities for the unique linguistic intricacies of Malay.

This paper consists of six Sections where Section I is the introduction of this paper, Section II will discuss the background of studies, Section III will venture any related works done before, Section IV explained the proposed methodology. Evaluation and discussion is presented in Section V. In Section VI

fig , it was concluded that the Tacotron model surpassed the Tacotron 2 model in performance, though both models were still unable to match the quality of human voice.

## II. BACKGROUND

End-to-end TTS models have taken the place of outdated statistical parametric speech synthesis (SPSS) systems based on hidden Markov models (HMMs) and deep neural networks (DNN) because of advancements in deep learning techniques [14]. Previous TTS techniques involved complex pipelines and language specific linguistic features, which were resource-intensive and often resulted in unnatural sounding audio. However, the end-to-end generative TTS models like Tacotron and Tacotron 2, simplified the speech synthesis process by utilizing a single neural network for future generation [4]. This section explains how Tacotron and Tacotron 2 were built.

Both Tacotron and Tacotron 2 models start with text processing, which involves text normalization, tokenization, and character embedding. These processes prepare the input text for speech synthesis by standardizing its format, breaking it down into smaller units, and transforming it into vector representations that capture semantic and syntactic data that helps both models generate more accurate and natural-sounding speech.

### A. Tacotron

Tacotron is a text-to-speech (TTS) model that generates speech in an end-to-end manner using a sequence-to-sequence (seq2seq) framework with attention [6] which includes an encoder-decoder that uses a convolutional neural network (CNN) and a recurrent neural network (RNN) to produce linear spectrograms [11]. To convert the linear spectrograms into speech waveforms, Tacotron adopts the Griffin-Lim algorithm [15] for phase estimation, followed by an inverse short-time Fourier transform. This end-to-end TTS model is designed to generate high-quality speech directly from text. Tacotron eliminates the need for phoneme-level alignment, enabling it to efficiently scale with large volumes of acoustic data and accompanying transcripts. With the capacity to be trained entirely from scratch using random initialization, Tacotron represents a significant advancement in the TTS domain. Tacotron has the capability to be trained entirely from scratch, given a set of paired text and audio. The Tacotron's block

diagram, shown in Fig. 1, consists of a pre-processing unit, encoder, decoder, and vocoder.

The text is first processed and embedded, and then transformed using a pre-net to reduce overfitting and improve training stability. The encoded characters are then fed into a series of encoder blocks, where a CBHG (Convolutional Banks, Highway Networks, and Gated Recurrent Units) module which contains 1-D convolutional banks, max pooling, a 4-layer highway and a bidirectional GRU is used to convert the pre-net outputs into the final encoder representation. Meanwhile, the attention mechanism computes the context vector using the outputs of the text encoder and the previous decoder state, enabling the model to focus on different parts of the input sequence at each decoding step. In the decoder block, a pre-net, attention RNN, decoder RNN, and CBHG module are used to focus on relevant parts of the input text and align speech signal frames.

Finally, the generated Mel-scale spectrograms from the RNN decoder's previous outputs are input into a CBHG module to correct prediction errors for each frame. From here, linear spectrograms can be predicted. The vocoder block uses Griffin Lim to convert the linear spectrograms into speech waveforms as the output.

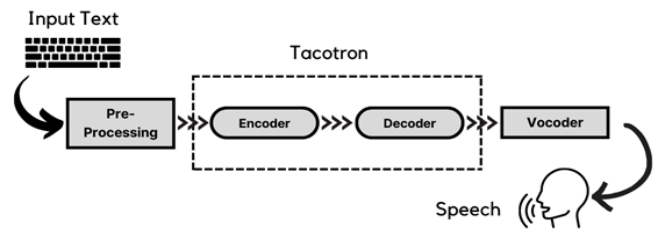


Fig. 1. Tacotron block diagram.

### B. Tacotron 2

Tacotron 2 is a deep neural network that generates speech directly from text, similar to its predecessor Tacotron. Fig. 2 summarizes the Tacotron 2 block diagram. The network utilizes a recurrent sequence-to-sequence model that maps character embeddings to mel-scale spectrograms, which represent the frequency content of audio signals. The encoder processes the character embeddings using convolutional layers to generate encoded features, followed by a bidirectional LSTM. The decoder, which is an autoregressive recurrent neural network, uses a location-sensitive attention network to predict a Mel spectrogram from the encoded input sequence. The decoder also includes pre-net and attention context vectors, which are passed through a stack of unidirectional LSTM layers to predict the target spectrogram frame. The predicted Mel spectrograms are then passed through a post-processing network consisting of CNN layers and a linear projection layer to generate the final Mel spectrograms. Finally, the Mel spectrograms are converted into sound waveforms using either Griffin Lim [13] or Wavenet [7]. Other than Griffin Lim, wavenet is also one of the vocoders that are used to convert mel-spectrograms to speech sounds [16]. Wavenet can learn how to match acoustic properties to speech waveforms on a sample-by-sample basis. In conclusion, the Tacotron 2 model is capable of generating speech with high

naturalness and intelligibility and has the potential to be used in various speech synthesis applications [7][13].

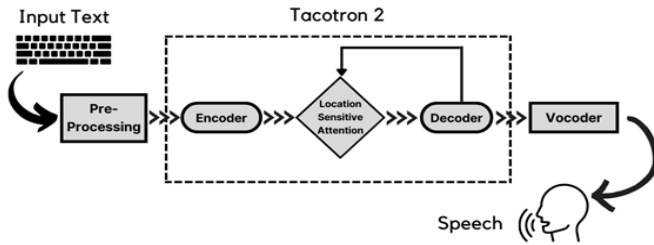


Fig. 2. Tacotron 2 block diagram.

### III. RELATED WORK

This section will discuss the development of TTS for the Malay language and previous work done on other languages using Tacotron and Tacotron 2.

#### A. Development of TTS for Malay Language

Even though TTS technology is rapidly evolving, especially in the English language, Malay language TTS technology however still has untapped potential. Several studies have been done on TTS for the Malay language, including studies that suggest a text to speech system based on Hidden Markov Models (HMM) and context-dependent labels to produce high-quality synthetic speech in Malay language [17]. The use of context-dependent labels is a common technique in TTS that allows for more natural-sounding speech by taking the surrounding linguistic context into account. This study developed a grapheme-to-phoneme database and identified the contextual factors of Malay language to generate the labels. This sequence of labels is then fed into the HMM-based acoustic model, which generates the corresponding speech waveform. The score of intelligibility and naturalness of the synthetic utterances were evaluated to gauge the module's effectiveness.

Another research for Malay language TTS involves using a bilingual voice synthesis system for Standard Malay and Indonesian using a hybrid method of Hidden Markov Model and Deep Neural Network (HMM-DNN) [5]. This study combines the corpus of these two similar languages Malay and Indonesian and introduces speaker codes to examine the bilingual speech synthesis system, comparing it with the monolingual speech synthesis system. The method involves training a hybrid system on a large corpus of speech data using HMMs to model the spectral and duration information, and DNNs to model the acoustic mapping function. The effectiveness of the TTS synthesis was assessed using the MOS score for naturalness of synthesis sound.

Both studies demonstrate that improvements are being made to the TTS system for the Malay language. However, utilizing the most recent TTS technology will help to advance TTS generally in the Malay language. Thus, the introduction of an end-to-end TTS method for the Malay language will enable the development of Malay TTS technology more quickly.

#### B. Tacotron

One of the famous studies for Tacotron is from [6]. This research focuses on the English language as the input data. The

model started with the data collection. The researcher collects a dataset of speech and text pairs using an internal North American English dataset that contains 24.6 hours of speech data. The text data is then processed by normalizing each character. The normalized text and speech data will go to a Tacotron model that contains an encoder and decoder, and the output will be a linear spectrogram. Finally, the linear spectrogram will be synthesized using the Griffin Lim synthesizer to create a speech sound from the designated input text. The quality of the outcome is evaluated based on a MOS score test, in which eight raters evaluate approximately 100 unseen phrases. This study compared the Tacotron MOS to the concatenative and parametric approaches and discovered that the Tacotron method is superior to the parametric method.

Research on Tacotron models is also available in Myanmar. The official language of Myanmar is Burmese, a Sino-Tibetan language that is written and spoken in Myanmar [12]. Like the research from [6], it starts with data collection. For this project, nearly 5000 pairs of text and audio from male speakers and 3000 pairs from female speakers were used. After that, the text is normalized. The Tacotron model will then be used with both normalized text and sound. The linear spectrogram created from the Tacotron model will then be synthesized using the Griffin Lim synthesizer to create an audio sound in Myanmar. The results are compared using the MOS method by comparing the MOS on naturalness and intelligibility of the Tacotron model with the original audio from the recorded speech. Around 20 speech outputs were used for this evaluation, with 5 people as evaluators.

#### C. Tacotron 2

One of the studies on Tacotron 2 done by [7] focuses on the English language. Data from a single female speaker's 24.6 hours of speech were used to begin this study's data gathering. The text will then be processed by normalizing each text and going for character embedding. The pair of processed text and sound is then inserted into the Tacotron 2 model, which consists of an encoder and decoder to create a Mel spectrogram. The Mel spectrogram is then synthesized using a wavenet synthesizer to create an audio sound from the input text. Similar to Tacotron [6] the subjective evaluation is based on the MOS score from eight raters with 100 unseen phrases. By contrasting the MOS with several TTS techniques, including parametric, Tacotron with Griffin Lim, concatenative, Wavenet, and ground truth audio, which is an authentic human voice, the synthesis audio from the naturalness of the Tacotron 2 model was evaluated. For intelligibility evaluation, this paper runs a MOS evaluation by generating 37 news headlines and comparing the MOS score on the Tacotron 2 model with the Wavenet model. In addition to the subjective assessment, the authors also conducted an ablation investigation to examine the effects of various model components on the performance of the entire system. These investigations aid in their comprehension of the significance of various model components, such as the attention process and WaveNet's conditioning on Mel spectrogram predictions.

The research report by [13] also addresses Tacotron 2. The paper focuses on the Myanmar language as a test subject. From a variety of sources, the researchers created a corpus of Myanmar speech which contains over 5000 pairings of

Myanmar's text and speech, with each audio pair's length ranging from 2 to 12 seconds. They then used a syllable segmenter and text normalizer to separate the Myanmar text into characters. Next, the researcher used a recurrent seq2seq network to map character embeddings to Mel-scale spectrograms. Finally, they used the Griffin-Lim algorithm to produce Myanmar speech output from the input text. The MOS score was used to assess the synthesis's quality. This study examined Tacotron and Tacotron 2 MOS scores for naturalness and intelligibility in the Myanmar language.

#### IV. PROPOSED METHOD

The journey of end-to-end TTS started with the speech corpus creation. For both models, audio and text from a single Malay speaking male speaker are paired together to make a dataset. The dataset was downloaded through the Speech Malaya website [18]. The datasets consist of text corpus files and wav files for audio. Both text and audio files are paired and numbered accordingly. The text corpus contains over 6445 lines of Malay sentences that were taken from the audio context, and the text corpus was saved in CSV format. The text corpus is a complete sentence ending with a full stop. For the audio file, it was a wav file recorded at a sampling rate of 24 kHz with a total duration of 14.29 hours. The audio data were cut into small sizes with minimum and maximum durations of 1.752 seconds and 21.24 seconds respectively, to make a total of 6445 pairs of text and audio datasets in Malay language.

The text will be fed into the pre-processing channel for text normalization, tokenization, and character embedding. In this paper, the setting for text normalization for Malay words is under the "malay\_cleaners" configuration inside the hyperparameter. Table I is an example of text normalization in which an input text is normalized by converting numbers to text, lowercasing the input text, and removing any punctuation marks.

TABLE I. EXAMPLE OF MALAY TEXT NORMALIZATION

No	INPUT TEXT	NORMALIZED TEXT
1	Daripada jumlah tersebut seramai 2,359 iaitu 44.6 % orang ibu tunggal	daripada jumlah tersebut seramai dua ribu tiga ratus lima puluh sembilan iaitu empat puluh empat persepuluh enam peratus orang ibu tunggal
2	Pada tahun 2010 jumlah pinjaman perumahan yang diluluskan oleh sistem perbankan adalah sebanyak	pada tahun dua ribu satu puluh jumlah pinjaman perumahan yang diluluskan oleh sistem perbankan adalah sebanyak
3	SOALAN 33 Dr Mansor Bin Abd Rahman minta MENTERI PERDAGANGAN ANTARABANGSA DAN INDUSTRI	soalan tiga puluh tiga doktor mansor bin abd rahman minta menteri perdagangan antarabangsa dan industri

From Table I, in the input text number 1 in Malay, "Daripada jumlah tersebut seramai 2,359 iaitu 44.6 % orang ibu tunggal" which means "Out of that number 2,359 44.6% are single mothers" in English, is being normalized into "daripada jumlah tersebut seramai dua ribu tiga ratus lima puluh sembilan iaitu empat puluh empat persepuluh enam peratus orang ibu tunggal" in Malay, which translate to "out of

that number two thousand three hundred and fifty nine forty four point six percent are single mothers" in English.

In Malay input text number 2, "Pada tahun 2010 jumlah pinjaman perumahan yang diluluskan oleh sistem perbankan adalah sebanyak" which translate to, "In 2010 the number of housing loans approved by the banking system was" in English. It is then normalized into "pada tahun dua ribu satu puluh jumlah pinjaman perumahan yang diluluskan oleh sistem perbankan adalah sebanyak" in Malay which is translated into English "In two thousand and ten the number of housing loans approved by the banking system was".

From input text number 3 Malay, "SOALAN 33 Dr Mansor Bin Abd Rahman minta MENTERI PERDAGANGAN ANTARABANGSA DAN INDUSTRI" which translated into English "QUESTION 33 Dr Mansor Bin Abd Rahman asked the MINISTER OF INTERNATIONAL TRADE AND INDUSTRY" was normalized into "soalan tiga puluh tiga doktor mansor bin abd rahman minta menteri perdagangan antarabangsa dan industri" in Malay and the English translation is "question thirty three doctor mansor bin abd rahman asked the minister of international trade and industry". All the input text from Table I is being normalized by converting numbers to text, lowercasing the input text, and removing any punctuation marks.

##### A. Tacotron

After the text is normalized and tokenized, 256-dimensional character embeddings are applied to Malay texts. Subsequently, the embedded text is fed into an encoder pre-net. The encoder CBHG module processes the encoder pre-net output to produce the final encoder representation that the attention module will utilize. As previously mentioned, the decoder comprises the decoder pre-net, attention RNN, decoder RNN, and CBHG (post-net CBHG). Finally, the CBHG synthesizes the linear spectrogram, and the Griffin Lim synthesizer with a power of 1.5 is used to convert it into a sound wave. Table II presents all the parameters.

##### B. Tacotron 2

In comparison to the Tacotron model, the Tacotron 2 model uses character embeddings of size 512, which are fed into a stack of three convolutional layers. The final convolutional layer's output is used as input for a single bidirectional LSTM layer to generate the encoded features for the model. The Tacotron 2 model utilizes the location-sensitive attention network, which computes location features using 32 1-D convolution filters of length 31. The decoder block includes a pre-net consisting of two fully connected layers with 256 hidden ReLU units that is followed by a stack of two unidirectional LSTM layers, each with 1024 units, and a linear projection to predict the target spectrogram frame. To enhance overall reconstruction of the output, the predicted mel spectrogram is passed through a 5-layer convolutional post-net, which predicts a residual. During inference, the model uses stop token prediction, where the concatenation of the decoder LSTM output and the attention context is projected to a scalar and passed through a sigmoid activation to predict the probability that the output sequence has completed. To synthesize the waveforms, the Griffin Lim synthesizer is used to generate sound waveforms. Unlike the Tacotron model, the

Tacotron 2 model does not employ CBHG stacks and GRU recurrent layers. All parameters can be found in Table III.

TABLE II. MALAY TACOTRON HYPER-PARAMETER

HYPER-PARAMETER NAME	HYPER-PARAMETER VALUE
Audio Parameter	number_mels=80; number_freq=1025, sample_rate=20000, frame_length_ms=50, frame_shift_ms=12.5, emphasis=0.97
Character Embedding	256-D
Encoder Parameter	Encoder Pre-net : FC-256-ReLU → Dropout(0.5) →FC-128-ReLU → Dropout(0.5) Encoder CBHG : Conv1D bank: K=16; conv-k-128-ReLU; Max pooling: stride=1, width=2; Conv1D projections=conv-3-128-ReLU→ conv-3-128-Linear; Highway net=4 layers of FC-128-ReLU; Bidirectional GRU=128 cells
Attention RNN	1-layer GRU (256 cells)
Decoder Parameter	Decoder Pre-net : FC-256-ReLU → Dropout(0.5)→FC-128-ReLU → Dropout(0.5) Decoder RNN : 2-layer residual GRU (256 cells)
Post-net CBHG	Conv1D bank: K=8, conv-k-128-ReLU; Max pooling: stride=1, width=2; Conv1D projections: conv-3-256-ReLU →conv-3-80-Linear; Highway net: 4 layers of FC-128-ReLU; Bidirectional GRU: 128 cells

TABLE III. MALAY TACOTRON 2 HYPER-PARAMETER

HYPER-PARAMETER NAME	HYPER-PARAMETER VALUE
Audio Parameter	sampling_rate=24000; n_mel_channels=80; ffilter_length=1024; hop_length=200; windows_length=800
Character Embedding	512-D
Encoder parameter	encoder_embedding_dim=512; encoder_kernel_size=5; encoder_n_convolutions=3
Attention Parameter	attention_dim=128; attention_rnn_dim=1024
Location Layer Parameter	attention_location_n_filters=32; attention_location_kernel_size=31
Decoder parameter	n_frames_per_step=1; decoder_rnn_dim=1024; prenet_dim=256; max_decoder_steps=1000; gate_threshold=0.5; p_attention_dropout=0.1; p_decoder_dropout=0.1

### C. Training

Training of the data is conducted based on the two models, utilizing the Malay text corpus. Both models use the same data, as explained in previous sections. There are some differences in the training parameters of both models. Table IV summarizes the training parameter summaries. Tacotron 2 requires a smaller batch size than Tacotron because it employs a more complicated representation. A large batch size will cause the processing time to take longer and sometimes cause

the program to crash. From Table IV also, Tacotron 2 requires a lengthy run time with nearly the same total steps. Steps for checkpoint intervals are steps where a predicted spectrogram is generated as an output after certain steps. Fig. 3 and Fig. 4 display the alignment plot results for both models at specific checkpoint intervals.

TABLE IV. TRAINING PARAMETER DIFFERENCES

TRAINING PARAMETER	TACOTRON	TACOTRON 2
Batch Size	32	28
Total Step Run (Steps)	95850	80000
Total Hours Run (Hours)	59.42	136.33
Steps for checkpoints intervals (Steps)	150	2000

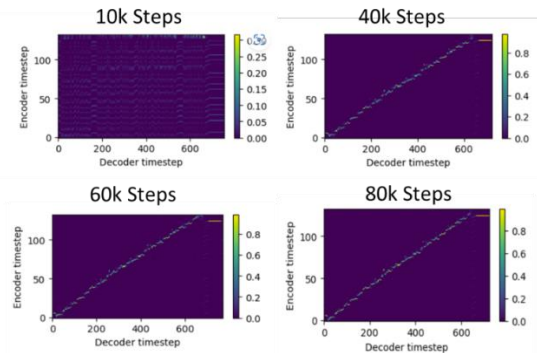


Fig. 3. Alignment for certain steps for Tacotron.

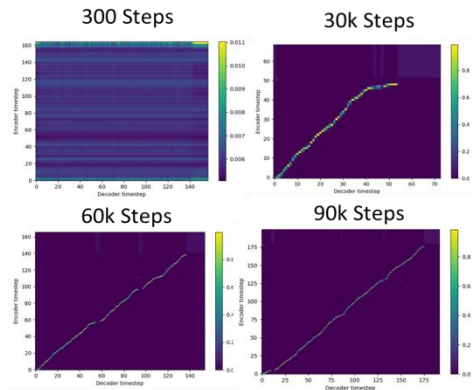


Fig. 4. Alignment for certain steps for Tacotron 2.

An alignment graph shows the visual representation of the learned attention mechanism between the input text and the output and also shows how the model aligns each input character with the corresponding output acoustic features. The graph should have a clear diagonal pattern to indicate that the model is aligning input characters with output features correctly. If it doesn't, it may be having difficulty or not being trained properly. The fig. 3 and 4 also demonstrate that the diagonal pattern on the graph does not appear until after a certain number of training steps.



## V. EVALUATION AND DISCUSSION

### A. Measurement Evaluation

To evaluate the effectiveness of the proposed method, a selection of approximately 20 Malay sentences were randomly sampled from an online news portal, as well as several sentences from Malaysian Hansard parliament speeches. These Malay sentences will then be synthesized using the Tacotron and Tacotron 2 models to get the audio speech. By using these 20 Malay sentences, an original human sound was recorded. For both synthesized models, this human voice serves as another point of comparison. The input word is taken from outside of the training data, which is why the original human voice is being used. Around 5 native speakers will then evaluate the naturalness and intelligibility of human sound, synthesized speech from Tacotron, and synthesized speech from Tacotron 2.

This experiment was based on subjective evaluations. According to [19], a MOS served as a gauge of the effectiveness for TTS, following guidance from the International Telecommunication Union (ITU-T P.85, 1994). To evaluate overall sound quality, a 5-point scale was used, with 5 being the highest quality and 1 being the lowest. Around 5 native speakers will then evaluate the naturalness and intelligibility of human sound, the synthesized speech from Tacotron, and the synthesized speech from Tacotron 2 follow the 5-point scale. To calculate the overall individual performance, the mean calculation is used to get the final answer. A simple mean calculation is shown in equation 1, where R is individual rating and N is the total number of speech output.

$$\text{Mean MOS} = \frac{\sum_{n=1}^N (R_n)}{N} \quad (1)$$

The evaluation for this experiment is based on naturalness and intelligibility. Naturalness and intelligibility are important qualities expected from a TTS system. Naturalness is how the model produces a speech that is human alike in terms of casual, emotional, and spontaneous styles of speaking. Currently, speech recordings used in TTS training typically follow formal reading styles, as pauses, repeats, changes in speed, varying emotions, and errors are not permitted [3]. However, in casual or conversational talk, humans seldom speak in a standard reading style. Intelligibility is how the model can produce speech that can be understood by everyone. Noise is one of the factors that affects the intelligibility of the model [20]. In a real-life situation, a listener is often unable to understand what another person is saying if the environment is noisy. This can lead to some information not being conveyed.

### B. Result

A subjective evaluation test was conducted to compare the method including with an original human voice in Malay speech synthesis. Fig. 5 and Fig. 6 show the results of naturalness and intelligibility for the human voice, Tacotron, and Tacotron 2.

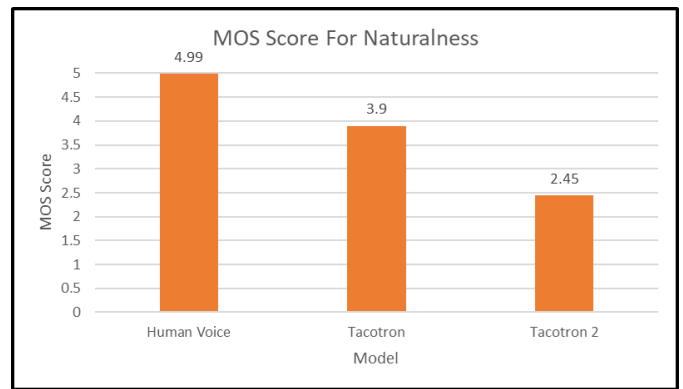


Fig. 5. Comparison of MOS score for naturalness.

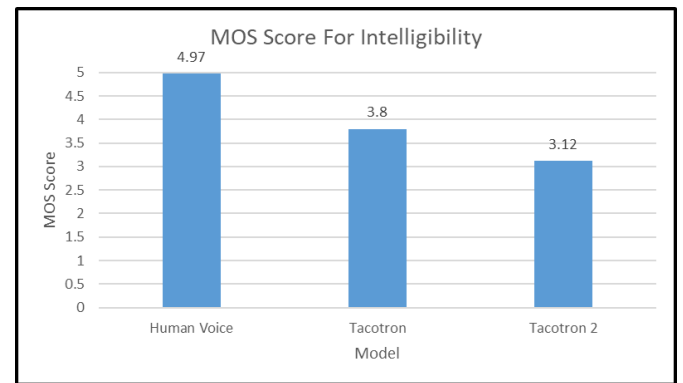


Fig. 6. Comparison of MOS score for intelligibility.

The result shows that in terms of naturalness, the Tacotron 2 model is lower compared to the Tacotron, but for intelligibility, the Tacotron 2 model has a slight improvement, though it is still considered lower compared to the Tacotron.

### C. Result and Discussion

From the result however shows that the outcome of this trial contradicts other experiments conducted in [7] for English and [13] for Myanmar language, which suggest that Tacotron 2 performance exceeded the Tacotron. But in this experiment, shows that Tacotron outperformed the Tacotron 2 model. Fig. 7, shows the comparison on the alignment graph between Tacotron and Tacotron 2. The alignment graph shows that Tacotron model diagonal pattern is marginally clearer and have a very straight diagonal pattern compared to Tacotron 2 model, and Tacotron 2 model also generate a longer decoder timesteps. From the previous explanation, a clear diagonal graph indicates that the model is aligning input characters with output features correctly.

This might be for a few reasons, one of which is that the model might not have learned the correct alignment between input text and output speech yet. Most likely, the model needs more training epochs or the hyperparameters need to be changed. Another reason might be issues with the attention mechanism. The model might be struggling to learn the appropriate alignment between the input and output sequences. Overall, the attention mechanism parameter needs to be adjusted to improve the quality of the Tacotron 2 model.



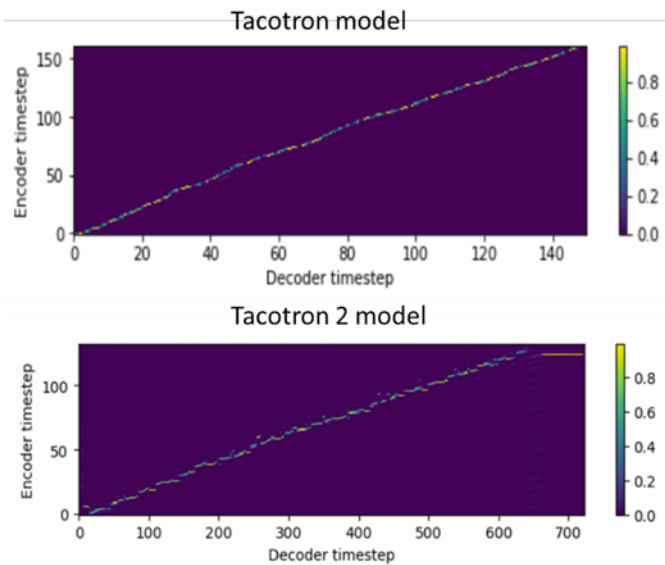


Fig. 7. Comparison alignment graph between Tacotron and Tacotron 2.

## VI. CONCLUSION

The purpose of this study is to provide an end-to-end TTS technique for the Malay language, hence contributing to the development of Malay language technology. In conclusion, this study shows that Tacotron and Tacotron 2 can both translate Malay text into speech, but the Tacotron model performs better when compared to Tacotron 2. In the future, to improve the Tacotron 2 model, some hyperparameters will need to be adjusted, especially in the attention and decoder parameter. Additionally, there could be a contemplation of the use of WaveNet as a vocoder in Tacotron 2. Given its flexibility, the WaveNet vocoder allows high user adaptability in manipulating synthesized speech to suit various scenarios, thereby enhancing overall performance. To further explore end-to-end TTS methods for the Malay language, other end to end models such as FastSpeech, Transformer TTS, and Parallel WaveGAN can be considered. This approach could provide increased flexibility in the application of end-to-end techniques for Malay language.

## ACKNOWLEDGMENT

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# A New Model for Blood Cancer Classification Based on Deep Learning Techniques

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**Abstract**—Artificial intelligence and deep learning algorithms have become essential fields in medical science. These algorithms help doctors detect diseases early, reduce the incidence of errors, and decrease the time required for disease diagnosis, thereby saving human lives. Deep learning models are widely used in Computer-Aided Diagnosis Systems (CAD) for the classification of various diseases, including blood cancer. Early diagnosis of blood cancer is crucial for effective treatment and saving patients' lives. Therefore, this study developed two distinct models to classify eight types of blood cancer. These types include follicular lymphoma (FL), mantle cell lymphoma (MCL), chronic lymphocytic leukemia (CLL), acute myeloid leukemia (AML), and the subtypes of acute lymphoblastic leukemia (ALL) known as early pre-B, pre-B, pro-B ALL, and benign. AML and ALL are specific classifications for human leukemia cancer, while FL, MCL, and CLL are specific classifications for lymphoma. Both models consist of different phases, including data collection, preprocessing, feature extraction techniques, and the classification process. The techniques applied in these phases are the same in both proposed models, except for the classification phase. The first model utilizes the VGG16 architecture, while the second model utilizes DenseNet-121. The results indicated that DenseNet-121 achieved a lower accuracy compared to VGG16. VGG16 exhibited excellent results, achieving an accuracy of 98.2% when classifying the eight classes. This outcome suggests that VGG16 is the most effective classifier for the utilized dataset.

**Keywords**—Deep learning; convolutional neural networks (CNNs); leukemia; lymphoma; computer-aided diagnosis systems (CAD)

## I. INTRODUCTION

According to a report by the World Health Organization (WHO), approximately 1 in 6 deaths worldwide is caused by cancer, making it the second leading cause of death globally. Among the various types of cancer, blood cancer holds significant prominence. It accounts for approximately 9% of all cancers and is now ranked as the fourth most common cancer in both men and women worldwide [1, 2]. As a result, researchers have shifted their focus towards applying artificial intelligence techniques to develop models that can assist in addressing this issue in the medical field. In the following section, we will provide a detailed description of the most prevalent types of blood cancer.

### A. Leukemia

Leukemia is a type of cancer that affects the blood cells and can occur in individuals of all ages, including children and adults [3]. It is characterized by an abnormal proliferation of immature blood cells in the bone marrow, which leads to the

replacement of healthy blood cells. In leukemia, a genetic mutation takes place in an immature blood cell, causing it to transform into a cancerous cell. These malignant cells do not function properly and multiply at a faster rate compared to normal cells, while having a shorter lifespan. Consequently, the presence of cancerous cells in the bone marrow displaces the healthy blood cells [4].

Leukemia can be categorized into two main types based on the rate of malignant cell growth. If the malignant cells grow rapidly, it is classified as acute leukemia, whereas if they grow slowly, it is classified as chronic leukemia [1]. As a result, there are four primary types of leukemia: Acute Myeloid Leukemia (AML), Acute Lymphoblastic Leukemia (ALL), Chronic Myeloid Leukemia (CML), and Chronic Lymphocytic Leukemia (CLL) [5].

- **Acute Myeloid Leukemia:** It is the most common type of acute leukemia. It occurs when the bone marrow produces abnormal blasts and immature white blood cells (WBCs). In some cases, it may also lead to the production of abnormal red blood cells (RBCs) and platelets. The symptoms of early-stage AML may resemble those of a common cold or other illnesses [6].
- **Acute Lymphoblastic Leukemia:** It is a type of cancer that primarily affects white blood cells and is commonly found in children. It is characterized by the uncontrolled growth and excessive production of immature white blood cells in the bone marrow. The symptoms of ALL, which include fatigue, weakness, and joint and bone pain, can resemble those of the flu and other common illnesses, making the diagnosis challenging. ALL is further classified into three subtypes: Early Pre-B, Pre-B, and Pro-B ALL [7, 8].
- **Chronic Myeloid Leukemia (CML):** It is a type of cancer that primarily affects white blood cells. In individuals with CML, there is uncontrolled growth of immature white blood cells, known as blast cells, in the body [4].
- **Chronic Lymphocytic Leukemia:** it is a haematological disease that affects B lymphocytes or B cells. It is more prevalent in adults and rare in children. CLL symptoms include weight loss, fever, sleep sweats, and frequent infection [6].

### B. Lymphoma

Lymphoma is a type of blood cancer that occurs due to the abnormal development of white blood cells called lymphocytes. Lymphocytes are specialized cells that circulate throughout the body via the blood and lymphatic systems, playing a crucial role in the immune response to prevent infections [9]. Lymphoma is characterized by the clonal proliferation of malignant lymphocytes, which can be either T cells or B cells. The diagnosis of different types of lymphoma is typically based on the growth pattern and cytological features of the abnormal cells observed under light microscopy using Hematoxylin and Eosin-stained tissue samples. Lymphoma is classified into three main subtypes: follicular lymphoma (FL), mantle cell lymphoma, and Chronic Lymphocytic Leukemia (CLL) [10].

As mentioned in the previous section, the most prevalent types of blood cancer include FL, MCL, CLL, AML, and ALL, which encompass Early Pre-B, Pre-B, Pro-B ALL, and benign subtypes. The objective of this study is to develop a classification model for accurately categorizing images into these different disease categories.

Blood cancer can be detected through manual counting using a hematological analyzer, which involves the classification of cells based on their morphological characteristics. However, this method is often time-consuming, labor-intensive, and expensive. Moreover, manual analysis

may yield inaccurate results in terms of leukocyte counts and classification. In order to address these challenges [9, 11], researchers have developed Computer-Aided Diagnosis (CAD) systems that utilize deep learning techniques to assist physicians in accurately identifying leukemia.

Deep learning algorithms have gained significant popularity in Computer-Aided Diagnosis (CAD) systems. Among these algorithms, the convolutional neural network (CNN) is one of the most widely used approaches. CNN consists of three main layers: the Convolutional Layer, the Pooling Layer, and the Fully Connected Layer. Illustrated in Fig. 1, a CNN can learn hierarchical representations of data by extracting more general features in the initial convolutional layers and progressively capturing more specific features in the subsequent layers. The effectiveness of CNNs in medical diagnosis has been well-established [4, 12].

This study makes several contributions to the field of blood cancer diagnosis. Firstly, an image augmentation technique is applied as a preprocessing step to enhance the quality of blood cancer images. Secondly, a classification method using two different CNN architectures is employed to distinguish between eight different classes of blood cancer that have not been used before. The performance of the model is also thoroughly analyzed and compared with existing state-of-the-art methods. Finally, mixed datasets are utilized to improve the accuracy of blood cancer classification.

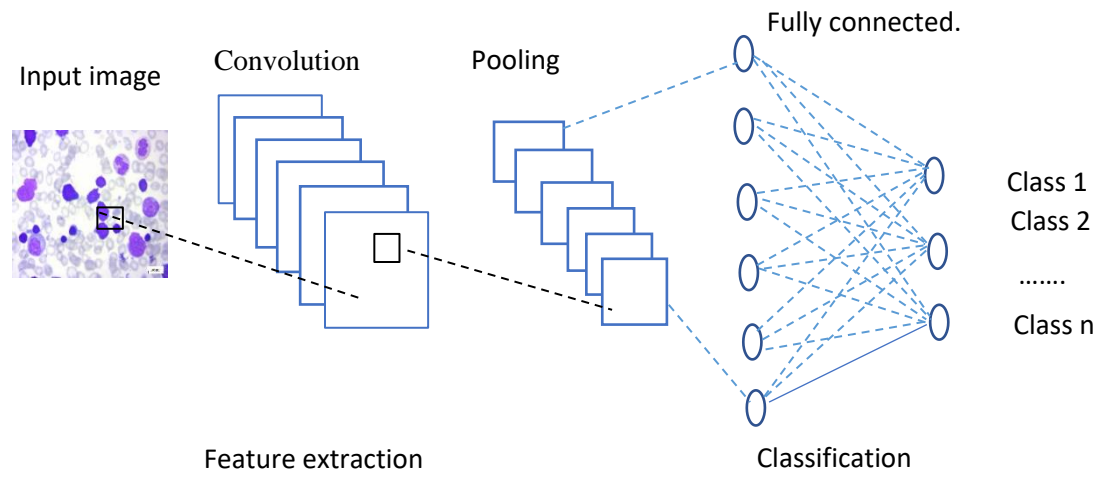


Fig. 1. Convolution neural network architecture.

## II. RELATED WORK

This section presents an overview of previous research conducted on blood cancer classification, focusing on the methods and techniques employed by researchers to accurately identify and classify various types of blood cancer. These studies have made significant contributions to the development of more effective diagnostic tools and have enhanced our understanding of this complex disease.

In [4] Mañla et al. (2022) developed a CNN-based model for the classification of leukemia. They utilized a dataset consisting of 3,536 images from 18 different sources, which

were divided into four classes: healthy (1,434 images), ALL (881 images), AML (978 images), and other types (243 images). To enhance the quality of the images, the study employed data augmentation techniques. By applying multilevel and ensemble CNN architectures to the four-class scenario, the researchers achieved accuracy rates of 94.73% and 94.59%.

In [13], Amjad et al. (2018) developed a CAD for the classification ALL subtypes. The dataset utilized in their study consisted of images of ALL subtypes, including 100 images of L1, 100 images of L2, 30 images of L3, and 100 images of normal cells. The proposed system employed segmentation and

deep learning methods, utilizing the AlexNet convolutional neural network architecture. With this approach, an accuracy of 97.78% was achieved.

In [3], Sara et al. (2019) proposed an automated deep learning method utilizing a hybrid approach for distinguishing between immature leukemic blasts and normal cells. The study employed two CNN architectures, namely MobileNet and VGG16. The ISBI 2019 dataset was utilized, consisting of 7,272 images of ALL cells and 3,389 images of healthy cells. The proposed approach achieved an accuracy of 96.17%.

In [6], Nighat et al. (2020) employed the DenseNet-121 and ResNet-34 Convolutional Neural Network architectures for leukemia subtype identification. Both ResNet-34 and DenseNet-121 utilized data augmentation techniques to analyze various image patterns. The study utilized the publicly available ALL-IDB and ASH image bank datasets for leukemia analysis. After augmentation, the dataset consisted of 1,079 images for the ALL class, 1,194 images for the AML class, 840 images for the CLL class, 1,243 images for the CML class, and 1,280 images for the healthy class. The accuracy rate achieved was 99.91% for DenseNet-121 and 99.96% for ResNet-34.

In [11], Maneela et al. (2021) proposed a model for AML detection using the AlexNet and LeNet-5 Convolutional Neural Network architectures. The dataset utilized in this study comprised 4,000 images, with 1,000 images in the lymphocytes class, 1,500 images in the abnormal monocytes class, and 1,500 images in the normal monocytes class. The data was obtained from a hospital in Peshawar, Pakistan. The AlexNet model achieved an accuracy of 98.58%, while the LeNet-5 model achieved an accuracy of 96.25%.

In [1], Arjun et al. (2022) developed a model for leukemia detection utilizing machine learning and deep learning techniques. The study introduced a novel dataset consisting of 500 blood smear images, including images of normal cells, AML cells, and ALL cells. Both binary classification and three-class classification were performed in the study. The

proposed approach achieved an accuracy of 97% using VGG16 and 98% using DenseNet121, along with a support vector machine for binary classification. For the three-class classification, an accuracy of 95% was achieved using ResNet50.

In [14], Laura et al. (2021) developed a predictive model for leukemia identification. The dataset used in this study consisted of 16,450 single cells. Various CNN architectures, including VGG16, ResNet101, DenseNet121, and SENet154, were employed to evaluate the model. The best performance was achieved by SENet154 and VGG16, both achieving an accuracy of 94.6%.

In [15], Xiaoli et al. (2021) proposed a deep residual neural network model for the classification of three types of lymphoma: CLL, FL, and MCL. The dataset used in this study consisted of 374 lymphoma pathology images. The model achieved an accuracy of 98.63%.

In [16], Nadia et al. (2019) developed a deep learning model to classify lymphoma subtypes, including CLL, FL, and MCL. The ResNet-34 architecture was utilized to evaluate the model, achieving an accuracy of 95.47%. The dataset used in this study consisted of 374 lymphoma images.

In [17], Hiroaki et al. (2020) proposed an ensemble deep neural network model for classifying three types of lymphoma: FL, diffuse large B-cell lymphoma (DLBCL), and reactive lymphoid hyperplasia (RL). The dataset used in this study consisted of a total of 6,183 images. The model achieved an accuracy of 97%.

### III. PROPOSED MODEL

The goal of this study is to build a model for blood cancer classification to help doctors and physicians diagnose blood cancer in its early stages and determine treatment to save human lives. This includes three main tasks: data collection, preprocessing, and finally, classification of blood cancer images using CNN architectures. The model is shown in Fig. 2.

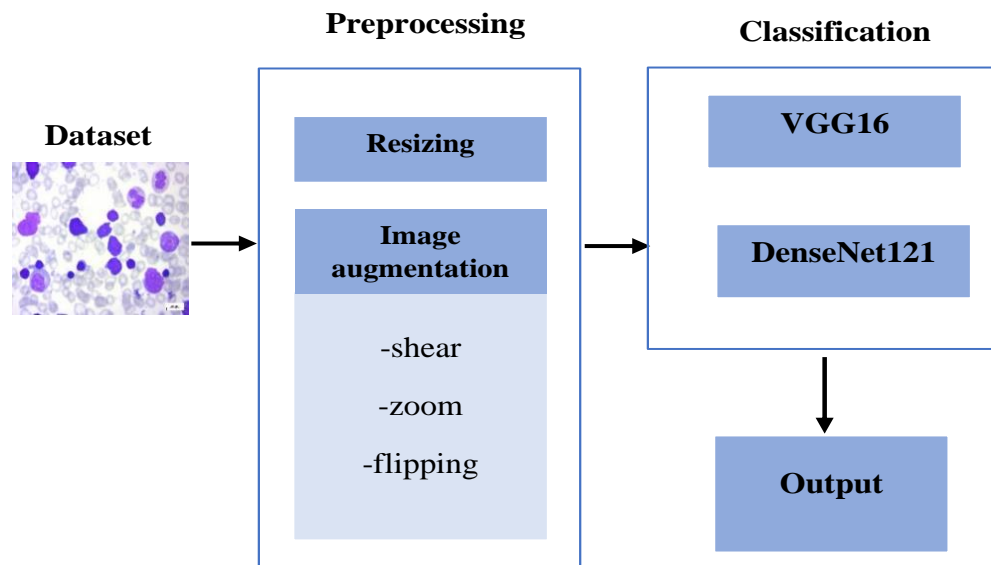


Fig. 2. Proposed model.

### A. Dataset

Due to the scarcity of medical data caused by privacy concerns, obtaining sufficient data for biomedical research can be challenging. In this study, we addressed this issue by combining three public datasets [18, 19] to create a larger and more comprehensive dataset for our blood cancer classification model. The dataset consists of 3,679 images across eight different classes. Table I provides a summary of the dataset used.

TABLE I. SUMMARY OF USED DATASET

Class	Number of images	Dataset	Image size
Benign	504	Kaggle	224 × 224
Early ALL	985		224 × 224
Pre-ALL	963		224 × 224
Pro ALL	804		224 × 224
CLL	113		1388 × 1040
FL	139		1388 × 1040
MCL	122		1388 × 1040
AML	49	ASH	960 × 720

### B. Preprocessing

We used pre-processing and augmentation techniques to improve the quality of visual information in each input image, thereby enhancing the visibility of essential structures.

1) *Resizing*: As a result of using multiple datasets with different image sizes, all input images were processed by resizing them to 224×224 to fit the input of our model.

2) *Image augmentation*: Image augmentation is utilized to train the model. It involves creating modified versions of the dataset images, thereby increasing the size of the training dataset. However, image augmentation serves a dual purpose: not only does it expand the dataset, but it also introduces variability to the data, enabling the model to generalize better to unseen data and address the issue of overfitting. Additionally, as the model is trained in slightly altered images, it becomes more robust and reliable. The preferred method of data augmentation is in-place or on-the-fly augmentation, implemented through Keras' ImageDataGenerator class [20]. This approach exposes the network to diverse variations in the dataset during each epoch of training. By creating additional versions of the original dataset images, the number of images used in each experiment is quadrupled, augmenting the data, and facilitating the classification process.

Before applying any processing, the input is rescaled by a factor known as "rescale." The original RGB coefficients of the images range from 0 to 255, which would be too high for the models to effectively learn at a standard learning rate. Therefore, the original images are rescaled by a factor of 1/255. This rescaling involves multiplying the image data by this value, resulting in image values between 0 and 1. Additionally, three image augmentation techniques are employed: shear, zoom, and flipping.

Shear is one of the image augmentation techniques employed by Keras' ImageDataGenerator, and it utilizes a shear range of 0.2. The shear angle is represented by a floating-point number, indicating the degree of shear in the anticlockwise direction.

The images are also enhanced through zooming. There are two zoom options available: zooming out of the image or zooming in on the image. The ImageDataGenerator class accepts a float value for the zoom range as input. The zoom is applied within the range [1 - zoom range, 1 + zoom range]. Alternatively, instead of providing a float number, a list with two values representing the lower and upper limits can be used [20]. When the value is less than one, the image zooms in, while any value greater than one causes the image to zoom out.

Flipping an image involves reflecting it around its vertical axis, horizontal axis, or both axes simultaneously. This technique allows users to augment the number of images in a dataset without the need for any artificial processing [20]. In this study, random horizontal flipping is used.

### C. Classification

Finally, the data was ready for the classification process. The model was trained using two CNN architecture models: VGG16 and DenseNet121. These classification architectures were implemented on Google Collaboratory.

1) *DenseNet121*: It facilitates the training of deep learning models by solving the vanishing gradient problem, increasing feature reuse, and reducing parameter usage. It has achieved progressive performance in a variety of computer vision tasks [21]. The DenseNet architecture is shown in Fig. 3.

2) *VGG16*: The VGG-16 network includes 16 convolution layers and a small receptive field of 3×3. It has a Max pooling layer of size 2×2 and 5 such layers in total. After the last Max pooling layer, there are three fully connected layer [22]. A schematic of VGG-16 architecture is illustrated in Fig. 4.

3) *Parameters*: All the model's parameters are explained, including the activation function, loss function, optimizer, and metrics.

a) *Activation function*: Another form of activation function applied in neural computing is the softmax function. It estimates the probability distribution from a vector of real numbers. The softmax function returns arrange of values between 0 and 1, with the total of the probability equal to 1[23]. Softmax is shown in Eq. 1. The softmax function is used in multiclass models to produce probabilities for each class.

$$F_{(y_i)} = \frac{e^{(y_i)}}{\sum_j e^{(y_j)}} \quad (1)$$

Where y is input vector.

b) *Loss function*: The loss function is employed to evaluate the network's effectiveness [24]. The Categorical Cross-Entropy loss, also described as softmax Cross-Entropy loss (CE), is employed in this research. It is employed in multi-class classification. the Categorical Cross-Entropy loss function is showed as in Eq. 2.



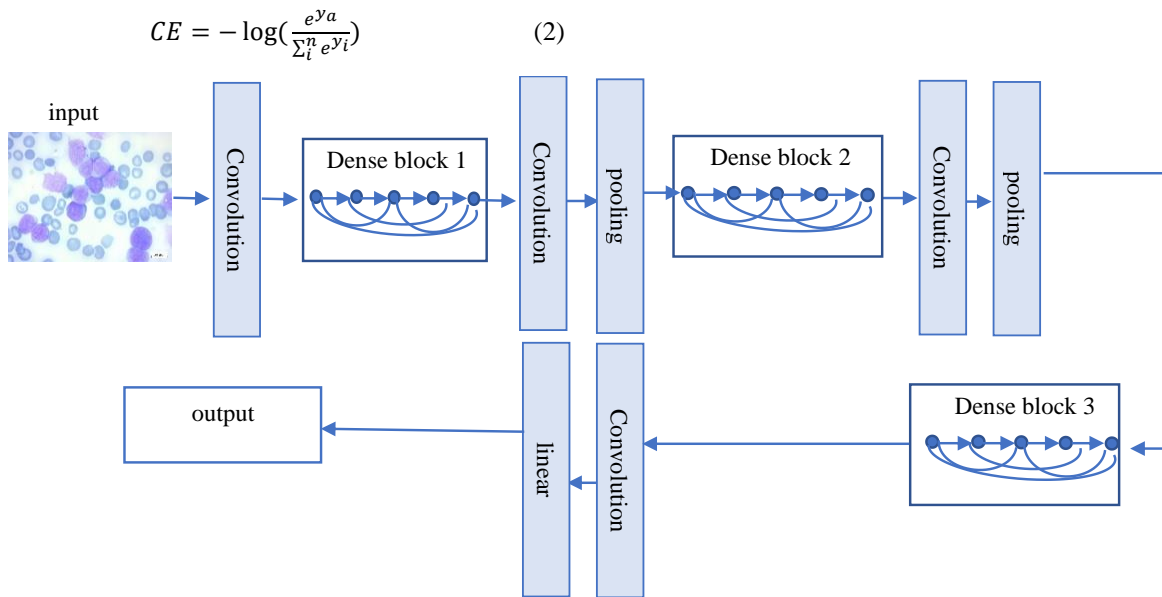


Fig. 3. DenseNet architecture.



Fig. 4. A schematic of VGG-16 architecture.

Where  $y_a$  represents the score for the positive classes in CNN.

c) *Optimizer*: In the training data, adaptive moment estimation (Adam) is used to correctly update the network weights iteratively. It employs first and second gradient descent computation to fit the learning rate parameter for each weight in the neural network, the first moment represents the mean, and the second represents the uncentered variance, The learning rate is the percentage by which weights are updated; the default learning rate is 0.001. High values accelerate learning before the rate is changed, and lower values slow learning in training [25].

d) *Evaluation metrics*: The model is evaluated based on accuracy (Acc) metrics; accuracy is a common metric used to evaluate the performance of a classification model. It measures the proportion of correct predictions made by the model compared to the total number of predictions. To calculate accuracy, we typically use a confusion matrix. A confusion matrix is a table that summarizes the performance of a classification model by showing the counts of true positive (TP), true negative (TN), false positive (FP), and false negative (FN) predictions. Each row of the matrix represents the instances in a predicted class, while each column

represents the instances in an actual class as shown in Fig. 5. Eq. 3 illustrates accuracy function.

- True Positive (TP): The model correctly predicted instances as positive when, they were positive. These are the correctly classified positive instances.
- True Negative (TN): The model correctly predicted instances as negative when they were negative. These are the correctly classified negative instances.
- False Positive (FP): The model incorrectly predicted instances as positive when they were negative. These are the instances of the model mistakenly classified as positive.
- False Negative (FN): The model incorrectly predicted instances as negative when they were positive. These are the instances of the model mistakenly classified as negative.

$$Acc = \frac{TP+TN}{TP+TN+FP+FN} * 100 \quad (3)$$



		Predicted value.	
		positive (P)	Negative (N)
Actual class	P	True positive (TP)	False negative (FN)
	N	False positive (FP)	True negative (TN)

Fig. 5. Confusion matrix.

#### IV. RESULT

VGG16 and DenseNet121 CNN architectures were utilized to classify 8 types of blood cancers. The models were trained for 20 epochs with a batch size of 64. The dataset comprised a total of 3,679 images, with 2,733 images allocated for training and 946 images for testing. Fig.6 displays samples of the blood cancer images. The models were evaluated using unseen data to assess their generalization capability. The accuracy of the models was measured, and the results revealed impressive accuracy rates. VGG16 achieved an accuracy of 98.2%, while DenseNet121 achieved an accuracy of 98.1%, as presented in Table II.

The plot diagram when using 20 epochs and DenseNet121 architecture is shown in Fig. 7, plot between train accuracy and validation accuracy is shown in Fig. 7(a), plot between train loss and validation loss is shown in Fig. 7(b). The plot diagram when using 20 epochs and VGG16 architecture is shown in Fig. 8, plot between train loss and validation loss is shown in

Fig. 8(a), plot between train accuracy and validation accuracy is shown in Fig. 8(b).

#### A. Comparison with the State-of-the-Art

In this section a comparison between the proposed model and the state of the art is presented as shown in Table III.

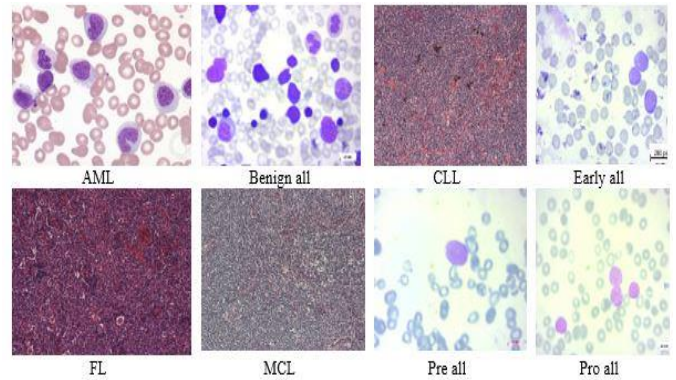


Fig. 6. Samples of the blood cancers images.

TABLE II. RESULTS OBTAINED BY VGG16 AND DENSENET121 CNN ARCHITECTURES

Model	#Of epochs	Accuracy	Batch size	Time for each epoch
VGG16	20	98.2%	64	21 s
DenseNet121	20	98.1%	64	21 s

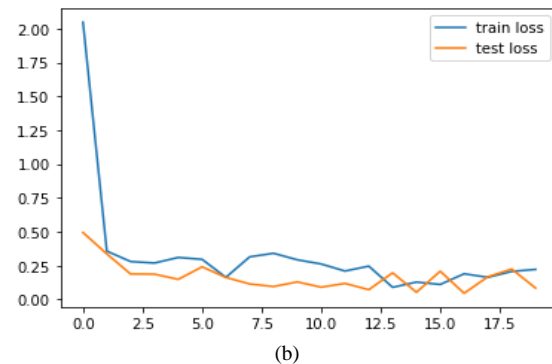
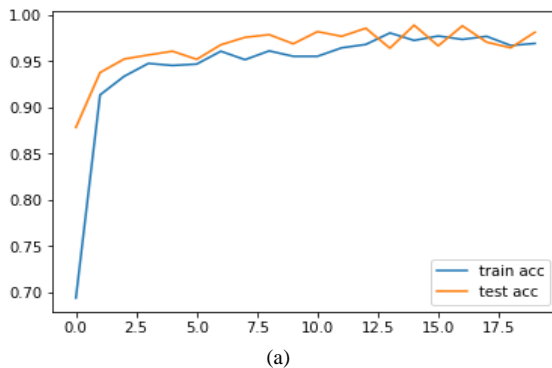


Fig. 7. The plot diagram when using 20 epochs and DenseNet121 architecture.

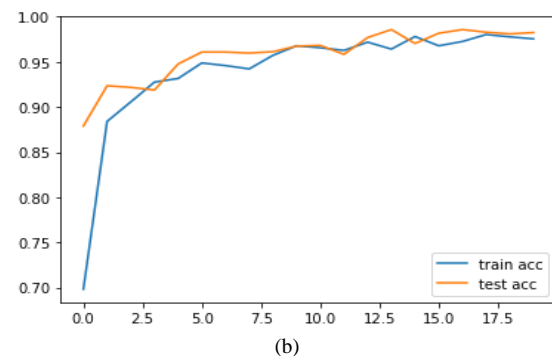
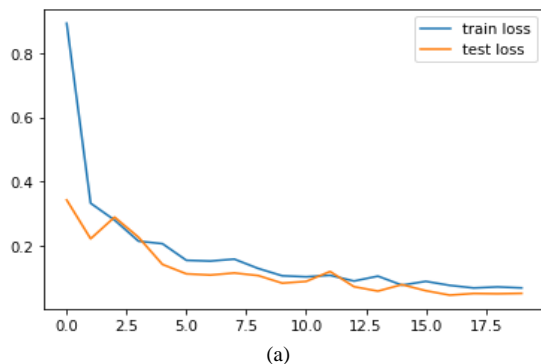


Fig. 8. The plot diagram when using 20 epochs and VGG16 architecture.

TABLE III. COMPARISON BETWEEN THE PROPOSED MODEL AND THE STATE-OF-THE-ART

#	Research	Year	Model	#Classes	#Images	Accuracy
1	[4]	2022	ensemble CNN architectures	4	3,536	94.73%
2	[13]	2018	Alexnet	4	330	97.78%.
3	[3]	2019	hybrid CNN architectures	2	10,661	96.17%.
4	[6]	2020	DenseNet-121	4	5591	99.91%
5			ResNet-34			99.96%.
6	[11]	2021	AlexNet	3	4000	98.58%
7			LeNet-5			96.25%.
8	[1]	2022	VGG 16	2	500	97%
9			DenseNet121	2		98%
10			ResNet50	3		95%
12	[15]	2021	residual neural network	3	374	98.63%.
13	[16]	2019	ResNet-34	3	374	95.47%.
14	[17]	2020	ensemble deep neural network	3	6,183	97%.
15	Proposed model	2023	VGG16	8	3,679	98.2%,
			DenseNet121			98.1%.

## V. DISCUSSION

This study has made significant progress in the field of blood cancer research by classifying eight different types of blood cancer using deep learning algorithms. Previous studies did not classify these eight types of blood cancer. Two different CNN architectures, namely VGG16 and DenseNet121, were employed for the classification process. The softmax activation function was used to calculate the probabilities of each class, ranging from 0 to 1, based on the CNN outputs. The highest probability corresponds to the predicted class for a given input. The effectiveness of the network was evaluated using the Categorical Cross-Entropy loss function, which measures the dissimilarity between the predicted probabilities and the actual target values, enabling the assessment of model performance. During the training process, the Adam optimizer was used to iteratively update the network's weights. The optimizer aims to find the optimal set of weights that minimize the loss function, thereby improving classification accuracy. The results of the classification process indicate that the VGG16 model achieved the highest accuracy among the two architectures, with a value of 98.2%. This means that the VGG16 model correctly classified 98.2% of the instances in the dataset. On the other hand, the DenseNet121 model achieved a slightly lower accuracy of 98.1%. These accuracy values suggest that both models performed exceptionally well in classifying the eight types of blood cancer, with VGG16 demonstrating slightly better performance compared to DenseNet121. However, the study encountered several challenges. Acquiring sufficient high-quality data proved to be a major hurdle as blood cancer datasets were often limited in size and lacked diversity, posing challenges in developing a robust and accurate model. Ensuring data accuracy and reliability was crucial for obtaining meaningful results. Another significant challenge was the interpretability and explainability of deep learning models. In the context of medical research, interpretability is vital for gaining insights into the underlying factors contributing to the classification.

Developing methods to explain the model's predictions and provide interpretable results was a significant undertaking. Furthermore, the study required substantial computational resources and time to train complex models on large datasets. Access to high-performance GPUs and collaboration with medical experts were essential for effective model training and evaluation. Bridging the gap between deep learning expertise and domain-specific knowledge posed additional challenges, emphasizing the need for collaboration with experts in blood cancer pathology, diagnosis, and treatment. Addressing these challenges was crucial in developing an accurate and reliable blood cancer classification model that aligns with clinical practices and aids in advancing diagnosis and treatment strategies.

## VI. CONCLUSION

This work presents the classification of blood cancer types using state-of-the-art deep learning techniques. Leukemia and lymphoma are hematological diseases and types of blood cancer that cause abnormal behavior in blood cells. In this study, we propose VGG16 and DenseNet121-based models to classify two types of leukemia and three subtypes of lymphoma and compare their performance. Data augmentation techniques are also employed to address the issue of overfitting, resulting in improved results. The proposed models are evaluated using unseen images that were not included in the training phase. The VGG16 architecture achieves the highest accuracy of 98.2%, while DenseNet121 exhibits slightly lower accuracy.

In future work, we plan to expand the classification to include other types of blood cancer, such as myeloma and chronic myeloid leukemia. Additionally, we aim to evaluate the proposed dataset using various deep learning algorithms to compare their performance in this field of research. Furthermore, an online Internet of Things (IoT) application will be developed to collect and analyze a larger volume of blood data.

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# Deep Feature Fusion Network for Lane Line Segmentation in Urban Traffic Scenes

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**Abstract**—As autonomous driving technology continues to advance at a rapid pace, the demand for precise and dependable lane detection systems has become increasingly critical. However, traditional methods often struggle with complex urban scenarios, such as crowded environments, diverse lighting conditions, unmarked lanes, curved lanes, and night-time driving. This paper presents a novel approach to lane line segmentation in urban traffic scenes with a Deep Feature Fusion Network (DFFN). The DFFN leverages the strengths of deep learning for feature extraction and fusion, aiming to enhance the accuracy and reliability of lane detection under diverse real-world conditions. To integrate multi-layer features, the DFFN employs both spatial and channel attention mechanisms in an appropriate manner. This strategy facilitates learning and predicting the relevance of each input feature during the fusion process. In addition, deformable convolution is employed in all up-sampling operations, enabling dynamic adjustment of the receptive field according to object scales and poses. The performance of DFFN is rigorously evaluated and compared with existing models, namely SCNN, ENet, and ENet-SAD, across different scenarios in the CULane dataset. Experimental results demonstrate the superior performance of DFFN across all conditions, highlighting its potential applicability in advanced driver assistance systems and autonomous driving applications.

**Keywords**—Lane line segmentation; deep learning; convolutional neural network; spatial and channel attention

## I. INTRODUCTION

As urbanization accelerates and our reliance on transportation intensifies, the need for safer and more efficient urban traffic systems is more pressing than ever. Among the numerous challenges in developing intelligent transportation systems, accurate lane line segmentation is a vital task for the functionality of autonomous driving and advanced driver-assistance systems (ADAS). By properly recognizing and predicting lane lines, these systems can better ensure the safety and efficiency of road traffic. Within the domain of computer vision and image processing, a plethora of methods have been proposed to address lane line segmentation. Traditional methods, like edge detection and Hough transform, provide some utility, but their performance can be significantly hindered under complex conditions such as variable lighting, weather, and diverse road markings. With the rise of deep learning, Convolutional Neural Networks (CNNs) have shown superior performance in various tasks including lane line segmentation [1], [2]. In recent years, a range of techniques for lane line segmentation employing Convolutional Neural Networks (CNNs) have been devised. Study [3] presents a robust method for lane detection in continuous driving scenarios, leveraging the power of deep neural networks. The

authors introduced a novel two-stage framework that first generates lane line proposals using a pixel-wise prediction model, and then refines these proposals through a sequential prediction model, leveraging temporal information between frames. Their method demonstrated impressive robustness in handling various complex scenarios and achieved notable performance on multiple benchmark datasets. Phillion [4] proposed a novel method to tackle the "long tail" problem in lane detection - the issue of detecting rare or unusual lane configurations. The approach uses a sequential prediction network that dynamically generates waypoints, thereby allowing it to adapt to a wide variety of lane shapes and configurations. In their study, Qin, Wang, and Li (2020) [5] introduced a structure-aware deep lane detection algorithm. The algorithm focuses on improving the speed and efficiency of lane detection by incorporating prior structural knowledge into a novel deep learning framework. Recently, Yoo et al. [6] proposed an end-to-end lane marker detection algorithm using a row-wise classification approach in their research. Their method transforms the challenging lane detection problem into a simpler row-wise classification task, improving both speed and accuracy of detection. Another approach [7] is to utilize a fully convolutional neural network with a novel instance segmentation head to simultaneously detect and separate different lane lines. In recent work, Abualsaud et al. [8] introduced LaneAF, a robust multi-lane detection method based on the concept of affinity fields. The proposed approach uses the affinity fields to encode relational information between different parts of the lane lines, enhancing the detection accuracy in challenging situations like close, parallel, and curvy lanes. Wang, Ren, and Qiu [9] introduced LaneNet, a real-time lane detection network designed for autonomous driving applications. LaneNet utilizes a two-branch neural network that simultaneously performs semantic segmentation for pixel-wise lane detection and instance segmentation for distinguishing between individual lane lines. In [10], Pan et al. introduced a novel concept of Spatial Convolutional Neural Networks (SCNN) that extends traditional CNNs by performing convolutions in the spatial domain. This novel SCNN framework, which treats spatial information as a type of deep information, was shown to be particularly effective in traffic scene understanding tasks, including lane line detection. Based on SCNN, Zheng et al. [11] proposed a Recurrent Feature-Shift Aggregator (ReSA) for lane detection tasks. The ReSA model uses a novel recurrent structure to shift and aggregate deep features, effectively capturing the spatial dependencies of lane pixels and thereby improving lane detection performance. Hou et al. [13] introduced a self-attention distillation strategy for developing lightweight lane

detection CNNs. The method involves training a smaller student network to mimic the attention maps of a larger, pre-trained teacher network, thereby improving the efficiency and performance of the student network. More recently, Vu et al. [14] proposed HybridNets, an end-to-end perception network for autonomous driving. HybridNets, combining multiple sub-networks tailored to different perception tasks, provides a unified architecture that can simultaneously perform various tasks, including lane line detection, while sharing learned representations. In addition to structures specifically designed for the task of lane line segmentation, some proposed methods use popular networks for general semantic segmentation such as Fully Convolutional Networks (FCN) [14], U-Net [15], SegNet [16], DeepLab v3+ [17], for the task of lane line segmentation, which also yield promising results and achieve significant outcomes.

Although the above methods show promise in lane line segmentation tasks, challenges remain due to the intricate nature of urban scenes that include varying lanes, unpredictable surrounding environments, and complicated traffic scenarios. To address these challenges, this paper presents a Deep Feature Fusion Network (DFFN) for lane line segmentation in urban traffic scenes. The core idea of the proposed method is to leverage the strength of deep learning and feature fusion to extract and combine multi-level and multi-scale features from the input images. This approach not only enhances the robustness of the network against complex conditions but also significantly improves the segmentation performance by effectively capturing both the local detailed information and the global contextual information of lane lines. The effectiveness of the proposed model has been verified through experiments on the CULane dataset.

The rest of this paper is organized as follows: Section II presents the detailed methodology of the proposed model, including the architectural design, key components, and training procedure. Section III describes the CULane dataset and the experimental setup, followed by a comprehensive analysis of the experimental results. Section IV summarizes the key contributions and highlighting the significance of the proposed model in improving the functionality and safety of autonomous driving systems and advanced driver assistance systems.

## II. METHODOLOGY

This section elaborates on the proposed DFFN structure designed for lane line segmentation in urban traffic scenes. DFFN is based on the DLA structure [18] used for the semantic segmentation task. Therefore, this section will first provide a summary of the DLA network structure, followed by a detailed explanation of the proposed modifications designed to enhance the DLA model specifically for the lane line segmentation problem.

### A. DLA Network for Semantic Segmentation

Deep Layer Aggregation is a powerful structure that has seen successful applications across a variety of computer vision tasks, including semantic segmentation. The design of DLA is based on the observation that semantic segmentation requires not only high-level semantic information but also low-level detailed information. The main aim of the DLA architecture is to effectively aggregate multi-scale and multi-level features to generate rich and detailed feature maps that are beneficial for tasks like semantic segmentation. DLA consists of two major components: a hierarchy of basic blocks and an aggregation mechanism, as shown in Fig. 1(a).

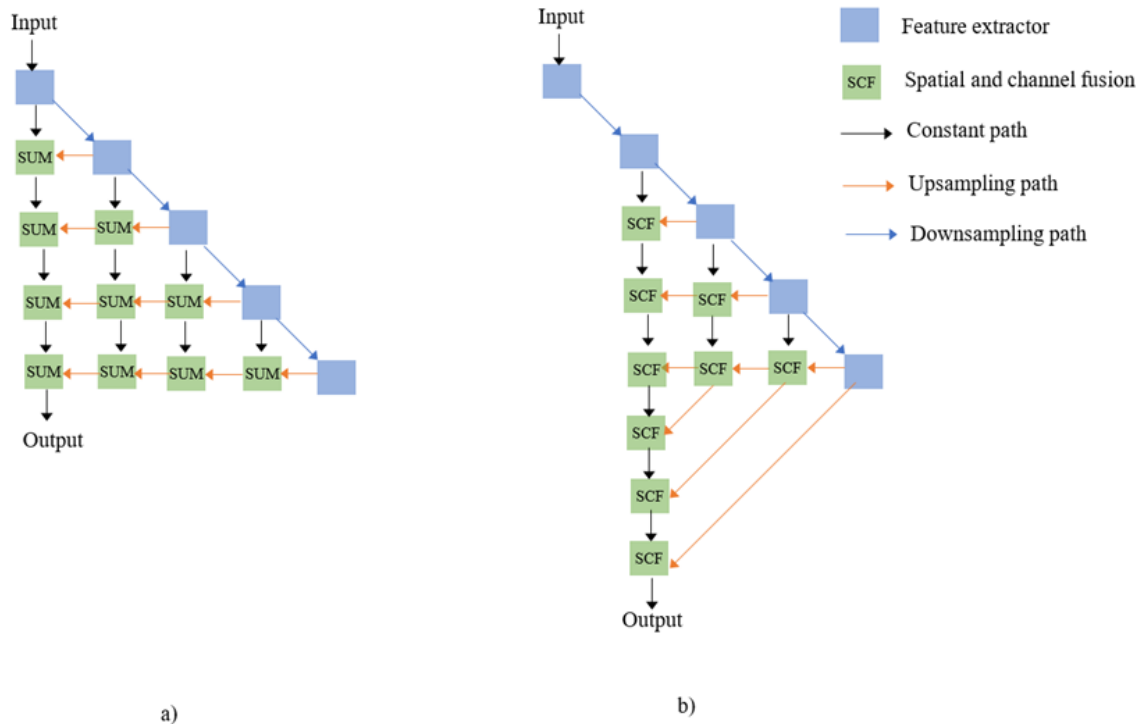


Fig. 1. The structure of original DLA (a) and the proposed DFFN (b).

1) *Hierarchy of basic blocks*: DLA adopts a hierarchical structure similar to typical convolutional networks such as ResNet [19] or ResNeXT [20], but with each level consisting of basic blocks, with each block being a small network of its own. Each basic block within the hierarchy operates at a different resolution, and the block output is a feature map of the corresponding resolution. Lower-level blocks capture fine-grained features, while higher-level blocks capture coarser but more abstract features.

2) *Aggregation mechanism*: The uniqueness of DLA lies in its aggregation mechanism. Traditional convolutional networks only use features from the highest level for prediction, which could result in a loss of detailed spatial information. DLA, however, introduces an aggregation mechanism that propagates the information from higher layers to lower layers, in a top-down manner. This aggregation allows high-level semantic features to be combined with low-level spatial features. The process begins with the highest level, where features are first processed by a  $1 \times 1$  convolution to reduce the channel dimension. Then, these features are upsampled and summed with the corresponding lower-level features. The combined features are then processed by another  $1 \times 1$  convolution before being passed to the next lower level. The aggregation mechanism allows DLA to generate rich feature maps that contain both high-level semantic information and low-level detailed information. This feature is particularly beneficial for semantic segmentation, which requires a good understanding of both the object (high-level) and the exact boundary (low-level) of each semantic class.

### B. Deep Feature Fusion Network with Spatial and Channel Fusion

Although DLA has achieved some success in semantic segmentation tasks, its performance in lane line segmentation in urban traffic scenes is greatly limited. There are several reasons to explain this. Firstly, the proportion of lane lines usually occupies a relatively small ratio in the image, and sometimes lane lines are not clearly visible. This severely restricts the accuracy of pixel-level segmentation of lane lines. Secondly, in complex environments where lane changes, changing lighting conditions, or irregular lane shapes frequently occur, the feature fusion scheme in DLA is easily affected by background noise. Inspired by attention mechanism [21], which employs channel and spatial self-attention for adaptive feature refinement to enhance the performance of convolutional networks in tasks like image classification, image captioning, and object detection, this paper designs the DFFN based on the DLA architecture for efficient lane line segmentation in urban traffic scenes. Fig. 1(b) illustrates the detailed structure of the proposed DFFN. It judiciously employs both spatial and channel attention mechanisms to learn and anticipate the significance of each input feature during the fusion process. Consequently, it amplifies lane line features from both spatial and channel dimensions, extracting effective lane line characteristics even in challenging environments. Specifically, DFFN utilizes ResNet-34 [19] as its backbone to create an optimal balance between precision and processing speed. It deviates from the traditional DLA by

integrating more skip connections between low-level and high-level features, resembling the operational structure of the Feature Pyramid Network [22]. Moreover, DFFN replaces the convolution layers in all up-sampling modules with deformable convolution, allowing for dynamic adjustments of the receptive field in accordance with object scales and orientations. This transformation not only offers flexibility but also helps mitigate alignment issues. In addition, each linear aggregation node in the original DLA structure is replaced by the spatial and channel fusion node (SCF), which is designed to compute spatial and channel attention based on the relation of the input feature maps. The next subsection will elaborate on the spatial and channel fusion design.

1) *Spatial and channel fusion*: The spatial and channel fusion is applied on two different input feature maps,  $I_S$  and  $I_L$ , where  $I_S$  is the shallower, higher resolution feature map and  $I_L$  is the deeper, lower resolution feature map, as shown in Fig. 2. Since  $I_S$  contains richer spatial information, this paper applies spatial attention operation on this feature map to enhance its spatial information. The spatial attention operation includes two  $3 \times 3$  convolution layers followed by sigmoid activation. Suppose  $I_S \in \mathbb{R}^{W \times H \times C}$ , the output of the spatial attention operation  $I'_S$  is calculated as follow:

$$I'_S = \sigma(h(I_S)) \quad (1)$$

where  $h(\cdot)$  is the convolution operation, and  $\sigma$  is the sigmoid function.

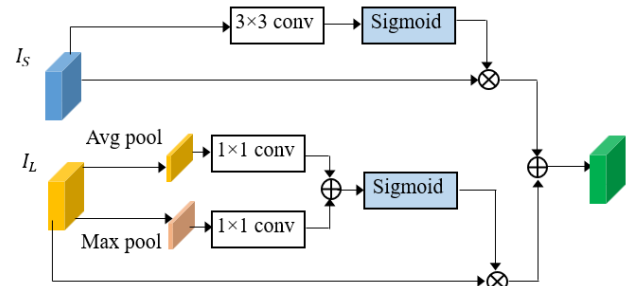


Fig. 2. Spatial and channel fusion.

On the other hand, as  $I_L$  have richer semantic representations, this paper applies channel attention operation on this feature map to improve its channel features. The channel attention operation first applies average pooling and max pooling to generate intermediate feature maps. Then, two  $1 \times 1$  convolution layers are applied in parallel to further transform these intermediate feature maps. Finally, the sigmoid activation function is used after summing the intermediate maps to generate the rich channel semantic maps. Suppose  $I_L \in \mathbb{R}^{W \times H \times C}$ , then the output of the channel attention operation  $I'_L$  is calculated as follow:

$$I'_L = \sigma(g(Avg(I_L)) + g(Max(I_L))) \quad (2)$$

After computing spatial and channel attention based on the relation of the input feature maps, this paper employs element-wise multiplication and summation to generate final enhanced feature map as follow:

$$I_O = I'_S \odot I_S + I_L \odot I'_L \quad (3)$$



Since the spatial and channel fusion module employs simple non-linear operation, it introduces negligible computation overhead.

### III. RESULTS

#### A. Dataset and Metrics

This paper employs the CULane dataset [10] to evaluate the proposed model. The CULane dataset has been utilized in various studies related to autonomous driving and advanced driver assistance systems. It's especially popular for tasks such as lane detection, semantic segmentation, and traffic scene understanding. The CULane dataset is quite large, containing around 55,000 images, and covering various scenarios with different traffic, lighting, and weather conditions. It consists of images from urban streets, highways, and rural areas captured at different times of the day. It also includes challenging driving scenarios like night driving, shadows, dazzling, and rainy or foggy conditions, thus offering a comprehensive dataset for robust model training. Each image in the CULane dataset is carefully annotated with high-quality pixel-level annotations of lane lines, including markings for straight lanes, curved lanes, and parallel lanes. This detailed annotation serves as an excellent training ground for lane segmentation models. It is worth noting that each image also contains corresponding binary lane segmentation maps, which are quite useful for model training and evaluation. The dataset is split into distinct training and testing sets, providing a reliable platform for both the development and evaluation of models. The training set contains around 88,880 images, while the test set contains approximately 34,680 images, spread across 9 different categories representing a range of driving conditions, as shown in Table I and Fig. 3. This paper carefully screened 40,000 annotated images containing lane lines in the dataset and used 70% of the filtered dataset for training. As in [10], this paper uses *F1*-measure as metric for evaluating the proposed model.



Fig. 3. Some examples for different scenarios.

TABLE I. PROPORTION OF EACH CATEGORY IN THE CULANE DATASET

Category	Proportion (%)	Resolution
Normal	27.7	590×1640
Crowded	23.4	
Dazzle light	1.4	
Shadow	2.7	
No line	11.7	
Arrow	2.6	
Curve	1.2	
Night	20.3	
Crossroad	9.0	

#### B. Experimental Results

This paper compared the performance of the proposed method against established models including SCNN [10], ENet [23], and ENet-SAD [12]. All experiments were conducted across eight distinct categories of the CULane testing set, evaluated based on *F1*-measure. The results are shown in Table II. In the Normal condition, DFFN demonstrated superior performance with an *F1* score of 70.25%, compared to SCNN (60.12%), ENet (65.62%), and ENet-SAD (67.72%). Under Crowded circumstances, the robustness of the DFFN model was notable, achieving an *F1* score of 58.71%, outperforming SCNN (45.38%), ENet (55.46), and ENet-SAD (55.81). In the Dazzle light and Shadow scenarios, DFFN continued to excel, achieving *F1* scores of 53.54% and 55.62% respectively, surpassing the scores of SCNN, ENet, and ENet-SAD. For the No line and Arrow conditions, DFFN maintained high performance levels, demonstrating impressive lane recognition capability in comparison to other models, as evidenced by the *F1* scores. In the Curve category, DFFN achieved an *F1* score of 58.80%, demonstrating superior performance in identifying and tracking curved lanes. Lastly, in the Night condition, DFFN upheld its strong performance, with an *F1* score of 58.62%, outperforming the compared models in low-light conditions. These experimental results underscore the effectiveness and robustness of the proposed DFFN method across varied traffic scenarios and lighting conditions. The consistently high *F1* scores, in comparison to other established models, suggest promising potential for DFFN in real-world applications, such as autonomous driving and advanced driver assistance systems.

Fig. 4 provides a detailed visual comparison of the performance of the proposed DFFN, SCNN, and ENet on the CULane testing images. The first column displays the original image, providing the actual scene context from the CULane testing set. The second column shows the ground truth, representing the ideal output that the models should aim to replicate. These images provide a benchmark against which the model outputs are evaluated. The third column presents the results of the proposed DFFN model. An initial visual comparison between these outputs and the ground truth may suggest the effectiveness of the DFFN in accurately segmenting lane lines under different traffic scenarios. The fourth column illustrates the output from the SCNN model. By comparing these images with the ground truth and the DFFN outputs, we can assess the performance of the SCNN in relation to both the ideal output and the proposed model. The final column depicts the results from the ENet model. Again, a comparison between these images, the ground truth, and the other model outputs helps evaluate the performance of the ENet model in various traffic conditions. A detailed examination of Fig. 4 would provide insights into the areas where the proposed DFFN outperforms or underperforms compared to the SCNN and ENet models. For example, we might observe that the DFFN model performs particularly well in crowded scenarios or shadow conditions, offering more accurate and robust lane segmentation than the comparative models. However, the DFFN might be sensitive to noise and outliers in the input data. This could result in misclassification or incomplete segmentation of lane lines, affecting the overall accuracy and reliability of the model's outputs. Addressing the

sensitivity to noise and outliers is an important challenge in lane line segmentation with deep learning models like the DFFN. Techniques such as data augmentation, robust feature

extraction, and outlier detection can be explored to improve the model's resilience to noisy input data and enhance its accuracy and reliability.

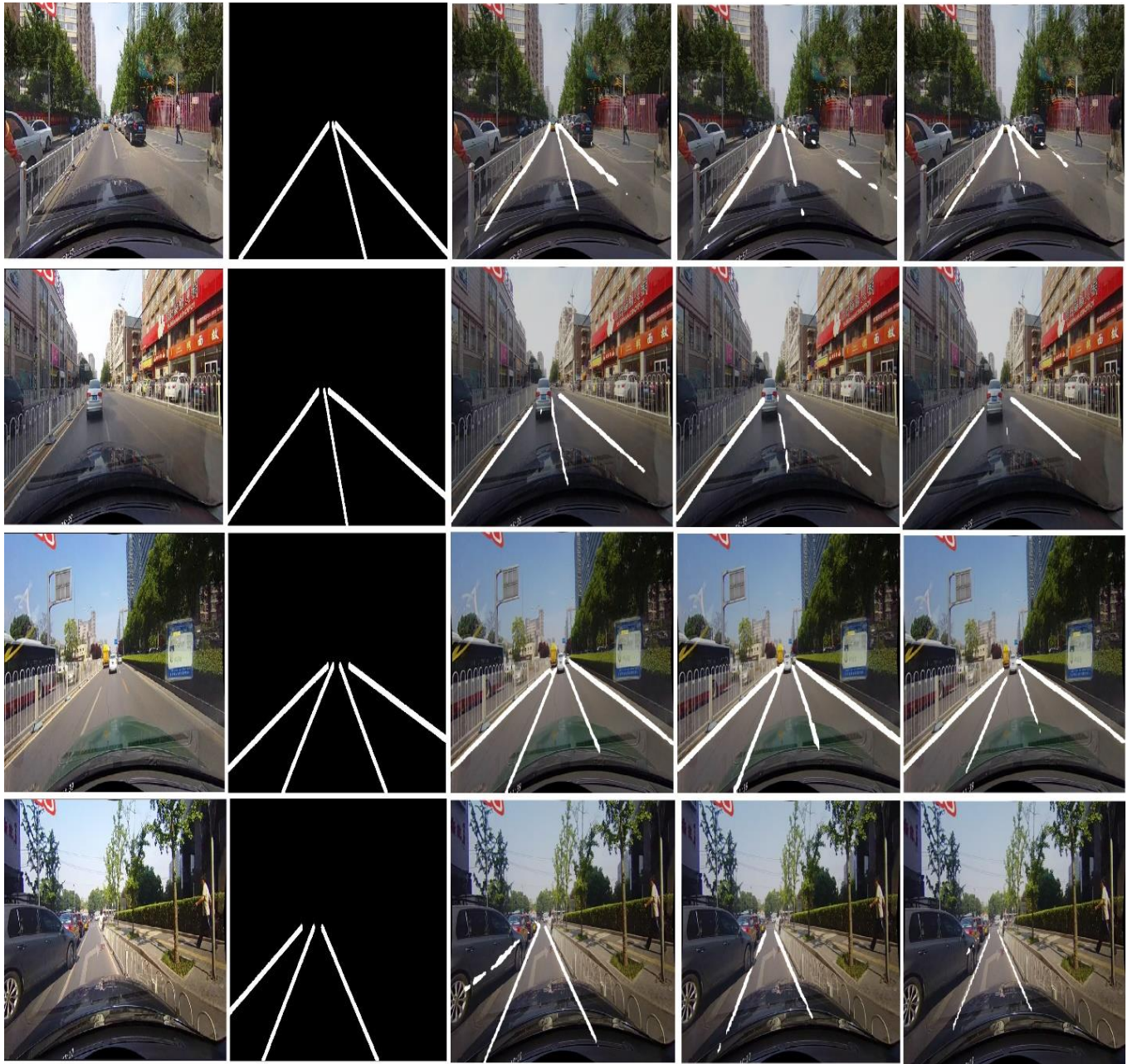


Fig. 4. Visualization of experimental results in CULane dataset of the proposed model and SCNN, ENet.

TABLE II. F1-MEASURE (%) OF DIFFERENT APPROACHES ON THE CULANE TESTING SET

Method	Category							
	Normal	Crowded	Dazzle light	Shadow	No line	Arrow	Curve	Night
SCNN [10]	60.12	45.38	37.52	41.44	36.34	45.31	44.44	41.20
ENet [23]	65.62	55.46	50.21	54.49	35.82	58.11	56.43	49.39
ENet-SAD [12]	67.72	55.81	52.91	54.51	39.06	56.94	57.91	54.12
Proposed model	70.25	58.71	53.54	55.62	39.86	59.17	58.80	58.62



#### IV. CONCLUSION

This paper introduces the Deep Feature Fusion Network (DFFN), a novel approach for lane line segmentation in complex urban traffic scenes. Based on the DLA structure, the DFFN integrates more skip connections between low-level and high-level features. In addition, each linear aggregation node in the original DLA structure is replaced by the spatial and channel fusion node to learn and predict the importance of each input feature during the fusing process. The DFFN has demonstrated its robustness in challenging scenarios, including crowded environments, varying lighting conditions, unmarked lanes, and curved paths, outperforming established models consistently. These results highlight the potential of the DFFN model in improving the functionality and safety of autonomous driving systems and advanced driver assistance systems. Despite its current performance, there is always room for improvement and optimization. Future work could focus on further enhancing the DFFN's ability to adapt to diverse environmental conditions and refining the model's capability to handle more complex and unusual lane line patterns, as well as addressing the sensitivity to noise and outliers.

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# Enhancing Skin Diseases Classification Through Dual Ensemble Learning and Pre-trained CNNs

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**Abstract**—Skin diseases represent a variety of disorders that can affect the skin. In fact, early diagnosis plays a central role in the treatment of this type of disease. This scholarly article introduces a novel approach to classifying skin diseases by leveraging two ensemble learning techniques, encompassing multi-modal and multi-task methodologies. The proposed classifier integrates diverse information sources, including skin lesion images and patient-specific data, aiming to enhance the accuracy of disease classification. By simultaneously utilizing image input and structured data input, the multi-task functionality of the classifier enables efficient disease classification. The integration of multi-modal and multi-task techniques allows for a comprehensive analysis of skin diseases, leading to improved classification performance and a more holistic understanding of the underlying factors influencing disease diagnosis. The efficacy of the classifier was assessed using the ISIC 2018 dataset, which comprises both image and clinical information for each patient with skin diseases. The dataset used in this study comprises images of seven different types of skin diseases and their associated medical information. The findings of our proposed approach show that it outperforms traditional single-modal and single-task classifiers. The results of this study demonstrate that the proposed model attained an accuracy of 97.66% for the initial classification task (image classification). Additionally, the second classification task (clinical data classification) achieved an accuracy of 94.40%.

**Keywords**—Multi-modal approach; multi-task approach; transfer learning; deep learning; skin diseases classification

## I. INTRODUCTION

Skin diseases, also known as dermatological conditions [1], represent a diverse group of disorders that can affect the skin, hair, nails, and mucous membranes. These disorders exhibit a wide spectrum of clinical presentations, ranging from benign and self-limiting conditions [2], such as common warts and seborrheic dermatitis, to severe and debilitating conditions, such as bullous pemphigoid and cutaneous lymphoma. The classification of skin diseases is crucial for proper diagnosis, treatment, and management. Accurate and timely diagnosis allows for the initiation of appropriate therapy and can prevent the progression of the disease. Moreover, the classification of skin diseases is a challenging task [3], that requires a thorough understanding of the clinical presentation, histopathological features, and laboratory results. In addition to this, a misdiagnosis or delayed diagnosis can lead to inappropriate treatment [4], which can result in poor outcomes, increased morbidity, and increased healthcare costs. The use of Artificial

Intelligence (AI) techniques for the classification of skin lesions and other diseases, including COVID-19 [5] and diabetes diseases [6], [7], have gained increasing attention in recent years [8], due to their potential to improve diagnostic accuracy and reduce the time required for diagnosis.

AI techniques are based on the ability of algorithms to learn from data and make predictions based on that learning. These techniques can be used to analyze large amounts of data and identify patterns [9], [10], that may be difficult for human experts to discern. In the context of skin disease classification, machine learning and deep learning techniques [11], [12], can be used to analyze images of skin lesions, identify patterns in clinical data, and analyze laboratory results. The utilization of these algorithms in skin disease classification has the potential to improve diagnostic accuracy and reduce the time required for diagnosis. However, the development and implementation of AI techniques for skin disease classification [13], requires a thorough understanding of the data and the algorithms used, as well as a rigorous evaluation of their performance. Recent advancements in AI have also had a significant impact on various other fields [14]–[16].

In the field of skin disease classification, previous studies have primarily focused on using deep learning techniques. While these approaches have shown promising results, there are significant gaps that necessitate further research. One notable gap is the limited exploration of multi-modal and multi-task deep neural networks for enhanced skin disease classification. Existing studies have predominantly focused on single-modal data or single-task models, neglecting the potential benefits of integrating diverse data modalities or leveraging multiple related tasks simultaneously. By addressing this gap, our research aims to develop a transfer learning approach in the context of multi-modal and multi-task deep neural networks, enabling more comprehensive and accurate skin disease classification. This approach holds the potential to leverage the complementary information from various data modalities, such as images, genetic data, and patient history, to improve the overall classification performance. Additionally, the inclusion of multiple related tasks, such as disease severity assessment or treatment recommendation, can further enhance the diagnostic capabilities of the system. By bridging this gap and exploring the potential of multi-modal and multi-task deep neural networks, our research contributes to the advancement of skin

disease classification techniques and has practical implications for improving diagnostic accuracy and patient care.

In this study, a multi-modal, multi-task DNN classifier is used to introduce an efficient MDSS [17], [18], that can identify skin conditions in dermatoscopic pictures. The innovative idea is to combine the outputs of two artificial intelligence models based on the TL approach and DNN models [19], [20], using multi-model and multi-task techniques. To build an accurate model compared to the published approaches at the time. To improve the performance of skin disease categorization, this model has been used to integrate medical information, such as past medical history and laboratory findings, with imagery data. This research used the ISIC 2018 dataset to train and evaluate our proposed MDSS, which contains photos of seven distinct types of skin disorders. Furthermore, in addition to the photos provided, the dataset used includes critical clinical information about each image [21], such as age, gender, and location. Hence, the main objective of our article is to enhance the accuracy of skin disease classification, leading to improved diagnostic outcomes, timely interventions, and better patient care. By providing practical insights and demonstrating the applicability of our approach, we aim to empower healthcare practitioners with a reliable tool [22], that can enhance their diagnostic capabilities and positively impact patient outcomes.

This manuscript is structured as follows: A thorough examination of prior research in the domain of skin disease classification utilizing DL techniques is provided in Section II. The design and implementation of the proposed Multi-Modal and Multi-Task classifier, as well as the methodology employed, are expounded upon in Section III. The results of the experiments, including a performance assessment, are detailed in Section IV. Finally, in Section V, the conclusion of this study and potential areas for future research are outlined.

## II. RELATED WORKS

Deep learning [23], a subset of machine learning [24], has been increasingly used in the field of skin disease classification in recent years. This is due to its ability to automatically extract features [25], and patterns from large and complex datasets, such as images of skin lesions. In this section, we will review the current state-of-the-art in skin disease classification over the last few years using DL techniques. We will examine the various techniques that have been proposed in these studies, such as TL and DNNs, to compare these methods with our proposed classifier in this manuscript.

A study presented in [26], explores the use of DL techniques for the classification of skin lesions on imbalanced small datasets. The authors propose the use of a single model of DL and evaluate its performance in comparison to traditional machine learning methods and human experts. They found that this approach has the potential to improve diagnostic accuracy and reduce the time required for diagnosis, even when working with small, imbalanced datasets. However, the use of DL on imbalanced small datasets also poses challenges such as overfitting and a lack of robustness in the classifier. The authors also suggest potential directions for future research in this field to overcome these challenges, such as the development of more advanced DL architectures and

techniques and the integration of additional clinical data. The best proposed model in this study, namely RegNetY-3.2G-Drop, achieved a balanced accuracy value of 85.8% using the ISIC 2018 dataset.

A scientific study featured in [27], presents a new method for skin lesion classification using DL techniques. The proposed method, called SSD-KD, is a self-supervised, diverse knowledge distillation method that uses a lightweight model to classify skin lesions from thermoscopic images. The authors evaluate the performance of this method and show that it can achieve an accuracy of 84.6% and generalization capability even when working with a small dataset. The authors also point out that this approach is an efficient method for skin lesion classification, especially when there is a lack of labeled data. On the other hand, one of the limitations of this study is that it achieves a low level of accuracy.

A scholarly article published in [28], introduces a new technique for diagnosing malignant melanoma using DL techniques. The proposed method, called 2-HDCNN, is a two-tier hybrid dual convolutional neural network feature fusion approach that fuses multiple features from different sources to improve diagnostic accuracy. The authors of the article have evaluated the performance of this method and have found that it is able to achieve high accuracy and generalization capability on the task of malignant melanoma diagnosis, with an accuracy of 92.15%. This means that the method can accurately diagnose malignant melanoma in a high percentage of cases.

A paper appearing in [29], provides a new method for extracting and classifying skin lesion features using DL techniques. The proposed method uses regularization techniques to improve the accuracy and robustness of the model. It also uses layer-wise weight norm-based feature extraction to extract informative features from the skin lesion images. The authors evaluate the performance of this method on several datasets and show that it can achieve an accuracy of 94.42% on the ISIC 2018 dataset, 91.73% accuracy on the ISIC 2019 dataset, and 93% accuracy when evaluated on the combined dataset.

A work documented in [30], discusses a novel approach for skin lesion classification using DL techniques. The proposed method, called End-to-End Decoupled Training (E2EDT), is designed to handle the long-tailed distribution problem, which is a common issue in the skin lesion classification task. E2EDT is a robust DL method that decouples the training process into two stages: pre-training and fine-tuning. The authors evaluate the performance of this method using the ISIC 2018 dataset and show that it can achieve a balanced accuracy of 87%.

Table I presents a comprehensive overview of the reviewed studies, highlighting essential information such as the number of classes, the implemented classifiers, and the highest performance attained based on the evaluation metrics employed. This table acts as a valuable resource, providing a condensed overview of the essential findings from the literature review. By presenting this information in a concise and structured format, Table I facilitates easy reference and comparison of the different approaches and outcomes reported in the studies. This condensed representation of essential

findings promotes efficient data analysis and aids in the identification of research gaps and future directions.

TABLE I. SUMMARY OF SOME LITERATURE WORK

Ref	Datasets (Classes)	Models	Accuracy
[26]	ISIC 2017 Dataset (3)	RegNetY-3.2G-Drop	74.6%
	ISIC 2018 Dataset (7)		85.8%
	ISIC 2019 Dataset (8)		59.3%
	7-PT Dataset (5)		65.7%
[27]	ISIC 2019 Dataset (8)	SSD-KD	84.6%
[28]	ISIC-2018 Dataset (2)	2-HDCNN	92.15%
[29]	ISIC 2018 Dataset (2)	CLCM-net	94.42%
	ISIC 2019 Dataset (2)		91.73%
[30]	ISIC 2018 Dataset (7)	E2EDT	87%

In recent years, deep learning techniques have gained significant popularity for skin disease classification. However, this approach is not without limitations. One primary limitation lies in the availability of labeled data, as deep learning models necessitate large amounts of accurately labeled data for effective training. Acquiring such data, especially for rare skin diseases, can be challenging, which hinders the development and deployment of deep learning models in these cases. Another limitation pertains to the quality of the available data. The performance of deep learning models heavily relies on the quality of the input data. Poor data quality, characterized by noise, missing information, or inconsistencies, can negatively impact the model's performance, leading to overfitting and limited generalization capabilities. Furthermore, deep learning models may struggle to generalize well to unseen data, particularly when the distribution of the new data differs significantly from the training data. This limitation poses challenges in real-world scenarios where the model needs to perform accurately in diverse and previously unseen cases. Additionally, the existing literature predominantly focuses on single-modal data or single-task models, neglecting the potential advantages of incorporating multi-modal data and leveraging multi-task learning approaches. By solely considering a single data modality or a specific task, previous studies failed to exploit the complementary information present in diverse data sources, which could potentially enhance the classification performance and broaden the scope of skin disease diagnosis.

Addressing these limitations and exploring the potential of multi-modal data and multi-task learning in the context of skin disease classification is crucial to overcome the data scarcity challenge, improve generalization capabilities, and advance the state-of-the-art in this field.

### III. MATERIALS AND METHODS

#### A. Schematic of the Planned Multi-Modal and Multi-Task Classifier for Skin Disease Monitoring

In this subsection, a comprehensive approach for building a multi-modal and multi-task classifier for skin diseases is presented. The proposed framework leverages the

EfficientNetV2L network for processing the image dataset and the DNN for handling the clinical dataset. The following paragraphs provide additional details, examples, and techniques to further elucidate the process.

To initiate the classifier's development, a large dataset of skin lesion images and corresponding clinical data is collected. In this study, the ISIC 2018 dataset is specifically chosen due to its widespread utilization and its potential as a valuable resource for constructing the multi-modal and multi-task classifier. The ISIC 2018 dataset comprises a diverse range of skin lesion images along with associated clinical information, enabling the model to learn from both visual and clinical data sources. On the other hand, pre-processing of the collected data is then conducted to ensure its suitability for model training. This crucial step involves data cleaning techniques such as eliminating noise, addressing data inconsistencies, and handling missing or irrelevant information. Furthermore, techniques such as normalization can be employed to enhance the quality of the image dataset, while feature scaling methods can be applied to the clinical dataset. Following data pre-processing, the classifier extracts meaningful features from the image data and the clinical data. The image data is processed using the EfficientNet V2L network, which has demonstrated its effectiveness in image classification tasks. The network employs advanced techniques such as convolutional layers and attention mechanisms [31], [32], to capture intricate visual patterns and extract discriminative features from the skin lesion images. Similarly, the clinical data is fed into a deep neural network (DNN) architecture that is specifically designed to handle heterogeneous clinical data, extracting relevant features from patient-specific attributes, laboratory results, and other clinical information. The extracted features from both modalities are then integrated within a multi-task learning framework. This framework allows the model to simultaneously learn from both image and clinical data, leveraging the complementary information contained in each modality. A shared encoder architecture is employed to concatenate the outputs of the EfficientNet V2L network and the DNN, combining the learned representations from both modalities into a unified feature representation. This fused representation is subsequently passed through a final classifier layer, enabling the model to make accurate predictions regarding skin disease classification. To assess the performance of the proposed multi-modal and multi-task classifier, a separate test dataset is utilized. This dataset comprises skin lesion images and corresponding clinical data that were not involved in the training process. By evaluating the classifier on this independent dataset, its ability to accurately diagnose skin diseases can be quantitatively measured, providing insights into its efficacy and generalization capability.

The flowchart (Fig. 1) accompanying the text visually illustrates the different stages and processes involved in the design and implementation of the proposed multi-modal and multi-task classifier. This flowchart serves as a comprehensive guide, offering a clear and organized overview of the sequential steps encompassing data pre-processing, model construction, and model evaluation.



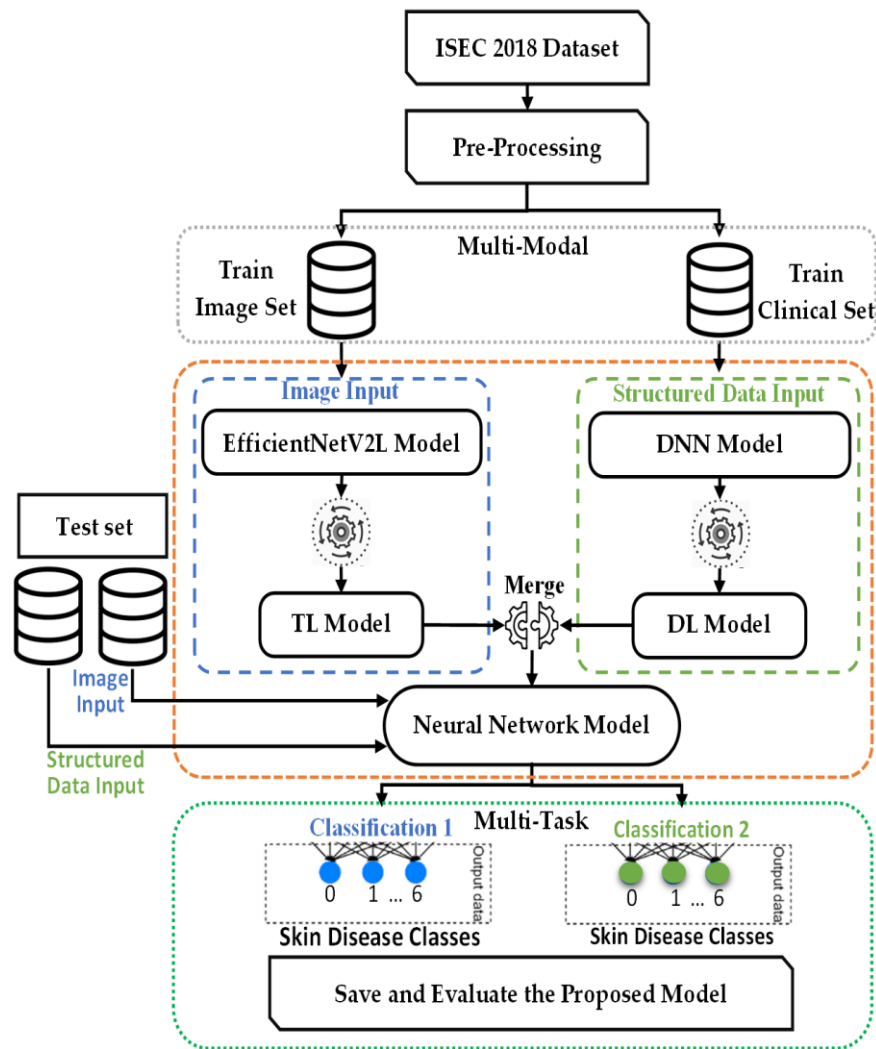
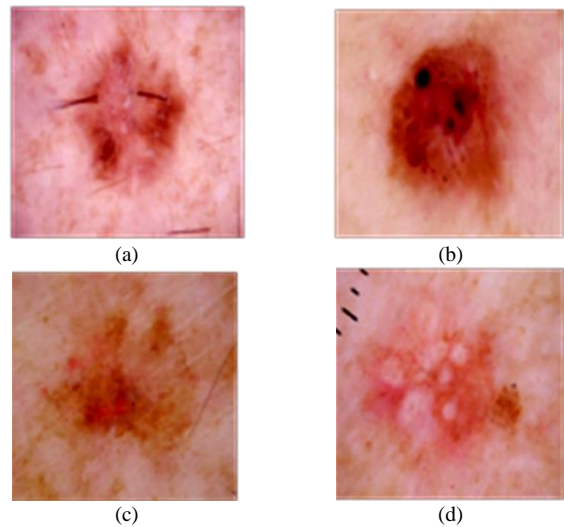


Fig. 1. The architecture of the proposed model.

### B. ISIC 2018 Dataset Description

The ISIC 2018 dataset is a collection of images of skin lesions, along with corresponding diagnostic information, used for research in the field of skin disease classification using AI techniques. The dataset includes over 10000 images of various skin lesions [33], including malignant melanomas, benign nevi, and other types of skin diseases. The diagnostic information provided with the images includes the diagnosis made by a dermatologist as well as other relevant clinical data. The ISIC 2018 dataset is a widely used benchmark dataset in the field of skin disease classification and is commonly used to evaluate the performance of new AI algorithms and models. As depicted in Fig. 2, several examples are presented from the ISIC 2018 dataset.



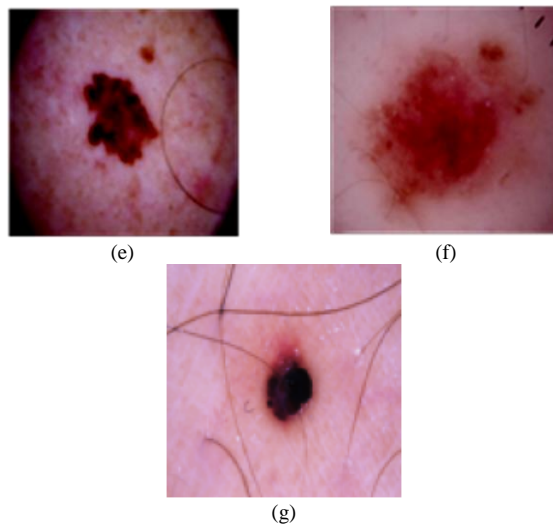


Fig. 2. The examples of the seven different classes of skin disease present in the dataset : (a) Actinic keratoses; (b) Basal cell carcinoma; (c) Benign keratosis-like lesions; (d) Dermatofibroma; (e) Melanoma; (f) Melanocytic nevi; and (g) Vascular lesions.

The dataset used in this study comprises images of 7 different types of skin diseases [34], including Actinic keratoses, Basal cell carcinoma, Benign keratosis-like lesions, Dermatofibroma, Melanoma, Melanocytic nevi, and Vascular lesions. Moreover, alongside the provided images, the dataset used encompasses essential clinical information pertaining to each picture, encompassing age, gender, localization, and Dx\_type (denoting the modality through which the skin disease was diagnosed). The dataset is divided into a training set and a test set, with 7500 images in the training set in addition to their clinical data and 2500 images in the test set with their associated medical information, respectively.

### C. Deep Learning Algorithms for Classification

*a) Multi-Modal and Multi-Task Neural Network:* A Multi-Modal and Multi-Task Neural Network is a type of DL architecture that can process and analyze multiple types of input data [35], such as images, text, and audio, simultaneously. This type of network can perform multiple tasks, such as classification and segmentation, using the same network architecture, allowing for more efficient and effective processing of data. Additionally, this type of network can improve the performance of each task [36], by leveraging the shared representations and features learned from the other tasks. This is done by sharing the weights of the network across different tasks, which can help improve the generalization of the model and reduce the need for additional training data. Overall, multi-modal, and multi-task networks are well-suited for applications where multiple types of data need to be analyzed together, such as medical imaging and clinical data. The diagram presented in Fig. 3 illustrates a multi-modal and multi-task neural network model, which is represented through its architectural components and connections.

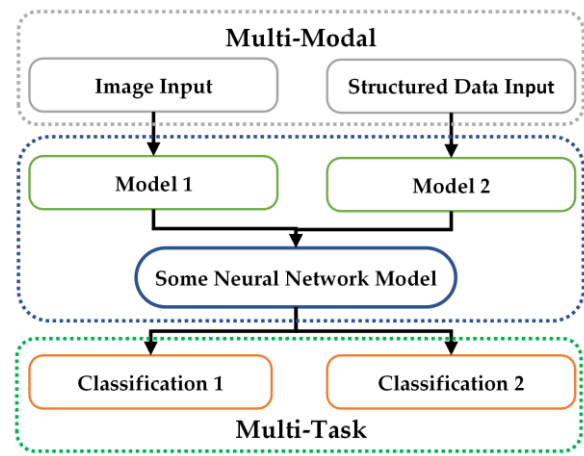


Fig. 3. An example of a multi-modal and multi-task neural network.

*b) EfficientNet V2L Network:* EfficientNet V2L is a type of neural network architecture [37], that is designed to improve the efficiency and effectiveness of DL models. This network is an updated version of the original EfficientNet, which was designed to improve the performance of DL models while reducing their computational complexity. The V2L version of EfficientNet is specifically designed to handle large-scale image datasets, and it can achieve state-of-the-art performance on a wide range of image classification tasks. The network is characterized by its unique architecture, which includes depth-wise separable convolutions, linear bottlenecks, and efficient scaling of network depth and width. These design choices allow the network to achieve high performance while using fewer parameters than other state-of-the-art architectures. EfficientNetV2 models utilize a scaling method and a neural architecture search algorithm to optimize both the architecture and hyperparameters of the network simultaneously. These models are specifically designed for image classification tasks and come in a range of sizes, referred to as "scales." Each scale corresponds to a distinct model architecture and number of parameters, with larger scales possessing a greater number of parameters and higher accuracy. The architecture search space has been expanded to include novel operations, such as FusedMBCConv, in addition to conventional CNN operations.

*c) Deep Neural Network:* DNNs are a class of machine learning models [38], that are composed of multiple layers of artificial neurons. These layers are interconnected and process the input data through a series of mathematical computations known as activation functions. DNNs are trained to learn patterns and features in the input data, allowing them to perform tasks such as image recognition, natural language processing, and speech recognition. DNNs are known for their ability to represent complex, non-linear relationships between input and output and can often achieve state-of-the-art performance on a wide range of tasks. They are widely used in many medical fields and have become a popular tool for solving complex problems.

#### D. Confusion Matrix and Measures

A confusion matrix is a table that is often used to describe the performance of a classification algorithm, specifically in the context of medical diagnosis. In the case of skin diseases, a confusion matrix [39], would display the number of True Positive (TP), False Positive (FP), True Negative (TN), and False Negative (FN) for a given diagnostic test. These values can then be used to calculate various performance measures [40], such as accuracy, precision, recall, and specificity, which can give insight into the effectiveness of the diagnostic test. The following formulas compute these metrics:

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \quad (1)$$

$$\text{Precision} = \frac{TP}{TP+FP} \quad (2)$$

$$\text{Recall} = \frac{TP}{FN+TP} \quad (3)$$

$$\text{Specificity} = \frac{TN}{TN+FP} \quad (4)$$

#### IV. FINDINGS AND DISCUSSION

In the current section, the primary experimental results of the scientific study are presented. Initially, the training performance of all utilized models is depicted through plots that depict the evolution of accuracy and loss over time. Furthermore, a confusion matrix is presented to provide a thorough understanding of the classification outcomes.

##### A. Implementation Platform

The present study carried out all experiments using the Python programming language and the Jupyter Lab environment. The AI models were trained on the Google Colab platform, which is a Jupyter Notebook-based cloud service for researching and training AI algorithms. The computational resources employed in this setup included a Tesla K80 GPU with 12GB of GDDR5 VRAM, an Intel Xeon Processor with two cores operating at 2.20 GHz, and 13 GB of RAM. The construction of models was facilitated through the utilization of two primary implementation libraries: Keras and Autokeras. Additionally, the Adam optimizer and cross-entropy loss

function [41], were employed for training all algorithms. Table II presents the hyperparameters used for fine-tuning the pre-trained models utilized in this research.

TABLE II. THE PARAMETERS AND FUNCTIONS UTILIZED IN THE TRAINING PROCEDURES

Network	Epochs	Batch Size	Loss Function	Optimizer	Learning Rate
Proposed Model	50	16	Categorical Cross entropy	Adam	1e-4

##### B. Experimental Results

a) *Training of DL Models Results:* The training results of the proposed multi-modal and multi-task DNN with TL were evaluated using accuracy, precision, recall, and specificity metrics. These results were also evaluated using learning curves, which showed a consistent improvement in performance as the number of training epochs increased. The learning curves also indicate that the proposed approach can effectively utilize the additional information provided by this proposed approach. The loss curve, on the other hand, shows a decrease, indicating that the model is learning and generalizing well. The convergence of both curves suggests that the proposed approach effectively leverages multi-modality and multi-task information, resulting in a robust classifier for skin disease classification. Generally, these results demonstrate the effectiveness of the proposed approach in improving the classification of skin diseases. Fig. 4 illustrates the accuracy and loss curves of the multi-modal and multi-task DNN with a TL classifier during the training phase.

b) *Testing of DL Models Results:* The effectiveness of the models was evaluated in this study using a separate set of test data that incorporated both image and clinical data inputs. The performance of the model for each class of skin disease was visualized through the generation of a confusion matrix, which subsequently informed the calculation of performance metrics. The results of the multi-class classification confusion matrix are presented in Fig. 5.

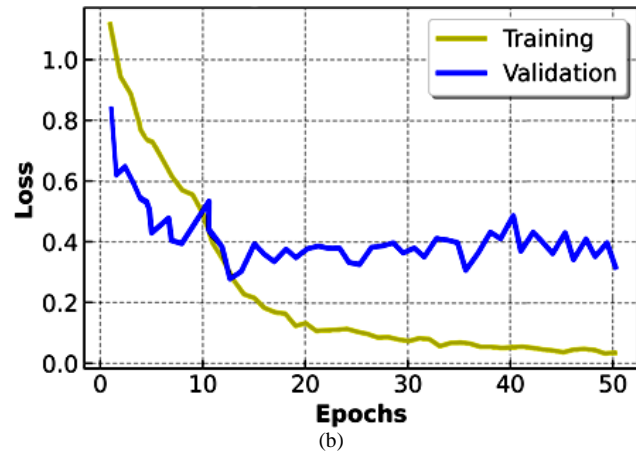
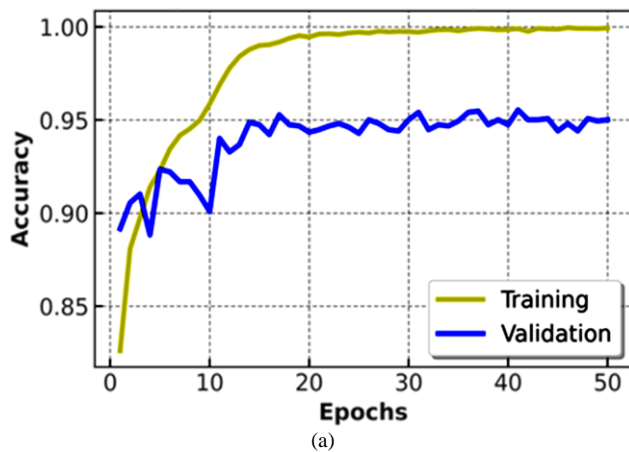


Fig. 4. Performance of the multi-modal and multi-task DNN with the TL classifier : (a) The accuracy of the model over time; (b) The decrease in loss function over time during the training phase.

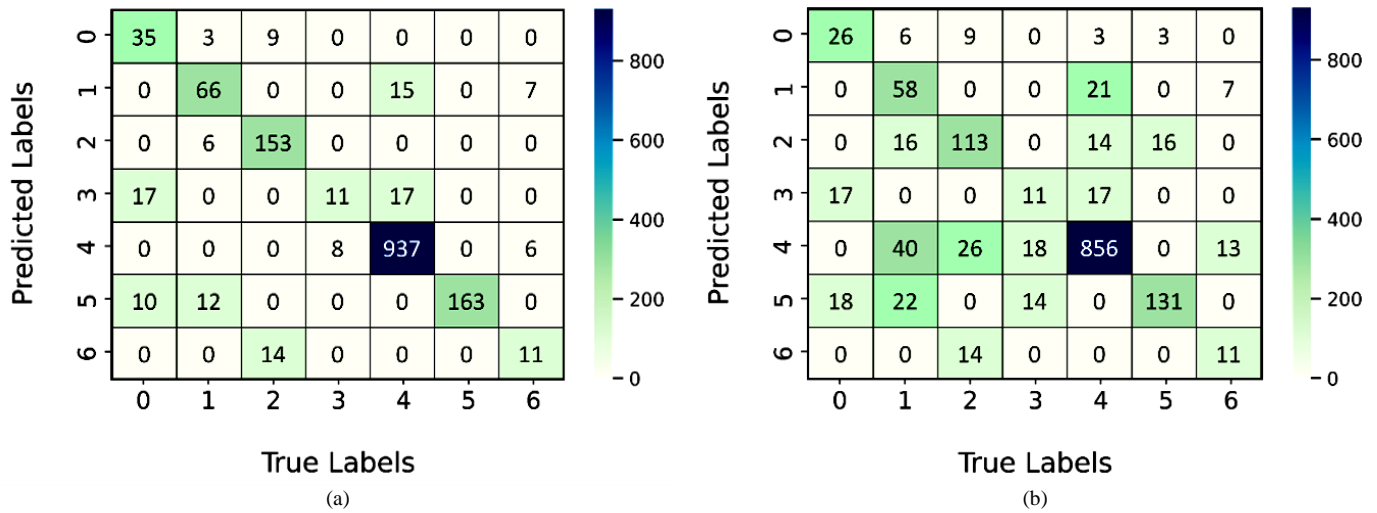


Fig. 5. Confusion matrix illustrates the performance of the proposed classifier: (a) Initial classification task (image input); (b) Second classification task (clinical data input).

These matrices show that the model performed well for most of the classes, with a high number of TP and a low number of FP and FN. The confusion matrix also revealed some misclassification for a few classes, which can be further investigated to improve the performance of the model. Overall, these results demonstrate the effectiveness of the proposed

approach in classifying skin diseases. Based on the results of the matrices, it can be inferred that the proposed approach for classifying skin diseases is effective. The assessment measures for the performance of the proposed model are also outlined in Tables III and IV.

TABLE III. PERFORMANCE ANALYSIS OF THE INITIAL CLASSIFICATION TASK USING METRICS: ACCURACY, PRECISION, RECALL, AND SPECIFICITY

Class	Accuracy	Precision	Recall	Specificity
0	97.43%	56.45%	74.47%	98.16%
1	97.16%	75.86%	75.00%	98.53%
2	98.09%	86.93%	96.23%	98.31%
3	97.23%	57.89%	24.44%	99.46%
4	96.97%	96.75%	98.55%	94.17%
5	98.55%	100.00%	88.11%	100.00%
6	98.22%	45.83%	44.00%	99.13%
<b>Average</b>	<b>97.66%</b>	<b>74.25%</b>	<b>71.54%</b>	<b>98.25%</b>

TABLE IV. PERFORMANCE ANALYSIS OF THE SECOND CLASSIFICATION TASK USING METRICS: ACCURACY, PRECISION, RECALL, AND SPECIFICITY

Class	Accuracy	Precision	Recall	Specificity
0	96.27%	42.62%	55.32%	97.59%
1	92.53%	40.85%	67.44%	94.06%
2	93.67%	69.75%	71.07%	96.35%
3	95.60%	25.58%	24.44%	97.80%
4	89.87%	93.96%	89.82%	89.95%
5	95.13%	87.33%	70.81%	98.56%
6	97.73%	35.48%	44.00%	98.64%
<b>Average</b>	<b>94.40%</b>	<b>56.51%</b>	<b>60.42%</b>	<b>96.13%</b>

The tables provide numerical values for each performance metric, which allows for a quantitative assessment of the multi-task classification performances. The numerical values represent the specific performance of the model for each metric, and by comparing these values to other metrics, we can understand how well the model is performing.

### C. Discussion

A novel methodology for skin disease classification is presented that incorporates the utilization of multi-modal and multi-task classifier. The proposed classifier integrates multiple modalities of data, including visual representations of skin lesions and patient-specific characteristics, to enhance the precision of disease classification. The multi-task aspect of the classifier enables it to concurrently classify the disease through the integration of image-based inputs and structured data. The proposed approach was evaluated using the ISIC 2018 dataset, which includes both image and clinical information for patients with skin diseases. This dataset encompasses data on 7 different categories of skin diseases. Our findings indicate that the proposed model exhibited a high level of accuracy, specifically 97.66% for the primary classification task (Image classification). Furthermore, the second classification task (clinical data classification) demonstrated an accuracy of 94.40%. The results of our proposed methodology demonstrate that it surpasses traditional single-modal and single-task classifiers.

The proposed classifier for improved classification of skin diseases offers several benefits. One of the key contributions of this model is that it utilizes multiple sources of information, including images of skin lesions and patient-specific information, to improve the accuracy of disease classification. Additionally, the multi-task aspect of the classifier allows it to simultaneously classify the disease and predict its severity, providing more comprehensive information for diagnosis. The use of transfer learning techniques also allows for better performance in real-world scenarios and faster training times. While the proposed approach for improved classification of skin diseases offers many benefits, it also has some limitations. One limitation is that the proposed approach is based on a dataset of skin diseases, which means that it may not be able to generalize well to other types of skin diseases or other medical conditions. Another limitation is that the model still requires a large amount of labeled data for training, which can be challenging to obtain. Moreover, while the proposed classifier shows promising findings, it is important to be aware of these limitations and to continue researching ways to improve the model's performance and applicability. Table V presents a comparison of the proposed multi-modal and multi-task DNN with a TL classifier to other methods discussed in the literature. The table compares the performance of our system to other efforts in terms of accuracy metrics. The results show that our proposed system outperforms the other methods discussed in the literature, indicating that it is a promising approach and offers significant potential for improving skin disease classification. The superior performance exhibited by our system reinforces its viability as an advanced and effective method in the field, highlighting its potential for enhancing diagnostic accuracy and facilitating improved patient care.

TABLE V. COMPARATIVE OUTCOMES OF THE PROPOSED APPROACH WITH EARLIER STUDIES PUBLISHED IN THE LITERATURE

Ref	Dataset (Classes)	Models	Accuracy
[26]	ISIC 2018 Dataset (7)	RegNetY-3.2G-Drop	85.8%
[27]	ISIC 2019 Dataset (8)	SSD-KD	84.6%
[30]	ISIC 2018 Dataset (7)	E2EDT	87%
Pr. Model	ISIC 2018 Dataset (7)	M3T_DNN_TL <sup>a</sup>	97.66%
			94.40%

<sup>a</sup>. Multi-Modal and Multi-Task DNN with TL

### V. CONCLUSION AND PERSPECTIVES

In conclusion, this study proposed a multi-modal and multi-task DNN with TL for improved classification of skin diseases. The proposed approach utilizes multiple sources of information, including images of the skin lesions and patient-specific information, to improve the accuracy of disease classification. The classifier's ability to perform multiple tasks enables it to classify the disease by utilizing both image input and structured data input simultaneously. The results of the study demonstrate that the proposed model achieved high accuracy on the ISIC 2018 dataset, outperforming traditional single-modal and single-task classifiers.

As perspectives, there are several promising avenues for future work building upon the findings of this research. One prospective direction involves exploring additional data sources to further enhance the accuracy and robustness of the model. On the other hand, incorporating genetic data, patient history, or environmental factors could provide a more comprehensive understanding of skin diseases and enable more precise classifications. Additionally, investigating advanced techniques, such as ensemble models and the XAI technique, may improve the performance and generalization capabilities of the classification system.

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# Auto-Regressive Integrated Moving Average Threshold Influence Techniques for Stock Data Analysis

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**Abstract**—This study focuses on predicting and estimating possible stock assets in a favorable real-time scenario for financial markets without the involvement of outside brokers about broadcast-based trading using various performance factors and data metrics. Sample data from the Y-finance sector was assembled using API-based data series and was quite accurate and precise. Prestigious machine learning algorithmic performances for both classification and regression complexities intensify this assumption. The fallibility of stock movement leads to the production of noise and vulnerability that relate to decision-making. In earlier research investigations, fewer performance metrics were used. In this study, Dickey-Fuller testing scenarios were combined with time series volatility forecasting and the Long Short-Term Memory algorithm, which was used in a futuristic recurrent neural network setting to predict future closing prices for large businesses on the stock market. In order to analyze the root mean squared error, mean squared error, mean absolute percentage error, mean deviation, and mean absolute error, this study combined LSTM methods with ARIMA. With fewer hardware resources, the experimental scenarios were framed, and test case simulations carried out.

**Keywords**—Dickey-Fuller test case (DF-TC); recurrent neural network (RNN); root mean square error (RMSE); long short-term memory (LSTM); machine learning (ML); auto-regressive integrated moving average (ARIMA)

## I. INTRODUCTION

This study focuses on predicting and estimating possible stock assets in a favorable real-time scenario for financial markets without the involvement of outside brokers about broadcast-based trading using various performance factors and data metrics. With regard to broadcast-based trading, the main objective of this study is to predict and estimate possible stock assets in a favorable real-time scenario for the Saudi financial markets, excluding outside brokers. Sample data from the Y-finance segment was assembled into API-based data series with exactitude and sharpness. Prestigious machine learning algorithmic performances for both classification and regression complexity increase significantly. Because stock movement is fallible, noise is produced as a result, which leaves decision-making vulnerable. Fewer performance measures were used in earlier research investigations. Previous studies relied on fewer

performance metrics [6]. The focus of the study is to use comprehensive models with unique parameters to predict more precisely. Methods considered in this research are long-short-term memory (LSTM) and auto-regressive integrated moving average (ARIMA), along with various performance measures. The major contribution of this study relies on the fast execution of simulation processes with fewer hardware resources in the case of predictions with the Long Short-Term Memory Algorithm. Every researcher wishes to prototype stock prices efficiently with less noise so that stock buyers can consequently decide when to trade or invest to make a generous profit [8].

Better time series models and intricate ML models can both contribute to success. Stock values, nevertheless, are very erratic and unpredictable [7]. Overall, this indicates that there is little consistency in data patterns for estimating stock prices across an effective time horizon. On time series data, LSTM meshes [26] are effectively used for classification evaluation, computation [15], and prediction. They inherit the ability to retain data or information over various time periods and have twice as much processing power to handle data points, sequences, and series [16]. In other words, LSTM is renowned for its ability to store large amounts of data [8]. The only components used by LSTM are those referred to as gates. Prices on the stock market are nonstationary data sources. In the intraday or off-market, rising and falling movements [4] are not linear. They fluctuate and diminish in response to repository, fund, and pressure; they are remarkably predictable when coupled with a model. Evaluation of stock price prediction can demonstrate its value in advancing an investor's career and development [25]. Many investors base their choices on financial news or the opinions of fictitious financial gurus working covertly. These financial counselors participate in insider trading, misuse investor emotions, and ultimately deplete or exploit investor wealth [14]. Companies' fundamental analyses take into account a number of factors, including quarterly net profit, long-term firm growth, and market risk tolerance. This study's goal is to provide a useful prediction data flow visualization for investors to use while making short-term decisions using unprocessed mathematical data from a variety of open-source repositories [13]. It is quite

difficult to predict stock prices in a real-time setting using both theoretical and numerical issues. The hypothesis study has been carried out by numerous researchers using various performance indicators, but which can determine the success or failure of future system implementation [10] based on the profit or loss experienced by individual investors [11] over the course of their lives.

**A. Evolution of Recurrent Neural Network (RNN)**

Firstly, it is anticipated that altogether inputs and outputs are interdependent of each segment in a neural terminology. However, it is not reliable for maximum scenario such as predicting the next day stock price in a financial market. RNN tends to utilize the resources of sequential pair information. They are so called recurrent due to their performance of the same simulation for every component of a sequence pair, in which output is dependable on the previous calculations. Thus, it is known that elements have recent memory that involves knowledge-based information that has been implemented so far.

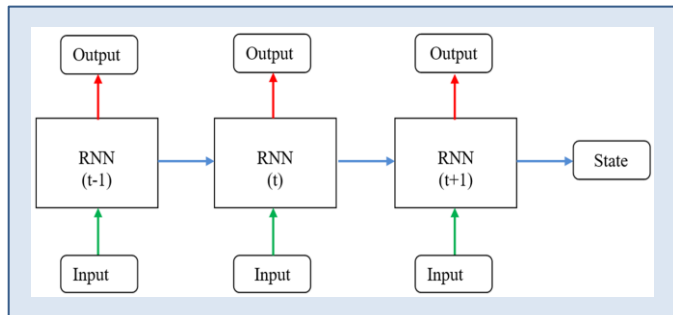


Fig. 1. Recurrent Neural Network and its states.

RNNs can make scrutinization of their internal state cell memory to compute pair of inputs in forecasting and prediction scenario. The full form of LSTM is classified as Long Short-Term Memory that comprises of three types of gates and cell state as shown in Fig. 1. LSTM has futuristic problem-solving capability and thus, it is introduced to overcome the problems inhibited by the RNN modeling [17] execution. The Fig. 2 represents the simulation depicting various sectors of Saudi stock market for ARIMA and LSTM. Undoubtedly, Input gate is activated when new piece of information is incremented into the current state of LSTM. LSTM can be implemented to elucidate Long Term interdependency [19] of variables issues in RNNs. The modules constitute of three gates namely Forget gate and next Input gate and then Output gate in the last segment. The forget gate manages what type of information has to be thrown out of memory state and responsible for take decisions related to time of remembrance. Output gate decides what to throw out of memory. Humans cannot think every time from the beginning of every problem from scratch [18].

**B. Auto-Regressive Integrated Moving Average (ARIMA) Model**

The terminology is composed of AR that stands for Auto regressive and it manipulates the dependency relationship among the observation and lagged time Observations. Integrated is responsible for operating differencing between

raw observations in order to maintain stationary state of data. Lastly, MA stands for Moving Average that anticipates the relationship of observations and residual sort of error [19]. Generally, time series consist of continuous [20] data that consist of seasonal component and cyclic component followed by trend component. During the statistical analysis of stock, it is recommended to focus on its returns which have been taken after investing in the financial market. The forecasting equation is prepared as mentioned.

The forecasting equation is prepared as follows.

$$\text{if } d=0 : y_t = Y_t \tag{1}$$

$$\text{if } d=1 : Y_t - Y_{(t-1)} \tag{2}$$

$$\text{if } d=2 : y_t = (Y_t - Y_{t-1}) - (Y_{t-1} - Y_{t-2}) = Y_t - 2Y_{t-1} + Y_{t-2} \tag{3}$$

In terms of y, the normal forecasting of ARIMA equation is as follows:

$$\hat{y}_t = \mu + \phi_1 y_{t-1} + \dots + \phi_p y_{t-p} - \theta_1 e_{t-1} - \dots - \theta_q e_{t-q} \tag{4}$$

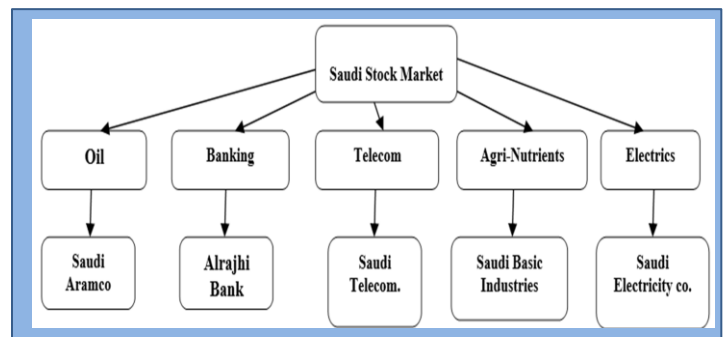


Fig. 2. Simulation depicting various sectors of Saudi stock market for ARIMA and LSTM.

In this study, Dickey-Fuller testing scenarios combined with time series volatility forecasting and the Long Short-Term Memory (LSTM) algorithm, which used in a futuristic recurrent neural network setting to predict future closing prices for large businesses on the stock market.

This article is organized in five sections: Section I included a detailed introduction about the key concepts, and Section II articulated the significant literature collectively with the background to the research work. Section III described the proposed methodology with Dickey-Fuller testing scenarios combined with time series volatility forecasting and the Long Short-Term Memory (LSTM) algorithmic sequences. The proposed methodology has integrated for simulation for different Saudi companies on the basis of ARIMA, LSTM and Agent Based Prediction. Section IV contains the experimental analysis, results, and discussions. Section V states the conclusions with achievements along with the future scope.

**II. RELATED WORK**

This section has analyzed the related study, innovations and executional scenarios of existing models and approaches. The author F. Kamalov, L. et al. (2020) compared various methods to perform prediction based on neural networks for the very forthcoming market opening value of SP 500 global indices by

focusing on its historic stock values [1]. B. B. P. Maurya, et al. (2019) explained the complexity of ML problems by using parameters such as E Ratio, Moving Average and MACD for better correctness [2]. C.C. Emioma et al. (2021) made intention to be implemented least-squares LR model for the guidance of intraday [3]. Nti IK, Adekoya AF et al. demonstrated that financial market investment decisions were 66% regarding technical analysis and further 11% and 23% were anticipating on the fundamental aspects and extended decisions 8.26% and 2.46% were dependent on combined analyses [28].

Samara A. Alves et al. (2018) focused on the Brazilian stock market and developed a decision model to compute the stock price with respect to certain technical indicators [29]. Traditional Neural Networks have few limitations for simulating the data as it is dependable on hardware structure with parallel processing. Moreover, Functioning of ANNs is so uncertain that it leads to why and how questions regarding trust build in the network. There is no determined assurance of Specific network structures; it is only possible with trial and experience. Chun-Hao Chen et al. (2020) proposed an algorithm for company-based portfolio by computing through Genetic programming algorithm and dividing the stocks into groups that can be effective for investor decisions [5]. Consequently, Traditional Neural network can work with numerical problems, but it faces performance issues while demonstrating the problem to the ANNs. The time duration of the network cannot be set, and it can be reduced to a specific value of error on a data sample that indicates training has been completed. Thus, ANNs do not give us exact results for simulation. Adaptive Neuro Fuzzy inference systems have major limitations in handling large inputs; thus, computation cost becomes very high in case of gradient learning and complex structure. Furthermore, few drawbacks are concerned with the location of the desired membership function and the curse of dimensionality [27].

Some researchers proposed neural networks, fuzzy logic control systems (FLCS) [30], genetic algorithms to analyze the stock market, medical and image based optical text recognition data [33][37][44]. Some other researchers proposed hybrid models such as neural fuzzy hybrid system [41][37][44], neural-genetic algorithm [38]. The neural fuzzy hybrid system (NFHS) operated separately. The unified NFHS utilizes the process to discover all factors from FLCS [42][45]. NFHS can correspond to exercise data produced from n-measurements of functionalities. NFHS comprises the fault figuring segment to advance the learning-training directions while the faults been unhurried, primarily membership sequences demarcated, then membership arrangements constraints stimulated. Zhao, Z., Zhou, H., Li, C., Tang, J., Zeng, Q. (2021) analysed that networks with incomplete information cannot be proposed effectively with partially familiar nodes, links and labels and their extended work is based on designing an inductive embedding model to solve real world network problems. The parameter used in ANFIS has a direct relation with computational cost [30]. In recent years, many researchers have been working diligently for this cause and experimented

over various ML algorithms to discover a prime solution in social benefit, numerous classical methods like SVM, DT, RF along with algorithms from NN family like DNN, ANN, neural fuzzy hybrid systems [39] and many others have come up with satisfactory result with some future scope [40][43]. The parameters used for evaluation are closing price, price differences, and daily return. Another research proposed automated decision making ResNet feed-forward neural network-based methodology for the medical diagnosis of diabetic retinopathy [51]. In another research integrated with the simple, multiple linear regression models [31][32][36] to generate a signal for SPY growth.

### III. METHODOLOGY

In the methodology, imported feasible libraries such as math, pandas, data reader, Sequential, Dense, LSTM are used in preliminary stage. Furthermore, Obtain the stock price using the Yahoo Finance API, then display the date in a table. Find out how many columns and rows there are in the data set. Visualize the history of closing prices while waiting. Convert a new Df to a numpy array after creating a new Df with a close column. Scale the data after obtaining the counting number of rows to train the computing model on. X\_train and Y\_train data sets should be created together with the training dataset and scaled training data set. X\_train and Y\_train should be converted to numpy arrays to transform the data into three dimensions. Build the LSTM model, compile the model and get the RMSE value. Plot the data and visualize and then show the validation and prediction price. If (Validation Price is greater than Prediction) then execute Buy Signal for the API Bridge. If (Validation Price is less than Prediction) then execute Sell Signal for the API Bridge. Set Money Management with maximum lose acceptance with proper Stop Loss at executive of each signal in API Bridge. Set Profit Target with each investment decision execution with Broker Account. Evaluate the Win ratio and Profit ratio. Repeat the process according to the Money management portfolio. The financial Market is quite a considerable at biggest challenge in statistics. Many individuals think that only technical analysis can beat it and can earn some sort of money, but reality is bit uncertain in the real time scenario as shown in the Fig. 3.

Build the LSTM model, compile the model and get the RMSE value. Plot the data and visualize and then show the validation and prediction price. If (Validation Price is greater than Prediction) then execute Buy Signal for the API Bridge. If (Validation Price is less than Prediction) then execute Sell Signal for the API Bridge. Set Money Management with maximum lose acceptance with proper Stop Loss at executive of each signal in API Bridge. Set Profit Target with each investment decision execution with Broker Account. Evaluate the Win ratio and Profit ratio. Repeat the process according to the Money management portfolio. The financial Market is quite a considerable at biggest challenge in statistics. Many individuals think that only technical analysis can beat it and can earn some sort of money, but reality is bit uncertain in the real time scenario as shown in the Fig. 3.

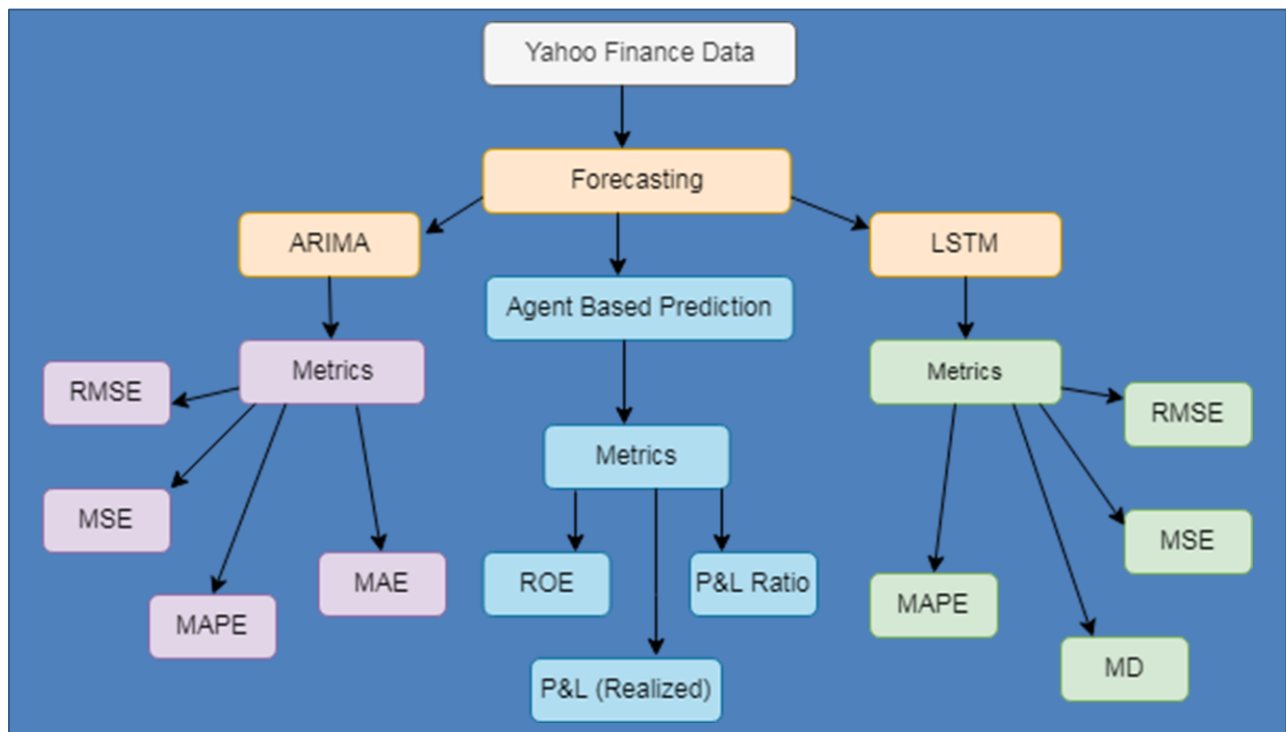


Fig. 3. Methodology for simulation for different Saudi companies on the basis of ARIMA, LSTM and agent based prediction.

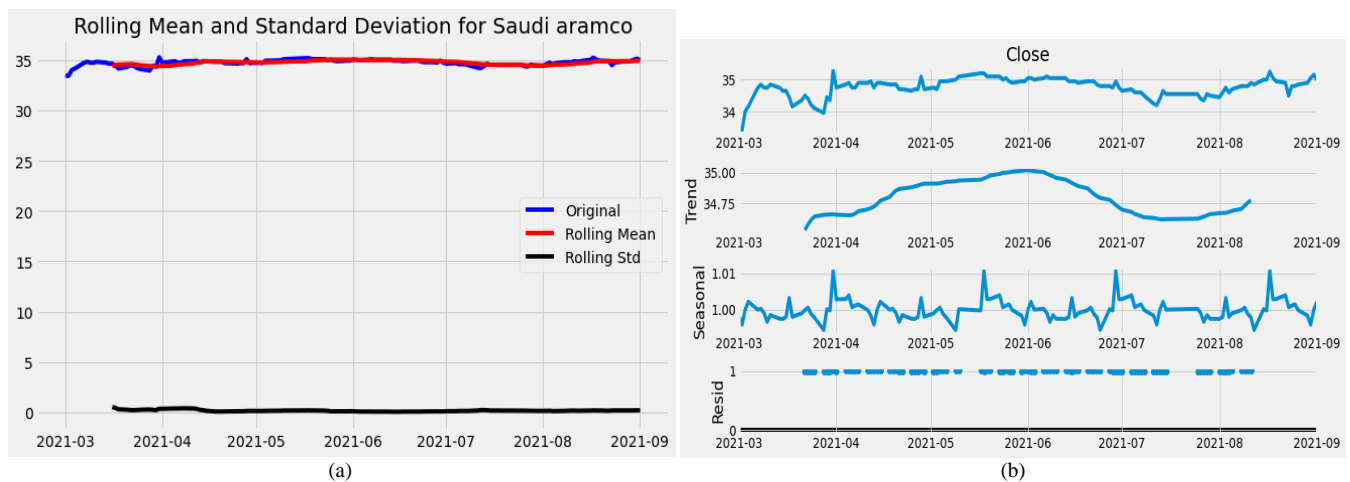


Fig. 4. (a) Test for stationary (b) Seasonal decay of Saudi Aramco.

Earlier, traditional statistics [22] models were emphasized on exponential smoothing and linear [21] prediction for ARIMA Models. Non-stationary [12] information is known as the information whose measurable properties for example the mean and standard deviation are not consistent over the long run but rather all things considered, these measurements change over the long haul. Firstly, Test for stationary and determine rolling statistics and Plot rolling. The Fig. 4(a) and 4(b) represents the test for stationary and seasonal decay of Saudi Aramco.

The tensor flow libraries are integrated in this research. Tensor flow will be utilized as a back end for LSTM model prediction of ten large cap companies listed on the Saudi stock exchange. Fig. 5 represents the forecasting of Saudi Aramco

using ARIMA model for training and predicting and Fig. 6 represents the simulation of Saudi Aramco using LSTM model. Data has been sourced from yahoo finance through API as it is continuous form of data with high precision and accuracy. The data set has been sourced online through yahoo finance API for past six Months. Furthermore, Data is fetched in terms of rows and columns [9]. The p-value of Saudi Oil Company comes out to be 0.000019. Company code for Saudi Aramco is 2222.SR and elaborates that the seasonal trend remained stable in May-2021 and showed a modest rise in August 2021. The Seasonal Trend reached its peak in August 2021 and further share price climbed down in consecutive months. Author has made sure of the installation of tensor flow libraries. Tensor flow will be utilized as a backend for LSTM model prediction of ten large cap companies listed on the Saudi stock exchange. Data has

been sourced from yahoo finance through API as it is a continuous form of data with high precision and accuracy. The data set has been sourced online through yahoo finance API for the past Six Months. Furthermore, Data is fetched in terms of rows and columns. Fig. 7(a) and 7(b) represents the test for stationary and seasonal decay of AlRajhi Bank.

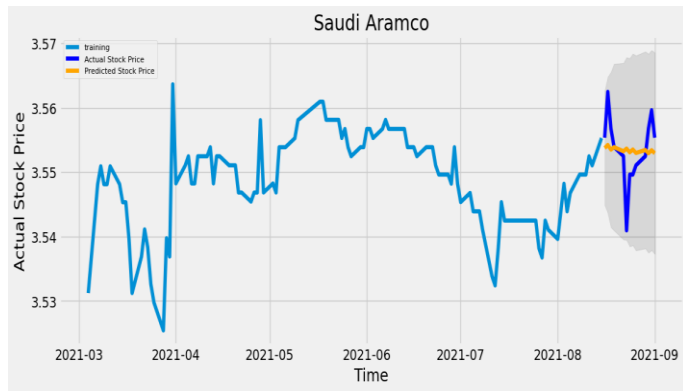


Fig. 5. Forecasting of Saudi Aramco using ARIMA model for training and predicting.

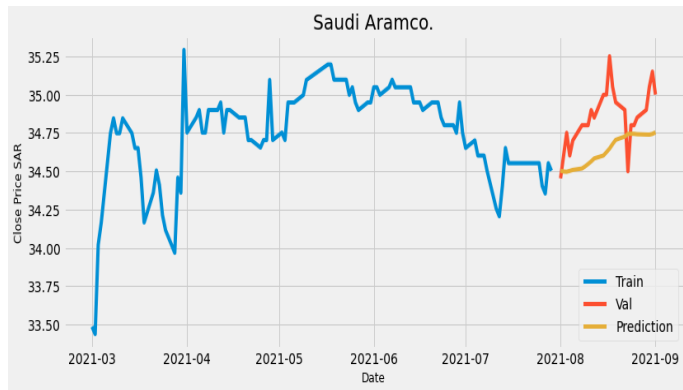


Fig. 6. Simulation of Saudi Aramco using LSTM model.

In the last case chosen to stop with the occasionally differenced information, and not done an extra round of differencing. In the previous case concluded that the information was not adequately fixed and taken an extra round of differencing. Fig. 8 represents the forecasting of AlRajhi Bank using ARIMA model for training and predicting scenarios.

Biggest challenge is to find the relation between independent variables and results of stock market movement. Author has utilized specific [23] set of features including Open Price, Close Price, Date, High Price and Low Price and increment of other variables such as Volume can be considered under observation forcing the model to over-fitting and using maximum limit of memory and execution time for Signal Generation. Nevertheless, Data collected should not be in irregular form, but it should be categorized into three components [24] such as trend, seasonal and irregular variations (noise). The Table I represents the results of dickey fuller test cases. Fig. 9 represents the simulation of AlRajhi Bank using LSTM model for training and predicting scenarios.

Meanwhile, it needs to choose what will yield. This yield will be founded on cell state yet will be a sifted adaptation. To begin with, it run a sigmoid layer which chooses parts of the cell state which will yield. Then, at that point, it put the cell state through tanh (to push the qualities to be somewhere in the range of  $-1$  and  $1$ ) and increase it by the yield of the sigmoid door, so it just yields the parts chose to. Another variety is to utilize coupled neglect and information doors. Rather than independently choosing what to neglect and what new data is to be added, it settles on those choices together. It possibly fails to remember when it will include something in its place. Figure.8 corroborates the upward trend starting from April 2021 till the Middle of August 2021 and thus represents the strong bullish trend. Fig. 9 represents the clear view of reaching a peak, supports the positive slope, shows the complex understanding, and thus results in inappropriate decisions based on forecasting.

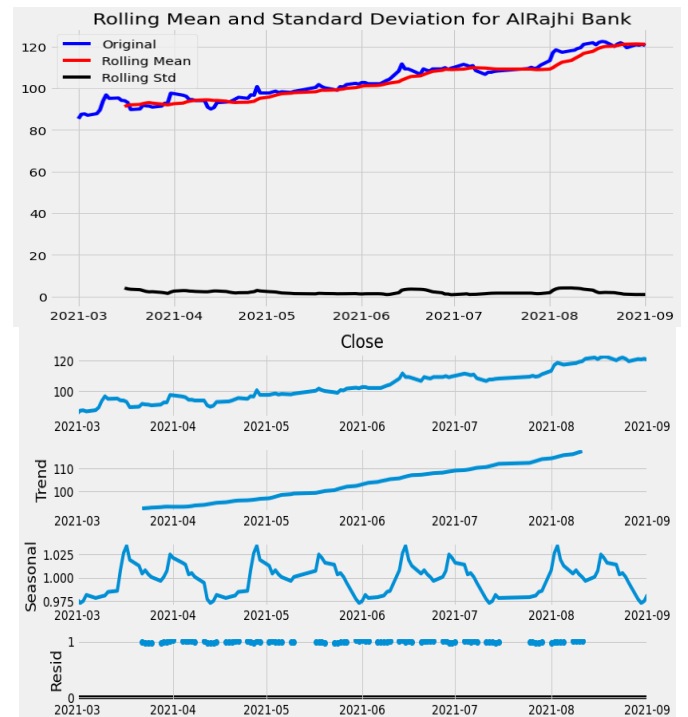


Fig. 7. (a) Test for stationary (b) Seasonal decay of AlRajhi Bank.

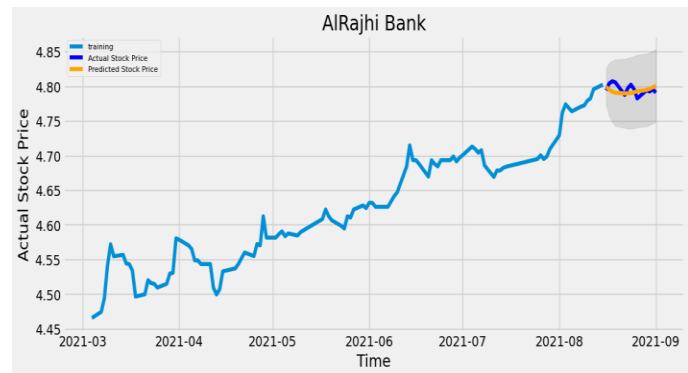


Fig. 8. Forecasting of AlRajhi Bank using ARIMA model for training and predicting.



TABLE I. RESULTS OF DICKEY FULLER TEST

Date	Saudi Oil Company	Sabic	Saudi Telecom Company	AlRajhi Bank	Saudi Electric
Test Statistics	-5.036501	-2.267665	-1.614740	-0.624222	-1.524622
p-value	0.000019	0.182609	0.475488	0.865414	0.521298
No. of lags used	1.000000	2.000000	0.000000	0.000000	0.000000
Number of observations used	122.000000	121.000000	122.000000	123.000000	123.000000
critical value (1%)	-3.485122	-3.485585	-3.485122	-3.484667	-3.484667
critical value (5%)	-2.885538	-2.885739	-2.885538	-2.885340	-2.885340
critical value (10%)	-2.579569	-2.579676	-2.579569	-2.579463	-2.579463

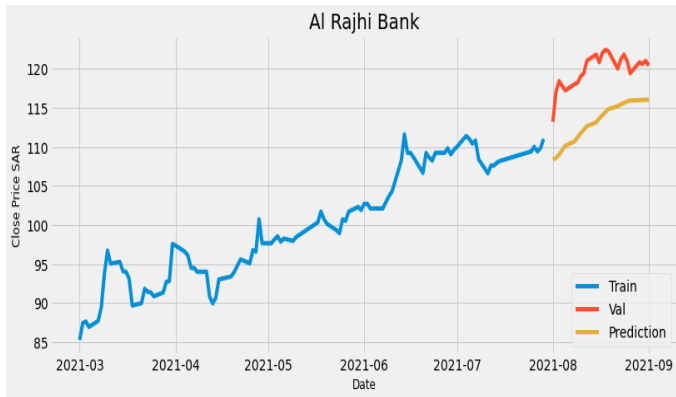


Fig. 9. Simulation of AlRajhi bank using LSTM model for training and predicting.

#### IV. RESULTS AND DISCUSSION

There are various Performance measures such as RMSE, MSE and MAPE which commutes the different models for better efficiency. Many Researchers have emphasized on volatility, risk-adjusted Returns, and annualized ROE. The conventional models have been extensively explored in the recent years with series of experiments with promising results in controlled environment. Mean absolute percentage error is used to check how accurate forecast system is for simulation. It works best if there are no extremes and no zeros. The Root Mean Square error is described by the famous equation:

$$MAE = \frac{\sum_{i=1}^n |y_i - x_i|}{n} \quad (5)$$

$$MSE = \frac{1}{n} \sum_{i=1}^n (Y_i - \hat{Y}_i)^2 \quad (6)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (\hat{y}_i - y_i)^2}{n}} \quad (7)$$

$$MAPE = \frac{1}{N} \sum_{i=1}^N \left| \frac{A_i - F_i}{A_i} \right| \quad (8)$$

The Table II and III represent performance evaluation of ARIMA, LSTM simulations for five Saudi large cap companies.

#### A. Performance Evaluation

Multiple Stock Implementation is an advanced system execution. Trend component is majorly responsible for the P/E ratio of the company. Oil Sector, Banking Sector, Telecom Sector, Electricity Sector, Agri-Nutrients sector are subjected to be in Neutral state and IT Sector has shown the tremendous return on investing in with six months as shown in graph above. Proposed strategy brings fruitful returns even in the downward trend of share price of the company whereas mutual funds perform in negative returns in the downward trend. Execution speed of simulation process is inversely proportional to the numbers of iterations and checkpoints. LSTM Model has outperformed in random behaviour of stock price in recent 6 months of Simulation. The Table IV represents LSTM simulation for prediction of future values for date range.

TABLE II. PERFORMANCE EVALUATION OF ARIMA SIMULATION FOR FIVE SAUDI LARGE CAP COMPANIES

Company	RMSE	MSE	MAPE	MAE
Saudi aramco	0.005070412205660918	2.5709079935315217	0.0010682802847078272	0.005744868
Sabic	0.027755576571618153	0.0007703720308229584	0.005226132552138616	0.0250790009
Saudi Telecom	0.04568627299705281	0.0020872355403612364	0.008360154621635196	0.0407561101
AlRajhi Bank	0.008819041195421698	7.777548760654495	0.008819041195421698	0.0075161085
Saudi Electric	0.03217546490482577	0.001035260541841675	0.008382192699030566	0.0275012912

TABLE III. PERFORMANCE EVALUATION OF LSTM SIMULATION FOR FIVE SAUDI LARGE CAP COMPANIES

Company	RMSE	MSE	MAPE	MD
Saudi aramco	0.238773991	0.057013019	0.574486769	0.005744868
Sabic	2.204756145	4.860949658	1.54812692	0.015481269
Saudi Telecom	3.695281521	13.65510552	2.487721972	0.02487722
AlRajhi Bank	5.132353049	26.34104781	4.083731512	0.040837315
Saudi Electric	1.234438743	1.52383901	4.471457408	0.044714574

TABLE IV. LSTM SIMULATION FOR PREDICTION OF FUTURE VALUES FOR PARTICULAR DATE RANGE

Date	Saudi Aramco	Sabic	Saudi Telecom	AlRajhi Bank	Saudi Electric
26/07/2021	34.56294	119.2195	131.6964	110.584587	24.65017
27/07/2021	34.55291	119.2312	131.5029	110.594391	24.70572
28/07/2021	34.54129	119.2938	131.3703	110.615211	24.7513
29/07/2021	34.53437	119.3825	131.2944	110.652504	24.7974
1/08/2021	34.52932	119.5055	131.3437	110.729454	24.84629
2/08/2021	34.52451	119.6569	131.5178	110.884186	24.89191
3/08/2021	34.52408	119.855	131.7979	111.176895	24.94292
4/08/2021	34.53044	120.0996	132.1428	111.580421	24.98923
5/08/2021	34.53705	120.395	132.525	112.023445	25.02607
8/08/2021	34.54638	120.7407	132.9404	112.458649	25.06011
9/08/2021	34.55962	121.0715	133.3473	112.889755	25.08574
10/08/2021	34.57486	121.2677	133.7529	113.305061	25.10249

B. Agent Based Prediction

Proposed Strategy can be considered as decision support mechanism that can be used to develop both classification and somewhat regression problem solver model. Implementation of Saudi Stock Market is more like if then else condition programmatically. It can be used in series of data that involve call node and sometimes leaves that means breaking of bigger problem into smaller one to onto sub classes. Real time performance metrics illustrated the exact return over investment can be considered as total return on equity (ROE), Total profit and loss (P/L), Total Gain/loss Ratio.ROE depicts the capability of the firm to return equity investment into profits. Initially, it is recommended to calculate the variance and then get desired value of standard deviation. Total gain/Loss ratio is just like a scorecard for an active person who major objective is to maximum gains. The simplest method to calculate the volatility of a company is to evaluate the standard deviation of stock prices for specific time interval. The tradition formula for evaluation return on equity is as following equation 9, 10 and 11:

$$ROE = \frac{\text{Net Income}}{\text{Shareholder Equity}} \tag{9}$$

$$\text{Profit and Loss Ratio} = \frac{\left(\frac{\text{Total Gain}}{\text{Number of Winning Trades}}\right)}{\left(\frac{\text{Total Loss}}{\text{Number of Losing Trades}}\right)} \tag{10}$$

$$\text{Profit and Loss (Realized)} =$$

$$(\text{Average Sell Price} - \text{Average buy Price}) \times \text{Quantity} \tag{11}$$

Initially, the yfinance module must be installed in google Collaboratory. The window size has been kept as 100. Starting Money has been set to 10000 and layer size as 400 and moreover, number of iterations as 300 and checkpoints are declared as 10. Research has calibrated on historical data through Yahoo Finance Application Interface Data. Period for data is six months starting from 2 March 2021 to 2 September 2021. The Fig. 10 represents the performance for proposed strategy for Saudi telecom Co. (7010.SR).



Fig. 10. Shows performance for proposed strategy for Saudi Telecom Co. (7010.SR).

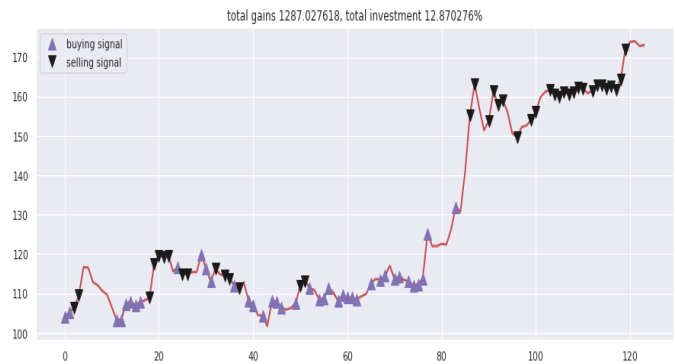


Fig. 11. Shows performance for proposed strategy for Al Moammar information systems (7200.SR).

Researchers have not used an overriding function to forcibly fetch data. Instead yfinance module is used for directly sourcing data with more precision and accuracy. Fig. 10 is concerned with the performance of the Saudi Telecom company with 3.8878 Percentage return over the initial investment of 10000 credits. Total gains reported in the simulation of strategy for the Saudi Telecom company were 388.78. Fig. 11 depicts performance for Al Moammar Information Systems with return over investments of 12.8702 percentages within 6 months and total gains are reported to be 1287.02 with respect to initial investment of 10000. Time-series anticipating models are the models that are proficient to foresee future qualities dependent on recently noticed qualities. Time-series anticipation is broadly utilized for non-stationary information. This non-stationary information (utilized as contribution to these models) is normally called time-series. The hypothesis study has been performed by various researchers using different performance measures, but it can judge success or failure of future implementation of the system depends on profit or losses faced by the individual investors in their lifetime process.

The Table V and Fig. 12 shows the comparative analysis of proposed methodology with existing approaches based on implicated methods, dependable and non-dependable parameters, time constraints, supporting data metrics and computational values. Researchers relied on neural networks, Support Vector Machines, trend indicators while computations on raw mathematical data utilized from various open-source repositories. Predicting stock values in a real time environment is a very uncertain task for both theoretical as well as numerical problems. Consequently, the company valuation depends on quarterly earnings and yearly cash flows using technical and fundamental analysis. However, it is bit risky to believe on the facts and figures released by the company to consider that a stock company has both justifiable earnings.

TABLE V. COMPARATIVE ANALYSIS OF PROPOSED METHODOLOGY WITH EXISTING APPROACHES BASED ON IMPLICATED METHODS

Author Name	Method	Prediction
Chun-Hao Chen et.al. [46]	GGA based GSP	87.8%
Gautam Srivastava et.al. [47]	SSACNN, CNNpred, SVM, NN	89%
Wen M [48] et.al.	CNN for trend-based prediction. LSTM, HMM, and ARIMA for Pattern Recognition	92.32%
Md. Mobin Akhtar et.al. [49]	LSTM, SVM, and news feature extraction.	80.3%
Pei-Yuan Zhou et.al. [50]	Relationship prediction rules	82.92 %.
Proposed Methodology	LSTM, SVR Regressor, and Linear Regressor based Hybrid simulation.	97.5 %

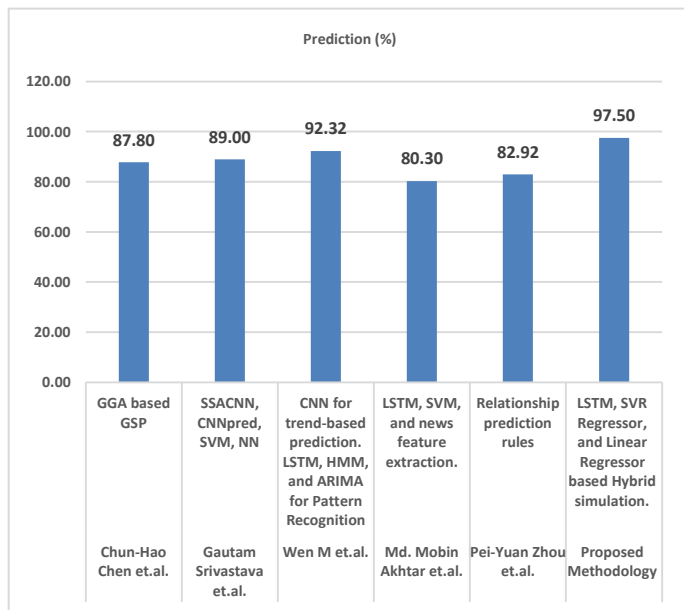


Fig. 12. Comparative analysis of proposed methodology with existing approaches.

The future system can be focused on multiple stock implementations that require high configuration hardware resources for concurrent execution [34][35]. A few instances of time-series incorporate the temperature esteems over the long haul, stock cost over the long haul, cost of a house over the

long haul and so forth in this way, the information is a sign (time-series) that is characterized by perceptions taken consecutively on schedule. There have been endeavors to anticipate stock costs utilizing time series investigation calculations; however, which not utilized to put down wagers in the genuine market.

## V. CONCLUSION

With regard to broadcast-based trading, this study focuses on the forecast and assessment of possible stock assets in a real-time favorable scenario for the Saudi financial markets, exclusive of external brokers. With the use of a futuristic recurrent neural network environment and the Long Short-Term Memory algorithm (LSTM), this research combined Dickey-Fuller testing scenarios, forecasted time series volatility, and anticipated the closing prices of large-cap businesses on the stock market in the future. Sample data from the Y-finance sector was assembled using API-based data series and was quite accurate and precise. In order to analyze the root mean squared error, mean squared error, mean absolute percentage error, mean deviation, and mean absolute error, this study combined LSTM methods with ARIMA. It is concluded that Aramco has demonstrated the lowest value of RSME when compared to other large-cap businesses. Various tests and simulations display validations and forecasts along with the value of the root mean square error. With fewer hardware resources, the experimental scenarios were framed, and test case simulations carried out. Using the available data, future work can be expanded to include low- or opening-price predictions for stocks. Aside from RMSE estimates, the extended work may also include other performance indicators.

## AUTHORS' CONTRIBUTIONS

Conceptualization, Singh., B., Henge. S.K.; methodology, Singh., B., Henge. S.K.; software, Singh., B., and Mandal. S.K.; validation, Iyer., S., B., Henge. S.K. and R.K.A. Gupta.; formal analysis, Singh., B., Henge. S.K.; investigation, Iyer., S., and Yadav, M.K., resources, Yadav. M.K., Yadav. P.T, Iyer., S.; data curation, Upadhyay, A., Singh., B., Yadav, M.K.; writing— Singh., B., Henge. S.K.; writing—review and editing, Singh., B., Henge. S.K.; visualization, Upadhyay, A., Singh., B., Henge. S.K., and Mandal. S.K.; supervision, Henge. S.K.; project administration, Henge. S.K.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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# Evaluations on Competitiveness of Service Sector in Yangtze River Economic Belt of China Based on Dual-core Diamond Model

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**Abstract**—By expanding and innovating Michael Porter Diamond Model, a Dual-core Diamond Model is developed in this paper with innovation and openness as the core factors in consideration of the actual needs of the development of service sector in the Yangtze River Economic Belt of China. This paper establishes an evaluation indicator system of service sector competitiveness profitability to measure and evaluate the competitiveness of service sector in 11 provinces and towns in the Yangtze River Economic Belt through PCA (principal component analysis) based on the relevant information of the 11 provinces and towns mentioned above in 2015 and 2016. The research results indicate that the design of Dual-core Diamond Model is in line with the current situation and future development needs of the service sector in the Yangtze River Economic Belt, and the dual-core factors, namely, innovation and openness, have become the most important factors influencing the competitiveness of the service sector in the Yangtze River Economic Belt. Based on the model analysis results, it should propose strategies to enhance the competitiveness of the service industry in the Yangtze River Economic Belt. It needs to enhance innovation ability as well as to further expand trade in services. Firstly, encourage the growth of related industries and create a coordinated development cluster for the service sector. Second, intensify efforts in talent cultivation and build a talent system in alignment with the development of service sector. Third, improve the relevant legal system and innovate the service supervision and governance system in the service sector. Last, focus on a coordinated and integrated inter-region development.

**Keywords**—Dual-core diamond model; service sector; Yangtze river economic belt; principal component

## I. INTRODUCTION

Eleven (11) provinces and towns, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan, and Guizhou, are included in the Yangtze River Economic Belt. They are the most developed regions in the Yangtze River Basin, accounting for 21.4% of China's national territory area and 40% of the China's national GDP. The Yangtze River Economic Belt accounted for 44.1% of the national GDP in 2018<sup>1</sup>. The Yangtze River Economic Belt has unique potential for growth and obvious advantages in transportation, natural resources, industrial groups, human

resources and urban construction. Supporting the development of service sector is an effective strategy to facilitate the industrial innovation and transformation and enhance the industrial competitiveness in the Yangtze River Economic Belt, which is conducive to tapping into the potential of domestic demand in the upper and middle regions of the Yangtze River, forming a pattern of cooperation and interaction and mutual benefits of advantages throughout the Yangtze River's upper, middle, and lower sections, effectively reducing the regional development gap. From 2009 to 2016, the GDP of the service sector in the Yangtze River Economic Belt increased from RMB 6,283.8 billion to RMB 16,538.6 billion, accounting for 43.14% of national GDP in service sector, up from 29.08%<sup>2</sup>. Directive Opinions on Promoting the Development of Yangtze River Economic Belt Supported by the Golden Waterway, Outline of Yangtze River Economic Belt Development Plan and other plans and policies have outlined the development needs for promoting the innovative and coordinated development, transformation and improvement of service sector in Yangtze River Economic Belt.

Some scholars have started to study industrial competitiveness under the framework of Michael Porter Diamond Model. Joshi incorporated the Diamond Model to examine the competitiveness of Indian automobile industry [1]. Yonghong constructed the evaluation indicator system of competitiveness of shipbuilding industry cluster based on the Diamond Model [2]. Esen studied the competitiveness of Turkish tourism industry by comparing with the Diamond Model [3]. Zhao utilized the Diamond Model to identify and examine the variables influencing the development of China's photovoltaic industry [4]. Based on the Diamond Model, Wu analyzed and investigated the competitiveness of China's coal sector [5]. Zheng et al. and Wan identified the variables influencing the trade in services sector of China and proposed countermeasures to enhance its competitiveness based on Porter's Theory of International Competitiveness Advantage [6][7]; Gu and Xia analyzed the main factors for enhancing the competitiveness of China's cultural industry based on the Diamond Model [8]. Zhuang et al. and Chen et al. believed that the four elements of Porter's "Diamond Model" are the

<sup>1</sup><https://baike.baidu.com/item/%E9%95%BF%E6%B1%9F%E7%BB%8F%E6%B5%8E%E5%B8%A6/5453694?fr=aladdin>

<sup>2</sup>Derived from *Statistical Yearbooks* of various provinces and cities.



main factors that affect the international competitiveness of the trade in services sector of China [9][10].

Based on researches on the level of growth of service sector in the Yangtze River Economic Belt, many scholars made an effort to establish an evaluation indicator system to identify the level of growth of service sector in the Yangtze River Economic Belt. Wu et al., Qian et al. and Zheng used factor analysis to evaluate the scale, structure, potential and benefits of service sector development in the Yangtze River Economic Belt [11-13]; Liu and Yao built models to evaluate the competitiveness of productive service sector and the development of modern logistics sector in the Yangtze River Economic Belt [14][15]; Xu et al. and Yang empirically analyzed the impact of human capital, transportation, income level and other factors on the development of service sector in the Yangtze River Economic Belt [16][17]; Wu et al. empirically tested the impact of market level of growth, economic level of growth, trade in services as well as the quantity of human capital and urbanization on the overall factor productivity of service sector in Yangtze River Economic Belt [18]. Yang et al. believed that carbon emission constraints and regression in technical level have a negative impact on the overall energy effectiveness of logistics sector in the Yangtze River Economic Belt [19]. Hu et al. and Sun et al. measured the amalgamation level of service sector in the Yangtze River Economic Belt [20-22]. Jing and Wang respectively adopted the Gray Relevance Total Analysis and Symbiosis Model to study the integrated development of service sector in the Yangtze River Economic Belt [23][24].

To sum up, enhancing the competitiveness of the service industry in the Yangtze River Economic Belt can promote the integration and development of industries in the Belt, as well as enhance the international competitiveness of the Belt. Some scholars have made some explorations on industrial competitiveness based on Michael Porter Diamond Model. Today, however, with the rapid development of service sector today, the research on the competitiveness of China's service sector needs to be further deepened and strengthened. This is especially demonstrated in the fact that the choice of factors affecting the competitiveness of service sector is scattered. Many scholars choose the affecting factors directly based on Porter's "Diamond Model". The selection of indicators has a certain degree of similarity. However, this paper holds that Michael Porter Diamond Model is not applicable to all countries, and its degree of explanation with regard to the industrial competitiveness of developing countries is not sufficient. This article believes that enterprises can improve their efficiency and competitiveness through technological innovation, institutional innovation, sales channel innovation, etc. By expanding openness, actively participating in international market competition, learning advanced management experience, and introducing more advanced

knowledge and technology, we can enhance the competitiveness of enterprises. Therefore, this paper combines Michael Porter Diamond Model and the authentic circumstances and conditions of Yangtze River Economic Belt to construct a "Dual-core Diamond Model" with "innovation" and "openness" as the core factors, and proves that this model is feasible and scientific for the service sector of Yangtze River Economic Belt through empirical test evidence.

## II. THE OVERALL DEVELOPMENT OF SERVICE SECTOR IN THE YANGTZE RIVER ECONOMIC BELT

### A. The Development Scale of Service Sector in 11 Provinces and Towns in the Yangtze River Economic Belt

Development scale of service sector in the Yangtze River Economic Belt. From 2009 to 2016, the GDP contributed by service sector in 11 provinces and towns in the Yangtze River Economic Belt increased continuously (see Table I and Fig. 1), from RMB 6,283.8 billion to RMB 16,538.6 billion, at a rate of 163.19%, indicating that the service sector in the Yangtze River Economic Belt is following a desirable development trend, and its scale is expanding constantly. Although its growth rate fluctuates slightly, it holds steady at a relatively high level.

Comparative analysis on the development of service sector in 11 provinces and towns of Yangtze River Economic Belt and the overall development of service sector in China. The GDP contribution of service sector in the Yangtze River Economic Belt rose to 43.14% in 2016 from 29.08% in 2009 (see Table I and Fig. 2). The service sector in the Yangtze River Economic Belt has grown rapidly, especially in recent years. The booming knowledge-intensive modern service sector has improved the quality of service sector development and promoted the modernization and transformation of the services sector. The service sector in the Yangtze River Economic Belt holds great development potential and is a pillar for the development of China's service sector.

Development of service sector of 11 provinces and towns in Yangtze River Economic Belt. As evidenced by the 2015 and 2016 statistics (Table II), there are obvious imbalances in regional development in 11 provinces and towns in the Yangtze River Economic Belt. In terms of service sector GDP in each region, Shanghai, Zhejiang and Jiangsu, which are located in the lower reaches, ranked among the highest, while Yunnan and Guizhou provinces in the western region of China, stayed at the bottom. The service sector GDP of Shanghai, the city with the top-scale service sector was nearly four times that of Guizhou, the city with the smallest service sector scale. Anhui ranked last in the service sector productivity, which was equivalent to approximately 1/4 of the value of Shanghai.

TABLE I. GDP OF SERVICE SECTOR IN YANGTZE RIVER ECONOMIC BELT AND ITS PROPORTION IN THE GDP OF CHINA FROM 2009 TO 2016

Year	2009	2010	2011	2012	2013	2014	2015	2016
GDP of service sector in 11 provinces and towns of Yangtze River Economic Belt (In RMB 100 million)	62838	64882	89708.9	101387	116633	130088	145193	165386
Growth rate of GDP of service sector in Yangtze River Economic Belt (%)	15.25	3.15	27.68	11.52	13.07	10.34	10.40	12.21
GDP of service sector in China (In RMB 100 million)	154748	182038	216099	244822	277959	308059	346150	383365
The proportion of GDP of service sector of the Yangtze River Economic Belt to that of China	29.08	35.64	41.51	41.41	41.96	42.23	41.95	43.14

Data source: China Statistical Yearbook, and Statistical Yearbooks of various provinces and cities

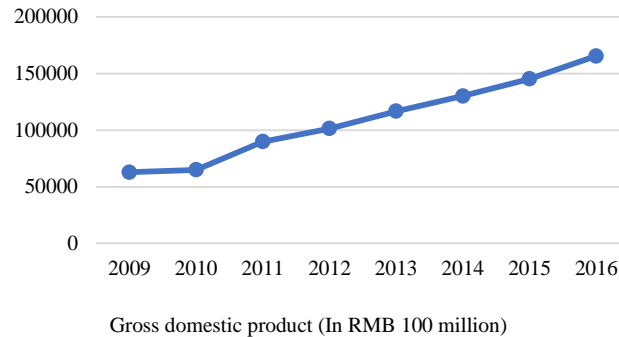
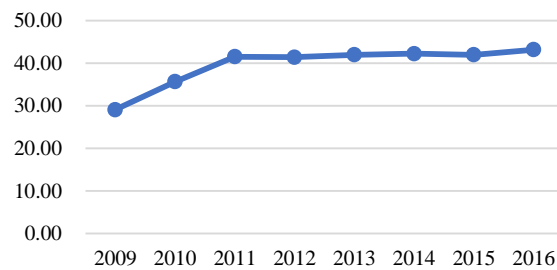


Fig. 1. Service industry in 11 provinces and cities of yangtze river economic belt.



Data source: Statistical Yearbook of various province and city

Fig. 2. Proportion of GDP of service industry of the yangtze river economic belt to that of China.

### B. The Scale of Employees in the Tertiary Industry in 11 Provinces and Towns of the Yangtze River Economic Belt

Fig. 3 depicts the shifts in the number of workers in secondary and tertiary industries in 11 Yangtze River Economic Belt provinces and cities between 2008 and 2016. It is obvious that the development trend in the scale of employees in the tertiary industry was quite consistent with the trend in the production scale of service sector, which continues to rise, and the gap between the employment by the tertiary and secondary industries was widening. It is evident that the service sectors of various provinces and towns in the Yangtze River Economic Belt have better capacity in boosting employment and attracting human resources.

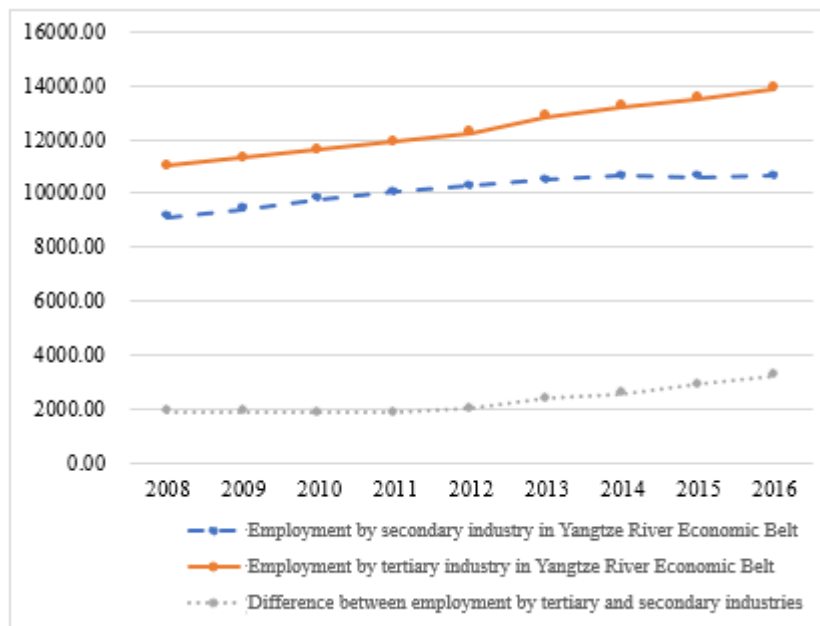
To sum up, the development of the service sector in the Yangtze River Economic Belt has become the powerhouse for the development of service sector in China. However, it still has certain shortcomings, such as a general lack of core technology, dependence on traditional industries in the

international market, and weak overall competitiveness in the service sector in the Yangtze River Economic Belt, especially in the middle and upper reaches of the Yangtze River. Therefore, a service sector driven by innovation will surely become a leading force behind economic development in the future. Meanwhile, with the high-quality economic development and the smooth progress in supply-side structural adjustment, the service sector in the Yangtze River Economic Belt needs to be further opened up in order to enhance economic benefits, encourage the modernization and transformation of industrial structures and raise the level of global industry competition. The efforts in the development of the service sector in the Yangtze River Economic Belt must be applied in a correct direction by seizing the emerging opportunities in global economic development and by identifying the strategies and routes that are aligned with the current development status and future development demands of the service sector in the Yangtze River Economic Belt.

TABLE II. GDP AND PRODUCTIVITY OF SERVICE SECTOR IN 11 PROVINCES AND TOWNS OF YANGTZE RIVER ECONOMIC BELT IN 2015-2016

Year	Province/city	GDP of service sector (In RMB 100 million)	Service sector productivity	Year	Province/city	GDP of service sector (In RMB 100 million)	Service sector productivity
2015	Shanghai	17274.62	20.19	2016	Hubei	14351.67	9.84
2016	Shanghai	19662.90	22.57	2015	Hunan	12796.87	8.98
2015	Jiangsu	34272.40	18.66	2016	Hunan	14631.83	10.30
2016	Jiangsu	38691.60	20.70	2015	Chongqing	7527.08	10.64
2015	Zhejiang	21341.91	14.86	2016	Chongqing	8538.43	11.46
2016	Zhejiang	24091.57	15.94	2015	Sichuan	13127.72	7.78
2015	Anhui	8602.11	5.02	2016	Sichuan	15556.29	8.99
2016	Anhui	9959.92	5.75	2015	Yunnan	6147.27	6.25
2015	Jiangxi	6559.63	6.69	2016	Yunnan	6875.50	6.78
2016	Jiangxi	7764.93	7.68	2015	Guizhou	4723.77	10.06
2015	Hubei	12819.76	9.03	2016	Guizhou	5261.01	10.39

Data source: China Statistical Yearbook, and Statistical Yearbooks of various provinces and cities



Data source: Statistical Yearbook of various provinces and cities

Fig. 3. Scales of employment by the tertiary industry and the secondary industry in the yangtze river economic belt and their difference.

### III. THEORETICAL MODEL

Porter put forward the Theory of Industrial Competitiveness Advantage for the first time and established the Diamond Model, which provided a further theoretical framework and reference for evaluating industrial competitiveness by breaking through the Theory of Comparative Advantage [25]. After that, some researchers used the Diamond Model to study industrial competitiveness, and the others expanded the model. Rugman et al. expanded Michael Porter Diamond Model into the “Double-diamond Model” by integrating the actual situation in Canada [26]. Cho et al. built the “Nine-Factor Model” based on the real conditions of South Korea, and believed that this model can explain the formation of competitiveness in underdeveloped

and developing countries [27]; Moon et al. built a “Generalized Double-diamond Model” adapted to the economic development of small countries based on the “Double-diamond Model” [28]. Rui added a core factor, namely, the “ability in knowledge absorption and innovation” to Porter’s “Diamond Model” and built the “New Diamond Model” by incorporating the actual development situation of China [29]. Zhao expanded Michael Porter Diamond Model and built the “New Diamond Model” with innovation in science and technology at its core [30].

The competitiveness advantage of the service sector in the Yangtze River Economic Belt is still concentrated on the traditional field. To build a high-end industry with high value addition in the international division of labor and to maintain a

sustainable competitiveness, we must integrate independent innovation in open market competition. The Communist Party of China's 19th National Congress report makes it clear that "Innovation is the key driving factor for development." The report also suggests a number of new initiatives and targets, including to "increase the service sector's opening up scope and quicken the cultivation of new advantages in international economic cooperation and competition." At present, as the process of global economic integration continues to accelerate and competition in the international market becomes more and more extensive and fierce, China needs to further open up its market and encourages the service sector to "go global", which has become a part of China's national strategic deployment. This paper holds that the promotion of competitiveness in service sector is the key task under the "go global" strategy, as the improvement of competitiveness relies on the transfer of kinetic energy between old and new, while the key determinant of kinetic energy transformation lies in innovation. The analysis of competitiveness in service sector in Yangtze River Economic Belt by Michael Porter Diamond Model does not reflect the crucial role played by innovation and openness against the background of globalization and a knowledge-driven society. Based on this, this paper expands Michael Porter Diamond Model to build a "Dual-core Diamond Model" with "innovation" and "openness" as the core factors, in consideration of the current conditions and demands of service sector development in the Yangtze River Economic Belt (Fig. 4).

Innovation is the primary core factor. It includes

technological innovation, knowledge innovation and market innovation. Industrial innovation can facilitate product sales and product improvement, and enhance economic benefits. Therefore, the industrial innovation process is also the process of the formation and promotion of industrial competitiveness, which is the potential impetus behind the sustainable development of industrial competitiveness.

Openness is another core factor. If a country (region) opens up, its enterprises are confined to the domestic market. After opening up, this country's dominant enterprises can grow and prosper during their participation in international competition, while underdeveloped enterprises are winnowed out in the process which allows the surviving enterprises to enjoy more living space and achieve greater development. Therefore, only by encouraging the service sector to "go global" and taking part in the full-scale international division in full of labor can those enterprises get sustainable competitiveness in international competition.

Production factor is also the primary key factor. It refers to various inputs of resources needed for the development of service sector, including natural resources, knowledge resources, human resources and capital investment. Porter believes that the demands of rudimentary factors (climate, geographical location, unskilled labor, etc.) are on the decline, so is their influence on competitiveness; and that developing and putting in advanced factors (high-quality human resources, improved urbanization level) are essential for obtaining industrial competitiveness, as they have a dominant effect on the improvement of competitiveness.

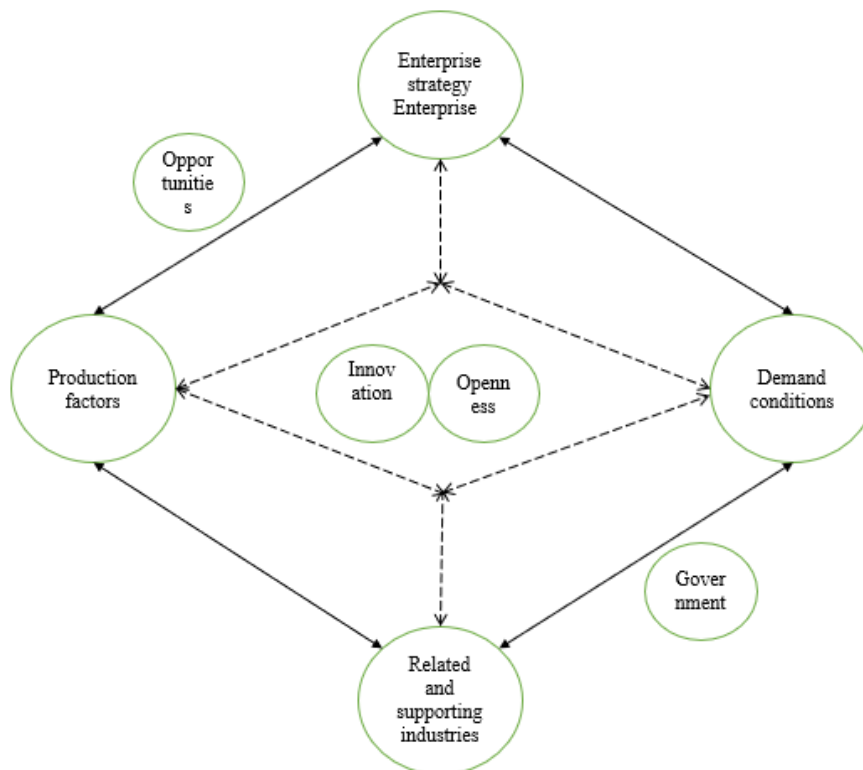


Fig. 4. Dual-core diamond model.

Demand condition is the fourth key factor. It refers to the demands for service products in a country's market. It is generally believed that the average income level of a country or the income level of the majority of its population reflects the representative demand of this country. Domestic enterprises are domestic market-oriented, so their investment, production and sales are mainly guided by domestic market demand. The size and nature of a country's market influence the scale and efficiency of production, will have a huge impact on promoting industrial development and stimulating industrial improvement and innovation, and are important factors determining whether enterprises can build up their international competitiveness.

Related and supporting industries are the also key factors, which refer to the upstream industries and complementary industries related to service sector. The competitive advantage of an industry does not stand alone, but are also correlated with related industries and they can complement each other to form stronger competitive advantages through cooperation and sharing resources; Supporting industries help downstream industries adapt to changes in market demand quickly and improve their competitive advantages. The stronger the related and supporting industries are, the more they can drive the development of the industry through inter-industry association assistance.

The quaternary key factors are enterprise strategy and enterprise structure. They refer to the choice and decisions by service enterprises in terms of objectives, management and organizational structures. In the fierce competition in the domestic market, an industry can enhance its local competitive advantage through forcing manufacturers to participate in competition in the international market, and finally enhance its international competitiveness. Therefore, if an industry is in line with the industrial competitiveness advantage of the country in terms of strategy and structure, the competitiveness of the industry will be developed accelerated and reinforced.

In addition to the above factors, there are two variables that have an impact on industrial competitiveness, namely, government and opportunity. The government directly influences the industrial competitiveness through policies, and opportunities create new possibilities for the promotion of industrial competitiveness by transforming the existing competitive environment and order. However, government and opportunity are not the decisive influencing factors of industrial competitiveness, and it is difficult to represent them with economic data, so this paper does not include them in the indicator system and quantitative economic model analysis.

#### IV. EMPIRICAL ANALYSIS

This part establishes the evaluation indicator system of competitiveness in the service sector of Yangtze River Economic Belt based on the "Dual-core Diamond Model", and applies PCA to measure and evaluate the competitiveness in the service sector of Yangtze River Economic Belt from a variety of perspectives, including innovation, openness, production variables, demand dynamics, associated and supporting industries, company strategy, and organizational structure.

#### A. Rely on the "Dual-Core Diamond Model" to Build the Evaluation Indicator System of Competitiveness in the Service Sector of Yangtze River Economic Belt

1) *Innovation*. The improvement in innovation ability facilitates the improvement in industrial productivity and competitiveness. Investment in R&D funds encourages enterprises to actively pursue scientific and technological innovation, management innovation, product innovation and market innovation, thus enhancing the development of emerging service industries. This paper makes reference to the method developed by Liu et al. (2019), where the number of patents obtained and R&D funds are adopted as indicators representing innovation ability [31]. The "number of valid inventive patents" for the current year is the number of patents obtained, and the R&D funds ratio is the ratio of R&D funds to GDP.

2) *Openness trade dependence reflects the degree of participation and dependence of a nation's economic development on the international market*. Many domestic scholars use trade dependence to measure a country's degree of openness to the global market. In this paper, export (import) dependence is selected to represent the degree of openness [32][33]. Formula: export (import) dependence = import (export) amount/GDP of a country (region).

3) *Production factors*. On the one hand, urbanization level reflects the development of infrastructures, including its transportation, information, and communication systems (region). The higher the urbanization level is, the stronger its support for the development of service sector will be. Urbanization not only facilitates the development of modern service sector, but also brings in high-end service sector and injects new impetus into urban economic development. On the other hand, the inputs of essential human resources of essence to enhancing industrial competitiveness. The service sector provides intangible products, and the service is provided by people engaged in the service sector. Therefore, the employment by the tertiary industry represents the development scale and potential of the service sector to a certain extent. In this paper, the urbanization level is selected by the method proposed by Zhuang [9], and the employment by the tertiary industry is taken into consideration to represent the production factors. Formula: urbanization level = urban population/total population.

4) *Demand conditions*. This paper draws from the practice of Mou [34], and selects per capita GDP to represent demand conditions; The per capita disposable income of urban and rural residents is chosen as the demand condition using the techniques proposed by Huang and Deng [35]. The former reflects the economic level of growth of a country (region), while the latter two reflect its purchasing power.

5) *Associated and auxiliary industries*. The secondary industry serves as the basis and starting point for the tertiary sector's growth. Without the former, there would be virtually no demand for the latter in society. The development of the tertiary sector itself determines whether it can grow into an

advantageous industry and participate in international competition. This paper selects the labor productivity of the secondary and tertiary sectors based on the practices of Zhuang [9], Lan and Dou to represent related industries and supporting industries [36]. Formula: The secondary (tertiary) industry's labor productivity is calculated by dividing the number of jobs it employs by the added value of its output.

6) *Enterprise strategy and structure*. Because of the profit-seeking nature of capital, foreign investors always choose enterprises with better development potential when

making capital investment decisions. Enterprises that attract foreign investment can not only introduce advanced hardware facilities and attract excellent human resources, but also enhance their technological level and management ability. This paper draws from the practices of Lan and Dou in selection of the overall amount of foreign direct investment to represent the enterprise strategy and structure [36].

The indicator system is established based on the factors selected above, as shown below in Table III:

TABLE III. THE EVALUATION INDICATOR SYSTEM OF COMPETITIVENESS IN THE SERVICE SECTOR OF YANGTZE RIVER ECONOMIC BELT DEVELOPED BASED ON THE "DUAL-CORE DIAMOND MODEL"

Target level	Factor level	Indicator level
The evaluation indicator system of competitiveness in the service sector of Yangtze River Economic Belt developed based on the "dual-core Diamond Model"	Innovation	X1: Invention patents
		X2: Ratio of R&D funds to local GDP
	Openness	X3: Export dependence
		X4: Import dependence
	Production factors	X5: Level of urbanization
		X6: Employment by the tertiary industry
	Demand conditions	X7: Per capita GDP
		X8: Per capita disposable income of permanent urban residents
		X9: Per capita disposable income of permanent rural residents
	Related and supporting industries	X10: Productivity of secondary industry
		X11: Productivity of tertiary industry
	Enterprise strategy and structure.	X12: Paid-up amount of foreign direct investment

### B. Data and Variables

1) *Selection and description of variables*: innovation: X1: invention patents (Nr.), X 2: ratio of R&D funds to local GDP (%); Openness: X3: export dependence, X4: import dependence; Production factors: X5: level of urbanization, X6: employment by tertiary industry; Demand conditions: X7: per capita GDP, X8: urban dwellers' per capita disposable income, X9: income available per person in remote areas; Related and supporting industries: X10: productivity of secondary industry, X11: productivity of tertiary industry; Enterprise strategy and structure: X12: paid-up amount of foreign direct investment.

2) *Data source*: In order to create two data sheets, this study chooses cross-sectional data from 11 provinces and cities in the Yangtze River Economic Belt in 2015 and 2016. Relevant indicator data come from *Statistical Yearbook* of 11 provinces and towns in Yangtze River Economic Belt and *China Statistical Yearbook*.

### C. Setting of Measurement Model

This paper evaluates the competitiveness of service sector in Yangtze River Economic Belt through Principal Component Analysis. Principal Component Analysis (PCA) is a dimension-reducing statistical method that selects a small

number of key variables from multiple variables by linear variation. The majority of the information from the original variables may still be found in principal components, and there are far fewer principal components than there were original variables.

PCA is applied on the basic data of 2015 using SPSS software, with results shown in Table IV and Table V.

Through PCA, two principal component eigenvectors are extracted. It can be seen from Table IV that the first and second principal components contribute 71.49% and 14.132% of the variance, respectively. The first two primary components' combined contribution rate is 85.622%, which contains most information and can significantly explain most variations of the original data. Therefore, the first two components are selected as comprehensive indicators in replacement of the 12 original indicators to evaluate the competitiveness of service sector in 11 provinces and towns in the Yangtze River Economic Belt.

The coefficient of each indicator in the two principal components is obtained by comparing the data of each indicator corresponding to components 1 and 2 in the composition matrix in Table V against the open square root value of eigenvalue corresponding to principal components. The principal component is expressed as follows:



TABLE IV. EIGENVALUE AND CUMULATIVE CONTRIBUTION OF VARIANCE OF THE PRINCIPAL COMPONENTS OF THE COMPETITIVENESS IN SERVICE SECTOR OF YANGTZE RIVER ECONOMIC BELT IN 2015

Component	Initial eigenvalue			Extracted quadratic sum		
	Total	Variance percentage	Cumulative percentage (%)	Total	Variance percentage	Cumulative percentage (%)
1	8.579	71.490	71.490	8.579	71.490	71.490
2	1.696	14.132	85.622	1.696	14.132	85.622
3	.715	5.955	91.577			
4	.584	4.863	96.440			
5	.164	1.363	97.803			
6	.154	1.283	99.087			
7	.052	.430	99.517			
8	.044	.363	99.880			
9	.012	.099	99.979			
10	.003	.021	100.000			
11	2.324E-16	1.936E-15	100.000			
12	-1.283E-16	-1.069E-15	100.000			

TABLE V. COMPONENT MATRIX IN 2015

Indicator	Component	
	1	2
Invention patents (Nr.)	.911	-.160
Ratio of R&D funds to local GDP	.930	.186
Export dependence (%)	.927	-.073
Import dependence (%)	.863	-.352
Urbanization rate	.795	.317
Employment by the tertiary industry (unit: 10,000 people)	.153	.907
Per capita GDP (RMB)	.994	-.009
Per capita disposable income of permanent urban residents (RMB)	.951	-.088
Per capita disposable income of permanent rural residents (RMB)	.947	.088
Productivity of secondary industry	.516	-.563
Productivity of tertiary industry	.929	-.159
Paid-up amount of foreign direct investment (unit: 100 million dollars)	.842	.476

$$F_1 = 0.3110ZX_1 + 0.3174ZX_2 + 0.3163ZX_3 + 0.2945ZX_4 + 0.2714ZX_5 + 0.0524ZX_6 + 0.3392ZX_7 + 0.3246ZX_8 + 0.3233ZX_9 + 0.1761ZX_{10} + 0.3172ZX_{11} + 0.2876ZX_{12} \quad (1)$$

$$F_2 = -0.1228ZX_1 + 0.1426ZX_2 - 0.0560ZX_3 - 0.2701ZX_4 + 0.2436ZX_5 + 0.6961ZX_6 - 0.0067ZX_7 - 0.0678ZX_8 + 0.0673ZX_9 - 0.4325ZX_{10} - 0.1222ZX_{11} + 0.3653ZX_{12} \quad (2)$$

$$F = \frac{71.490}{85.622} F_1 + \frac{14.132}{85.622} F_2 \quad (3)$$

Wherein  $ZX_1 \dots ZX_{12}$  is the indicator value normalized by SPSS software. By applying this formula, the comprehensive scores of competitiveness in the service sector of 11 provinces and cities in the Yangtze River Economic Belt in 2015 are derived, as shown in Table VI. Table VI shows the gaps among 12 provinces and cities in terms of competitiveness of service sector.

Following the same measurement method, the comprehensive scores of competitiveness in service sector of 11 provinces and cities in the Yangtze River Economic Belt in 2016 are derived, as shown in Table VII.

TABLE VI. COMPREHENSIVE SCORES OF SERVICE SECTOR IN 11 PROVINCES AND CITIES IN 2015

Ranking	Province/city	F1	F2	F
1	Shanghai	5.2920	-0.2472	5.0448
2	Jiangsu	2.9331	0.1074	3.0404
3	Zhejiang	2.2420	0.1704	2.4124
4	Chongqing	-0.1936	-0.0592	-0.2528
5	Hubei	-0.5581	-0.0211	-0.5792
6	Hunan	-0.7899	0.0075	-0.7825
7	Anhui	-1.1951	0.2085	-0.9866
8	Sichuan	-1.3859	0.1160	-1.2699
9	Jiangxi	-1.5793	0.0624	-1.5169
10	Yunnan	-2.3608	-0.1531	-2.5139
11	Guizhou	-2.4043	-0.1916	-2.5959

TABLE VII. COMPREHENSIVE SCORES OF SERVICE SECTOR IN 11 PROVINCES AND CITIES IN 2016

Ranking	Province/city	F1	F2	F
1	Shanghai	5.2638	-0.3085	4.9553
2	Jiangsu	2.9421	0.2104	3.1525
3	Zhejiang	2.4159	0.1869	2.6028
4	Chongqing	-0.1675	-0.1392	-0.3067
5	Hubei	-0.5802	0.0185	-0.5617
6	Hunan	-0.7165	0.0455	-0.6711
7	Anhui	-1.1769	0.2709	-0.9060
8	Sichuan	-1.4794	0.1696	-1.3098
9	Jiangxi	-1.5421	0.0213	-1.5208
10	Yunnan	-2.5040	-0.1900	-2.6940
11	Guizhou	-2.4554	-0.2852	-2.7405

#### D. Analysis of Model Results

As shown by comparing the 2015 and 2016 data, the scores and rankings of service sector's growth level among the 11 provinces and towns in the Yangtze River Economic Belt are relatively stable, indicating a healthy and robust development trend. While there are obvious gradients and gaps in the level of growth of service sector among those provinces and towns, they can be categorized into three classes. Class I include Shanghai, Jiangsu and Zhejiang, which are situated in the Yangtze River's lower reaches, Class II is composed of Chongqing, Hubei, Hunan, Anhui and Sichuan, and Class III consists of Jiangxi, Yunnan and Guizhou. It demonstrates the significant disparity between the upper, middle, and lower levels of the Yangtze River Economic Belt in terms of the development of the service sector.

It can be known from the basic data that the innovation indicator, namely, "the ratio of R&D funds to local GDP", of the regions in the lower reaches of the Yangtze River, which rank the top three, is obviously ahead of other regions. Chongqing, situated in the upper reaches of the Yangtze River and ranked above other regions in the middle and upper reaches of the Yangtze River, remains at the 4th place, because its indicators "export dependence" and "import dependence"

when compared to those other provinces and towns, are much greater. This is closely related to a series of measures implemented by Chongqing in recent years to speed up the development of inland highland for openness. Therefore, it is evident that "innovation" and "openness" are crucial factors to influence and determine the competitiveness of service sector.

#### V. RESEARCH CONCLUSIONS AND COUNTERMEASURES TO ENHANCE THE COMPETITIVENESS OF SERVICE SECTOR IN YANGTZE RIVER ECONOMIC BELT

##### A. Research Conclusions and Suggestions for further Researches in the Future

The study's findings demonstrate that there is still much room for improvement in the competitiveness of the service sector in the Yangtze River Economic Belt. The "Dual-core Diamond Model" developed and designed based on Michael Porter Diamond Model in this paper accords with the present situation and future development needs of the service sector in the Yangtze River Economic Belt. The feasibility and scientificity of the "Dual-core Diamond Model" are further verified by the evaluation indicator system of the competitiveness of the service sector in the Yangtze River Economic Belt built based on the "Dual-core Diamond

Model” and the quantitative model analysis on the 12 selected indicators. In addition, empirical analysis shows that “innovation” and “openness” have become the important factors that enhance the competitiveness of service sector in the Yangtze River Economic Belt. In this paper, the research on service sector is relatively macroscopic, Provincial level research and the research on segmented industry deserve a closer and deeper look while considering the failure to test the mechanisms by which innovation and openness affect the competitiveness of the service industry. In the future, modern service sector and high-end service sector will become the focus and key areas in the development of service sector in China, so the next step is to carry out researches on segmented modern service sector and high-end service sector to verify the mechanism transmission path of influencing factors, and focus on analyzing more responsible situations and seeking more effective ways to enhance the competitiveness of the service industry in the Yangtze River Economic Belt.

#### *B. Countermeasures for Improving the Competitiveness of Service Sector in Yangtze River Economic Belt*

Enhancing innovation ability. Continually improve the overall design and accelerate the formation of an innovative development model to serve the development of the service sector in the Yangtze River Economic Belt; continuously improving R&D and innovation capabilities, and developing outstanding products, technologies and services; further increasing R&D investment to raise the technological level; spearheading technological innovations with institutional innovations, integrating the resources of local governments, universities and research institutes, and establishing an innovation capability improvement system; attaching more importance to the significance of human resources in the middle and upper reaches of the Yangtze River, and allowing the expanding human resources to exert their potential strength and make use of late-mover advantages in the fierce international competition [37,38].

Further expanding trade in services industries. Firstly, we should introduce a scientific and reasonable competition mechanism, build an open and fair competition environment for businesses with laws and regulations, and boost service industry exports by expanding openness in service industry; Secondly, we should identify and determine the key areas of service sector, especially in the domains such as finance, medical care, education, culture, tourism and other fields. Meanwhile, we should orderly liberalize the fields of pension service, trade circulation and e-commerce, and actively promote the export of capital-intensive and technology-intensive services such as computer information services; Lastly, we should encourage the appropriate liberalization in service industry, mobilize and utilize more resources, reinforce the interconnection ties among various industries and accelerate the growth momentum under China’s significant and epoch-making “Belt and Road” Initiative. We should also strive to further realize market alignment and integration, and facilitate the process of East Asian integration by investing significant resources into the process of building a platform of multilateral cooperation for China-ASEAN in service industries, so as to incentivize more countries and regions to get involved into economic globalization. We

should make full use of both international and domestic markets to build a strong and dynamic industrial and market foundation for expanding service industry exports [39].

Encouraging the growth of interconnected industries and create a coordinated development amalgamation for the service sector. We should encourage the thorough and seamless integration of manufacturing and service industries and focus on accelerating the transformation and improvement of the logistics transportation industry in the traditional service sector and continue to tap into the enormous potential and resources of tourism and extend the industrial chains. We should also introduce corresponding preferential policies on financing and finance sector as well as industrial support policies in order to break the industrial dichotomy between manufacturing and service industries, and fully utilize cutting-edge technologies such as big data, AI, and the Internet of Things to encourage the thorough integration and coordinated expansion of manufacturing and service sectors as well as to encourage growth in the general competitiveness of the service industries.

Paying more efforts on talent cultivation and building a talent system in alignment with the development of service sector. We should carry out pilot talent training programs for service sector, introducing the relevant laws and regulations about trade services of various countries and cultivate the ability to proficiently use software and technology. We should also promote the cultivation of an entrepreneurial team proficient in international business, and accelerate the cultivation of a group of high-end talents specializing in financial insurance, cultural creativity, business consulting and other fields. We should strive for a balanced development of talents cultivation in various regions by focusing on the education and cultivation of the overall quality of non-urban population while improving the overall quality of urban population. We should promote the supply-side structural changes in the employment market for the service sector by maximizing the demographic dividends enjoyed by the Yangtze River Economic Belt, so as to conserve talents for the development of service sector and the promotion of competitiveness.

Improving the relevant legal system and innovate the service supervision and governance system in the service sector. Traditional supervision methods mainly rely on administrative power, which is difficult to adapt to the new economic modes in modern economy. Therefore, it is necessary to innovate supervision concept and enhance the flexibility and effectiveness of policies. In addition, we should make efforts to establish an early warning mechanism for service sector security; we should improve the judicial safeguard system, optimize the commercial dispute resolution system, and build a new co-governance mechanism based on integration of multi-dimensional supervision.

Focusing on coordinated and integrated inter-region development. We should highlight the radiating effect and the leading role of Shanghai, Jiangsu, Zhejiang and other regions, and actively solidify the strategic alliance of service sector among regions in the upper, middle and lower reaches of the Yangtze River Economic Belt. We should also encourage the

gradient transfer of service sector and development in industrial sector. We should transform the various resources and advantages under the opening-up policy over numerous regions and towns into the amelioration of the economy [40]. The “Belt and Road” Initiative, the plans for the development of the Yangtze River Economic Belt, and the New Western Land-sea Corridor have provided enormous potential and numerous opportunities for regions along the Yangtze River to discover a new form of opening up. Undoubtedly, inland areas may learn from the salubrious experience of economically leading areas and integrate it into their own development strategies in their efforts to reform their current system and they can definitely achieve the continuous upgrading and optimization of the development mode for opening up their industries and maximize their respective competitiveness in various fields.

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# Enhancing COVID-19 Diagnosis Through a Hybrid CNN and Gray Wolf Optimizer Framework

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**Abstract**—Covid-19 is an infectious respiratory disorder brought about using a brand-new coronavirus first found in 2019. The severity of symptoms can vary from mild to life-threatening. No vaccine or specific treatment has been developed to address Covid-19. Hence the most effective preventive measure is to practice social distancing and adhere to good hygiene practices. Medical imaging and convolutional neural networks are used in Covid-19 research to quickly identify infected individuals and detect changes in the lung tissue of those infected. Convolutional neural networks can be used to analyze chest CT scans, detecting potential signs of infection like ground-glass opacities, which indicate the presence of Covid-19. This article introduces a powerful framework for classifying COVID-19 images utilizing a hybrid of CNN and an improved version of Gray Wolf Optimizer. To demonstrate the efficiency of the projected framework, it is verified on a standard dataset and compared with other methods, with results indicating its superiority over the others.

**Keywords**—Covid-19; respiratory disorder; medical imaging; convolutional neural networks; improved gray wolf algorithm

## I. INTRODUCTION

This In Wuhan, Hubei Province, China, a cluster of pneumonia cases with an undetermined reason was described in Dec. 2019. Middle East Respiratory Syndrome (MERS-CoV) and severe acute respiratory syndrome (SARS-CoV) are just two examples of the diverse diseases that can be brought on by the coronaviruses (CoV) family of viruses. Formerly undetected in people, the coronavirus illness (Covid-19) is a new type that was discovered in 2019.

The way of transmission of Covid-19 makes it a very dangerous disease. The disease can be transmitted by airborne droplets (discharges that appear invisibly when talking, sneezing, or coughing.). Medical imaging is also essential in determining the severity of COVID-19 and providing guidance for treatment. Medical imaging can be used to diagnose pneumonia.

Automated CT or X-ray analysis techniques based on artificial intelligence exist for the detection, monitoring and quantification of the coronavirus. They are used to detect infected patients from healthy individuals. At first, blood tests were taken from patients hospitalized with corona symptoms after some time, and it took 2 to 3 days to confirm their infection. It was dangerous and caused the number of patients to increase for a long time. The beginning of this decade should be marked by the coronavirus pandemic, spurring the development and advancement of various digital technologies to combat multiple diseases and clinical issues.

Machine learning, a subdivision of artificial intelligence, enables a system to gain knowledge from prior data, detect patterns, and make decisions with little human input. Examples of algorithms include logistic regression [1], SVM [2], K-means clustering [3], etc.

DL (Deep Learning) is a type of ML (machine learning) that utilizes multiple layers of computation to analyze and learn data representations, extracting features at various levels of abstraction. CNNs methods are one example of DL and are employed in various uses related to Covid-19 identification.

For example, A DL-based technique for diagnosing the Covid-10 utilizing X-ray images was offered by [4]. The researchers employed chest X-ray radiographs to identify coronavirus pneumonia in patients by utilizing five transfer learning-based convolutional neural networks, namely ResNet101, ResNet50, InceptionV3, Inception-ResNetV2, and ResNet152. Five-fold cross-validation was implemented, and three binary categorizations were established containing four groups (viral pneumonia, bacterial pneumonia, and COVID-19, normal (healthy)). Findings presented that the ResNet50 system can provide the greatest segmentation efficiency among the other 4 utilized models, according to the performance findings.

Using chest CT X-ray pictures, Aslan et al. introduced two DL methods for the automated detection of positive COVID-19 patients [5]. These suggested designs used ANN methodology to autonomously conduct lung segmentation (pre-processing) on CT images (ANN). The AlexNet architecture was included in both designs. Hence, a pre-trained application is the suggested approach. The second suggested design, meanwhile, had a combined configuration since it included a BiLSTM (Bidirectional Long Short-Term Memory) layer that also considered temporal aspects. The findings show that the suggested architecture performs very well at detecting infections. Consequently, this research contributes to previous studies with its advanced architectural design and high segmentation accuracy.

A structure for COVID-19 image segmentation that combines deep learning and metaheuristics was suggested in [6]. As a deep learning system, appropriate visual representations were learned and extracted using MobileNetV3 as the foundation for feature extraction. To reduce the dimension of the image representations and improve classification precision, the Aquila Optimizer was used as a characteristic selector and metaheuristic method. Two datasets, including CT COVID-19 and X-ray images, were applied to verify the suggested framework. The tests' findings

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demonstrated that the suggested framework performed well regarding segmentation precision and dimension decrease throughout the characteristic extraction and choice stage. The Aquila Optimizer feature selection algorithm demonstrated superior performance metrics than other prior approaches.

However, despite the advancements in deep learning techniques for COVID-19 identification using medical imaging, there is still a need for more efficient and accurate classification frameworks. While previous studies have demonstrated the effectiveness of convolutional neural networks (CNNs) in analyzing chest CT scans and X-ray images, there is room for improvement in terms of classification performance and computational efficiency. Furthermore, the existing literature lacks research on the utilization of hybrid models that combine CNNs with optimization algorithms to enhance the classification accuracy of COVID-19 images. Optimizers play a crucial role in fine-tuning the model parameters and improving its overall performance. Therefore, there is a gap in the literature regarding the development and evaluation of a hybrid CNN framework incorporating an improved version of the Gray Wolf Optimizer for COVID-19 image classification. Closing this gap in the research is essential as it can lead to the development of a more effective and accurate framework for identifying COVID-19 infections. Such a framework would not only assist in the timely diagnosis of the disease but also aid in monitoring the severity of the infection and providing appropriate treatment guidance. Additionally, an enhanced classification model would contribute to the efforts in containing the spread of the virus by enabling the rapid identification of infected individuals.

The approach outlined in this article for detecting and identifying covid-19 from medical photos is based on the combination of the Improved Gray Wolf Algorithm and Convolutional neural networks. There are two critical steps in this process. The photos are subjected to pre-processing in the first stage to minimize and eliminate the noise. To identify the kind of tumor through data training, the operation of segmentation and extraction of brain tumor features is performed in the second phase. This section describes the pre-processing processes, formulation of the Improved Gray Wolf Algorithm, and convolutional neural networks.

## II. PRE-PROCESSING STAGE

Category of image pre-processing is one of the most basic stages of image processing because the images that are given to the computer system mainly have noise in their pixels. These noises should be reduced as much as possible and ideally eliminated. Medical images of Covid-19 are no exception to this rule.

The noise image is considered in the form of an initial image, and after that, the noise removal operation is performed by the MFT filtering method [7]. To achieve the constituent structure and components of the images and their analysis, as well as their small and large details, the quantum MFT filtering method was considered. The output of the pre-processing step is a set of decomposed coefficients.

In this process, a set of these coefficients is randomly selected to perform the reconstruction operation. The parts used in this process consist of median filtering, Gaussian filtering, quantum matching, criterion change, single-point columns and rows, point detection and point-to-point matching. In Gaussian filtering, a Gaussian filter is applied to the image. The value of this filter is chosen by chance. This value can be 3×3 or 5×5 pixels. After performing this filtering, the median filter is utilized for the image. In the following, the total pixels are randomly multiplied by a suitable criterion. This numerical value is in the interval between 0.7 and 1.3. Once the appropriate criterion is chosen, the process of quantum adaptation must begin.

In this step, the amount of light in each part of the image is matched by the quantum processing method of the MFT filtering method. In a single-point row and column steps, pixels are determined randomly. In the point-to-point matching phase, each pixel of the decomposed coefficients is determined randomly until the new image is generated. In the last step, all row, column and diagonal points are identified by MFT filtering to reduce image noise. After completing the mentioned operation, the whole image is sorted by the unique pixel values they have. Threshold functions and active contours have two characteristics which are oscillating and wave, and they are written according to the below Equation:

$$\int_{-\infty}^0 |\psi(t)|^2 dt < \infty \quad (1)$$

where, the maximum energy in  $\psi(t)$ , which is proportional to time and changes according to it, has a time interval assigned to it, expressed according to the below formula.

$$\int_{-\infty}^0 \psi(t) dt < 0 \quad (2)$$

Considering that reducing the noise of the images is intended, its relationship is written as follows:

$$\begin{aligned} \text{Min - Noise} = & \left( \sum_{\Omega} \sqrt{1 + (\beta |\nabla l|)^2} \right) \\ & + \frac{\lambda}{2} (l - I)^2 \end{aligned} \quad (3)$$

In this equation, several parameters are involved, each serving a specific purpose in the noise reduction process:

$I$  represents the target image, which refers to the ideal or noise-free image that we aim to reconstruct or approximate.

$I$  denotes the noisy image, which is the input image that contains the noise and requires denoising.

$\nabla l$  represents the total variation of the determination period. Total variation is a measure of the image's smoothness or the amount of changes between neighboring pixels. By considering the total variation, the algorithm can effectively preserve the edges and important features while reducing noise.

$\beta$  is the balance level parameter. It controls the trade-off between noise reduction and preserving image details. Adjusting  $\beta$  allows for fine-tuning the denoising process to achieve the desired level of noise reduction while maintaining important image characteristics.

$\lambda$  is the regularization parameter, also known as the smoothing parameter. It controls the smoothness of the denoised image and balances the fidelity to the noisy input image. A higher value of  $\lambda$  promotes smoother results, while a lower value preserves more details but may not effectively suppress noise.

$\Omega$  represents the total points in the image, indicating the spatial domain over which the noise reduction process is applied.

By minimizing the expression in Equation (3), the algorithm aims to reduce the noise in the input image (I) while preserving important image details and minimizing artifacts introduced during the denoising process. This noise reduction step is essential to enhance the quality and accuracy of the COVID-19 image analysis, facilitating more reliable classification and diagnosis. Overall, incorporating the noise reduction relationship into the proposed framework contributes to improving the robustness and effectiveness of COVID-19 image classification by reducing unwanted noise and enhancing the clarity of the images.

The performance of Equation (3) is such that it always considers the edge of the corresponding image and preserves its important features. The expression  $(l - l)^2$ , which is present in Equation (3), shows the amount of verification and confirmation of the validity of the existing image during review and processing with the base image.

### III. METHODS AND TOOLS

In this investigation, the concept of DL is used to train the network. DL is a type of ML that utilizes a variety of algorithms to represent abstract concepts numerically in the form of a graph. Deep models comprised multiple layers of linear and non-linear transformations. In other words, it is based on learning to display knowledge and features in model layers, which are based on artificial neural networks that model very complex networks.

#### A. Deep Learning

Its impact has been felt in almost all scientific fields and has changed businesses and industries. Recently, deep learning method has been widely utilized in the automatic identification of COVID-19 in patients [8-9]. Since then, numerous CNN designs have been created to classify images, and it has been demonstrated that these architectures outperform humans on the same dataset [10]. In order to forecast picture class labels, connectivity loss, as well as operational parameters (e.g., convolution kernels), are learnt from peripheral images [11].

A convolutional neural network is generally comprised of input, convolution, activation, fully connected, and output layers.

1) *Convolution layer*: The convolution layer is the maximum essential layer in a CNN. It can automatically identify features of an image without the need for manual definition. This layer can be expressed mathematically as follows:

$$f(g(t)) \cong \int_{-\infty}^{\infty} f(\tau)g(t - \tau)d\tau \quad (4)$$

where, convolution is determined by taking the integral of the product of two functions after inverting and altering one of them. As stated in Equation 4,  $g(t)$  serves as the filter that is reversed and shifted across the input function  $f(\cdot)$ . The result of this intersection between  $g(\cdot)$  and  $f(\cdot)$  is the convolution value.

The "stride" parameter indicates the intervals at which the filter function traverses the input function. The stride is the distance the filter function  $g(\cdot)$  moves across  $f(\cdot)$ . Generally, after a convolution operation, the output feature map will have a reduced size compared to the inputs. To prevent this from happening and maintain the dimensions of the output map, "padding" is utilized.

2) *Activation layer*: Activation layers, which typically follow convolution layers and are nonlinear in nature, play a crucial role in the selection of neurons to be activated. The input of the activation layer is an actual number that is transformed by a nonlinear operation.

3) *Pooling layer*: Pooling layers are usually placed between convolutional layers to reduce the three-dimensional size of the demonstration and decrease the number of variables and computations in a system. A pooling layer filters out important pixels and eliminates noise from the output feature map of a convolutional layer. Furthermore, pooling layers are utilized to increase the spatial invariance of the network.

4) *Fully connected layers*: The fully associated layers, which receive the output from the characteristic extraction layers, are typically positioned at the end of the neural network. The principal objective of the Dense layer is to assess all of the characteristics generated by preceding layers and use them for classification tasks. The following is a description of this notion.

$$L = \sum_{i=1}^N \sum_{j=1}^k -D_k^j \log Z_k^j \quad (5)$$

where,  $N$  is the sample count,  $D$  describes the chosen output vector, and  $Z_k^j$  shows the actual output vector for the  $m$ th class as determined by the following formula:

$$Z_k^j = \frac{\exp(f_j)}{\sum_{j=1}^k \exp(f_j)} \quad (6)$$

The function  $L$  is developed to contain a value to raise the weights'  $\eta$  values, and this is done with the weight penalty:

$$L = \sum_{i=1}^N \sum_{j=1}^k -D_k^j \log Z_k^j + \frac{1}{2} \eta \sum_P \sum_Q \omega_{p,q}^2 \quad (7)$$

where,  $L$  describes the whole number of layers,  $K$  defines the layer  $q$  connections, and  $p$  is the connection weight. A block schematic of a typical CNN for skin cancer detection is shown in Fig. 1.

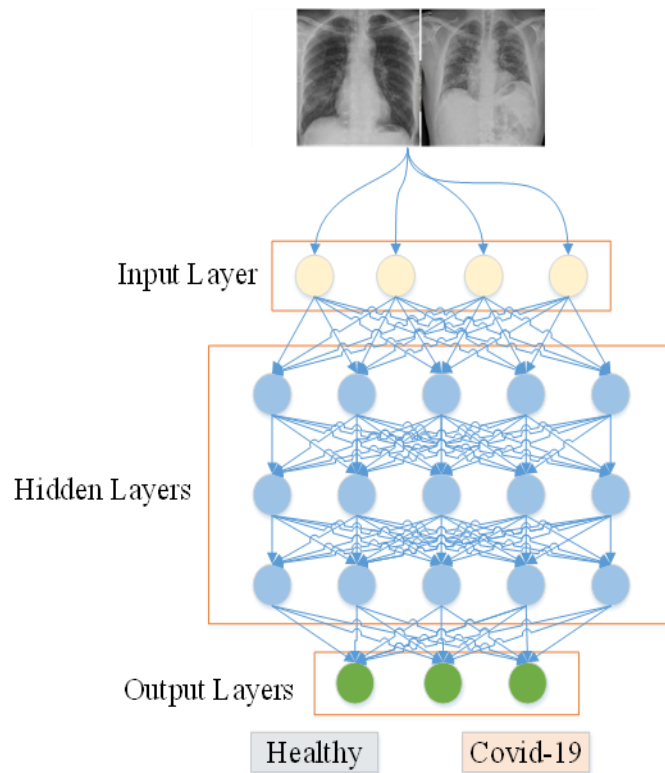


Fig. 1. The convolutional neural network's common construction.

### B. Improved Gray Wolf Algorithm

The Gray Wolf Optimization (GWO) algorithm draws inspiration from the collective behavior of gray wolves while hunting, which is a variety of Swarm Intelligence Algorithm. The wolves' location in the issue-solving area shows how the issue can be solved [12]. Gray wolves live and hunt in groups.

The wolves employ a strategic approach to hunting, first forming a perimeter around the targeted prey and gradually tightening the circle until the animal is exhausted. They begin to attack in succession, taking direction from the alpha wolf and eventually bringing down their target [13]. Gray wolves exhibit a hierarchical social structure. This hierarchy is shown in Fig. 2 and explained below:

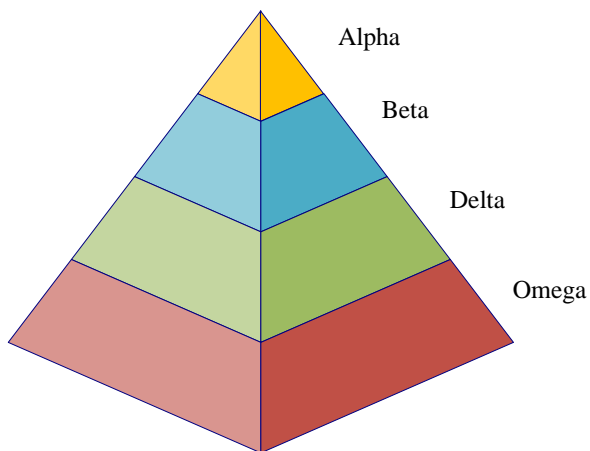


Fig. 2. The gray wolf hierarchy.

- The alpha category ( $\alpha$ ) is known as the group leader and is responsible for making decisions about hunting. Alpha decisions apply to the entire group.
- The beta wolves ( $\beta$ ) constitute the second hierarchical class within a wolf pack and are relied upon for making decisions and performing other duties. These wolves are often called upon to assume the alpha position when the existing alpha reaches advanced age or passes away.
- The Omega wolves ( $\omega$ ) can be classified as the lowest hierarchical order in the wolf pack. This group of wolves functions similarly to a Peshmerga, requiring obedience from all other members of the pack and being the last to receive sustenance.
- Wolves which are not included in the aforementioned social structure are referred to as Delta wolves ( $\delta$ ). These wolves are subordinate to Alpha and Beta but have a higher rank than Omega.

Gray wolves surround their victim when hunting, as was already described. The following relationships are employed to model hunting:

$$\vec{D} = |\vec{C} \cdot \vec{X}_p(t) - \vec{X}(t)| \quad (8)$$

$$\vec{X}(t+1) = \vec{X}_p(t) - A \cdot D \quad (9)$$

Hence,  $t$  denotes the coefficients,  $A$  and  $C$  represent the vector of hunting position and the vector of position for the gray wolf.

$$\vec{A}Z = \vec{a} \cdot \vec{r}_1 - \vec{a} \quad (10)$$

$$\vec{c}(t + 1) = 2 \cdot \vec{r}_2 \quad (11)$$

In the above Equations,  $i$  is equal to the repetition of the algorithm. Vectors  $A$  and  $C$  are the vector coefficients of the prey location, and  $X$  is the location of the gray wolf.  $a$  is linearly decreased from 2 to 0 throughout iterations.  $\vec{r}_1$  and  $\vec{r}_2$  are accidental vectors in the interval between 0 and 1.  $X_p$  is the bait position.

It is assumed that the position of prey  $X_p$  is uncertain in the search space. Therefore, the hunting position is considered the alpha position (the best solution obtained). With this assumption, the position of the wolves is obtained by considering the hierarchy:

$$\begin{aligned} \vec{X}_1 &= \vec{X}_\alpha - \vec{A}_1 \cdot (\vec{D}_\alpha) \cdot \vec{X}_2 \\ &= \vec{X}_\beta - \vec{A}_2 \cdot (\vec{D}_\beta) \cdot \vec{X}_3 = \vec{X}_\delta - \vec{A}_1 \cdot (\vec{D}_\delta) \end{aligned} \quad (12)$$

where,

$$\begin{aligned} \vec{D}_\alpha &= |\vec{C}_1 \cdot \vec{X}_\alpha - \vec{X}| \cdot \vec{D}_\beta \\ &= |\vec{C}_2 \cdot \vec{X}_\beta - \vec{X}| \cdot \vec{D}_\delta = |\vec{C}_3 \cdot \vec{X}_\delta - \vec{X}| \end{aligned} \quad (13)$$

$$\vec{X}(t + 1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \quad (14)$$

By using these relationships, the position of the wolves is obtained in each iteration. Finally, when the stop condition is met, the algorithm ends.

In the following, the proposed improved algorithm will be presented. The gray wolf algorithm is one of the powerful optimization algorithms based on collective intelligence. But the performance of collective intelligence algorithms decreases when faced with complex cost functions [14]. Therefore, to cover this weakness, the developed gray wolf algorithm is introduced in this section. Discovery and extraction features are two fundamental pillars of efficient optimization. The meaning of exploration is to search the entire space of variables. Having this feature will make the algorithm able to explore the entire search space and avoid getting stuck in local extremes. The presence of parameter  $A$  in the gray wolf algorithm creates a balance between exploration and extraction properties.

When the parameter  $A$  is in the range  $A > 1$  or  $A < -1$ , the algorithm works in a heuristic manner, and when this parameter is in the range  $-1 < A < 1$ , the extraction property of the algorithm will increase [15]. This parameter is defined as  $\vec{A} = 2\vec{a} \cdot \vec{r}_1 - \vec{a}$  and its value depends on the value of  $a$ . In the main algorithm, the amount of this variable is equivalent to 2 at the beginning of the algorithm, and as the repetitions pass, it reaches zero value linearly. To improve the efficiency of this

algorithm, in the suggested technique, the following relationship is used to apply changes to  $a$ :

$$a = \cos\left(\frac{\pi i}{T}\right) + 1 \quad (15)$$

where,  $i$  and  $T$  represent, in turn, the iteration of the algorithm and the maximum algorithm iteration.

The values of parameter  $a$  in the proposed method in the exploration stage are larger than its values in the original method. This means increasing the power of discovery in this stage of the proposed method. On the other hand, the values of parameter  $a$  in the extraction stage are lower than those in the main algorithm. This helps to increase the convergence velocity of the improved algorithm compared to the original technique.

In addition to using Equation (15) to update the parameter, in order to improve the efficiency of the algorithm, instead of averaging the position of wolves  $\alpha$ ,  $\beta$  and  $\delta$  in Equation (14), their weighted average is used. In this way, the weight coefficient of each position is considered proportional to the inverse of the resulting cost function. Therefore, instead of using the relation (14), the following relations can be used to obtain the position in the next iteration.

$$\vec{X}(t + 1) = \frac{L_1 \vec{X}_1 + L_2 \vec{X}_2 + L_3 \vec{X}_3}{L_1 + L_2 + L_3} \quad (16)$$

where,

$$G_\alpha = \frac{1}{\text{cost}_\alpha} \quad (17)$$

$$G_\beta = \frac{1}{\text{cost}_\beta} \quad (18)$$

$$G_\delta = \frac{1}{\text{cost}_\delta} \quad (19)$$

where,  $\text{cost } t$  describes the value of the cost function of the corresponding position, and  $L_1$ ,  $L_2$ , and  $L_3$  represent three weights of the updated Equation.

### C. Optimized CNN

Different studies are conducted to improve the structure of a CNN. The application of optimization algorithms to CNNs has produced interesting results. This paper introduces a new optimized approach to optimize CNN structure. The construction of the projected CNN has been shown in Fig. 5, and the input images are 32x32 pixels in size. The proposed algorithm is clearly illustrated in Fig. 3.

For this issue, the size of the sliding window is denoted by "max", and the smallest value that can be accepted of the max-pooling minimum (which is 2 here) is labeled "min" to cut down the error of the system. It's worth mentioning that the amount of the sliding window must be less than the input data. As a result, a selection of answers has been randomly obtained.

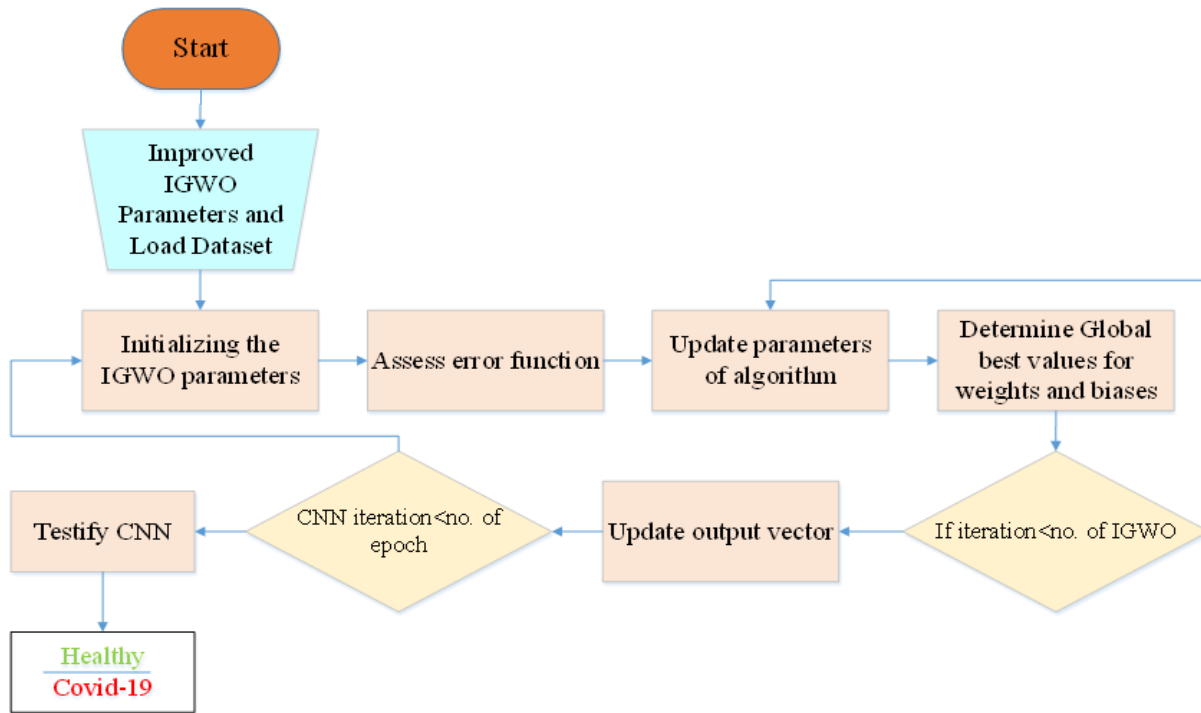


Fig. 3. Schematic representation of the suggested CNN/IGWO.

CNN training is paramount for achieving the best outcomes from layer parameters so that each layer is properly connected and identifies the image accurately. Utilizing the gradient descent algorithm to optimize the parameters of a model, such as convolution filters and fully connected layer weights, is commonplace. In particular, the latter layer plays an integral role in image classification. Thus, it is imperative to refine the training of its weight vector by utilizing an enhanced Whale Optimization Algorithm. The number of search agents should be set at fifty, and a maximum of two hundred iterations with vectors varying linearly between 0 and 2 can be applied. To minimize CNN, a fitness function should be used:

$$E = \frac{1}{T} \sum_{i=1}^{n_t} \sum_{j=1}^{n_{ol}} (D_{ji} - Z_{ji})^2 \quad (20)$$

where,  $D_{ji}$  and  $Z_{ji}$  denote the chosen output and the output amount generated by the Convolutional Neural Network (CNN), respectively, where  $n_{ol}$  and  $n_t$  represent the number of output layers and the amount of training samples, respectively.

This research utilized the half-value precision function to validate the optimized Covid-19 by accurately determining the parameters of the algorithms and applying them to a Convolutional Neural Network. Parameter initialization and evaluation of the function value were conducted, and then the Improved Gray Wolf Algorithm was utilized to update the algorithm parameters. This iterative process was repeated until termination criteria were met. The two essential CNN parameters of weights and biases were selected for optimization in accordance with this research.

$$W = [w_1, w_2, \dots, w_p]$$

$$b_n = [b_{1n}, b_{2n}, \dots, b_{Ln}] \quad (21)$$

$$A = [a_1, a_2, \dots, a_A] \quad (22)$$

$$w_n = [w_{1n}, w_{2n}, \dots, w_{Ln}] \quad (23)$$

With  $A$  denoting the whole number of agents,  $L$  specifying the whole number of layers,  $l$  representing the layer index,  $n$  representing the number of agents, and  $w_{in}$  Signifying the amount of the weight in layer  $i$ ;  $l$  ranges from 1 to  $L$  and  $n$  from 1 to  $A$ .

By employing the Improved Gray Wolf Algorithm for error minimization instead of backpropagation, we can optimize both weights and biases with ease since it does not require any backward computation.

#### IV. SIMULATION RESULTS

##### A. Dataset Explanation

The open-source repository on GitHub, run via Dr Joseph Cohen, was used to obtain 65 X-ray images of people with COVID-19 for this study[16]. The majority of the patients in this repository have severe acute respiratory syndrome (SARS), COVID-19, Middle East respiratory syndrome (MERS), or acute respiratory distress syndrome (ARDS) pneumonia. Chest X-ray Images (pneumonia) from the Kagel repository, which contains 65 standard X-ray images, have also been used [17]. Our investigation utilised a dataset composed of chest X-ray images from 65 healthy individuals and 65 patients diagnosed with COVID-19. A total of 130 images were collected and resized to 224×224 pixels. As illustrated in Fig. 4(a) and 4(b), samples of chest X-ray images of both usual and Covid-19 cases are presented.

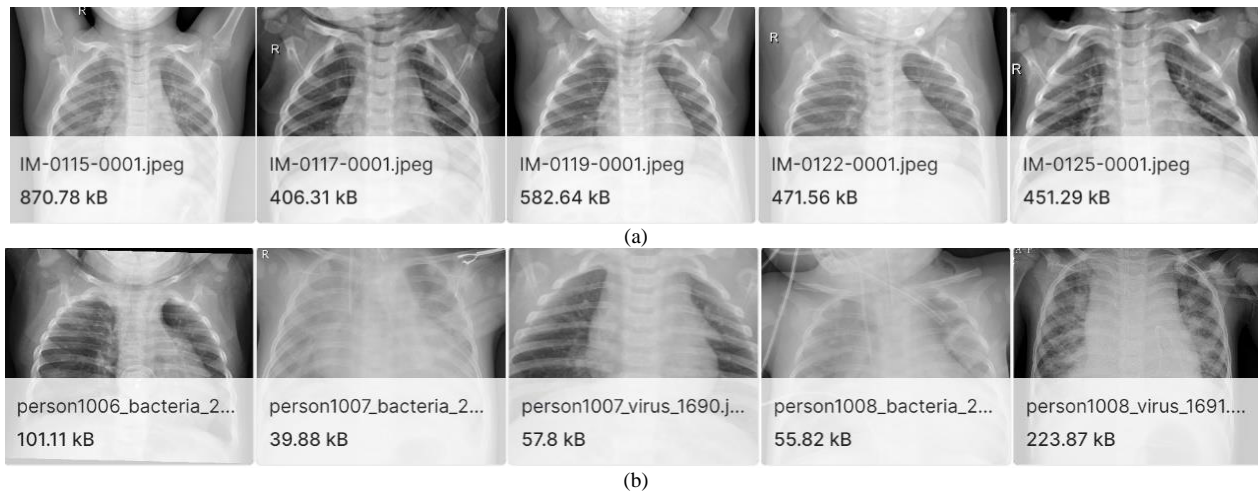


Fig. 4. Some chest X-ray image examples to (a) Normal and (b) Covid-19 cases.

### B. System Configuration

Utilizing MATLAB R2018b with 64-bit Windows, our algorithm was programmed and executed on an Intel Core i7 CPU 2.00GHz, 2.5GHz, 16GB RAM and 64-bit operating system. In addition to the variable of the competitive algorithms, we set the population size ( $N = 50$ ), maximum iterations ( $tmax = 200$ ), and 10 independent runs for each optimization problem. This ensures a reliable and effective optimization process.

The dataset was partitioned randomly into two subsets: 75% for training and 25% for testing. K-fold cross-verification was employed to validate the results, which are presented in Fig. 5 with five different values of k.

### C. Operation Criteria

The proposed system's efficiency was validated by employing five criteria for evaluating deep transfer learning models; Sensitivity, particularity, precision, and positive and negative predictive value (PPV and NPV).

$$Sensitivity (\%) = \frac{TP}{TP+FN} \quad (24)$$

$$Specificity (\%) = \frac{TN}{FP+TN} \quad (25)$$

$$Accuracy (\%) = \frac{TP+TN}{TP+FP+FN+TN} \quad (26)$$

$$PPV (\%) = \frac{TP}{TP+FP} \quad (27)$$

$$NPV (\%) = \frac{TN}{FN+TN} \quad (28)$$

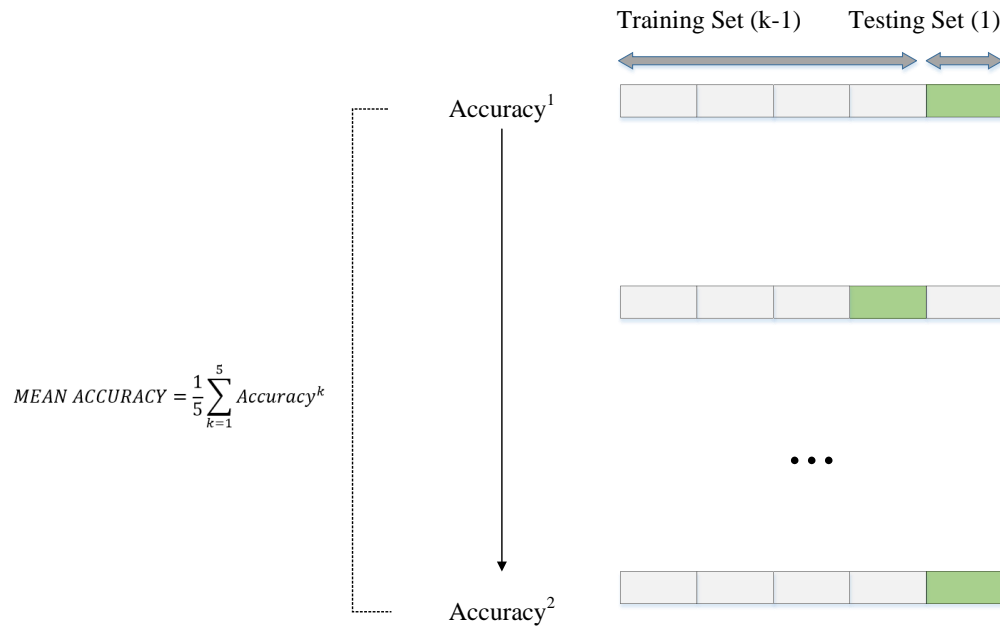


Fig. 5. Visual representation of test and training data sets for five-fold cross-validation.



The percentage of examples correctly classified as positive is known as True Positive (TP), while the percentage of examples incorrectly classified as positive is known as False Positive (FP). The False Negative (FN) count corresponds to the number of examples that is falsely labeled as negative. In contrast, the True Negative (TN) count corresponds to the amount of example that is correctly declared negative. Concerning a given dataset and test model, the True Positive (TP) count denotes the amount of positive COVID-19 cases the model has accurately identified. The number of false positives (FP) is the number of normal results that were incorrectly classified as positive for COVID-19. In contrast, the number of true negatives (TN) is the number of normal results that have been correctly identified. The number of false negatives (FN) is the amount of positive COVID-19 results that are misclassified as negative.

**D. Results and Discussions**

1) *Confusion matrix and accuracy analysis:* In this investigation, chest X-ray images are utilized to forecast Covid-19 cases. The outcomes of the simulation were trained and assessed on chest X-ray images, and then, they were

compared to traditional convolutional neural networks [18] and CNN/GWO methodology. As previously explained, the k-fold cross-validation method has been used to prevent overfitting. According to the analysis of the graphs in the proposed CNN/IGWO model in fold-2, according to the graphs and the confusion matrix, it performs better. Also, in the CNN/GWO model, fold-1 performs better according to the graphs and the confusion matrix, shown in Fig. 6.

As can be observed, Fig. 6 clearly demonstrates that the proposed CNN/IGWO model outperforms the CNN/GWO model and CNN model in terms of predictive performance, as evidenced by the various metric indicators. The CNN/IGWO model astoundingly recognized COVID-19 contaminated illness (65 images) as accurate positive and ordered images (65 images) as true negative with an impressive 99 percent accuracy score upon analyzing the uncertainty matrix.

Fig. 7 and Fig. 8 reveal the remarkable improvement in precision and loss of a CNN optimized by the IGWO algorithm using the Joseph Cohen dataset, compared with CNN [18] and CNN/GWO methodology.

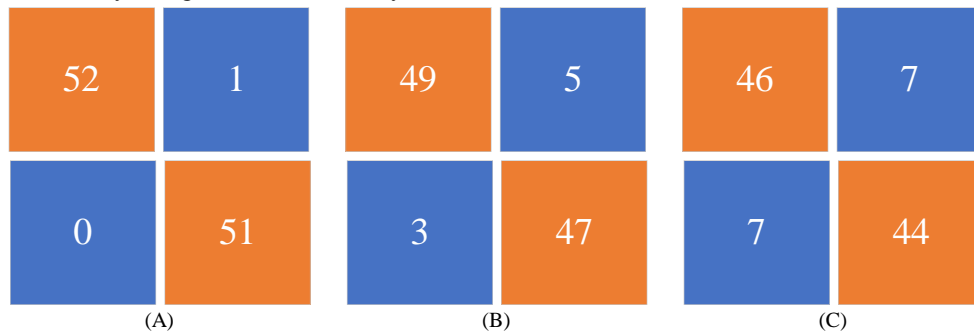
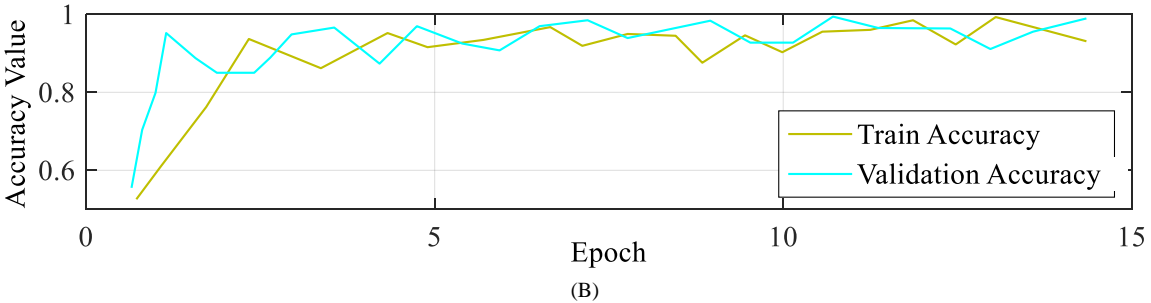
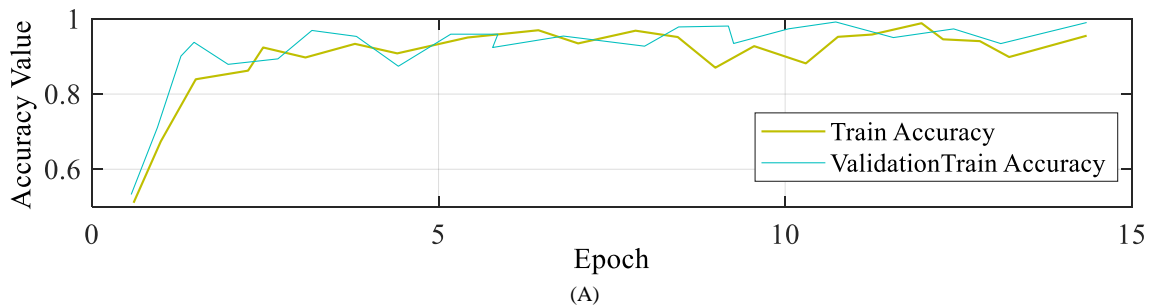


Fig. 6. Confusion matrix of (A) CNN/IGWO, (B) CNN/GWO, and (C) CNN/GWO.



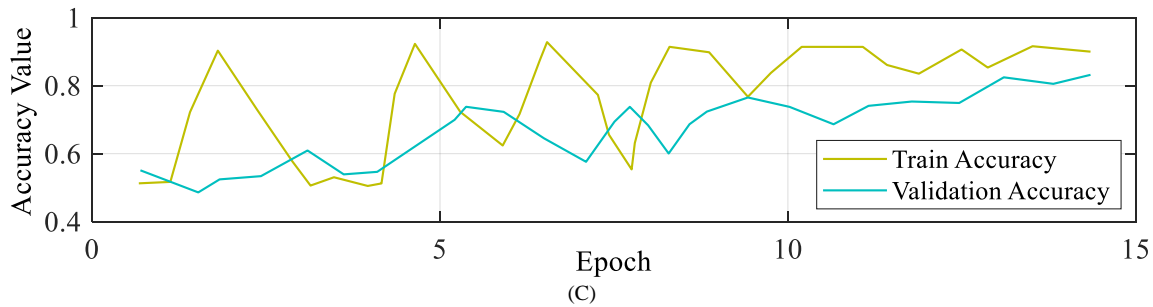


Fig. 7. Accuracy value of (A) CNN/IGWO, (B) CNN/GWO, and (C) CNN/GWO.

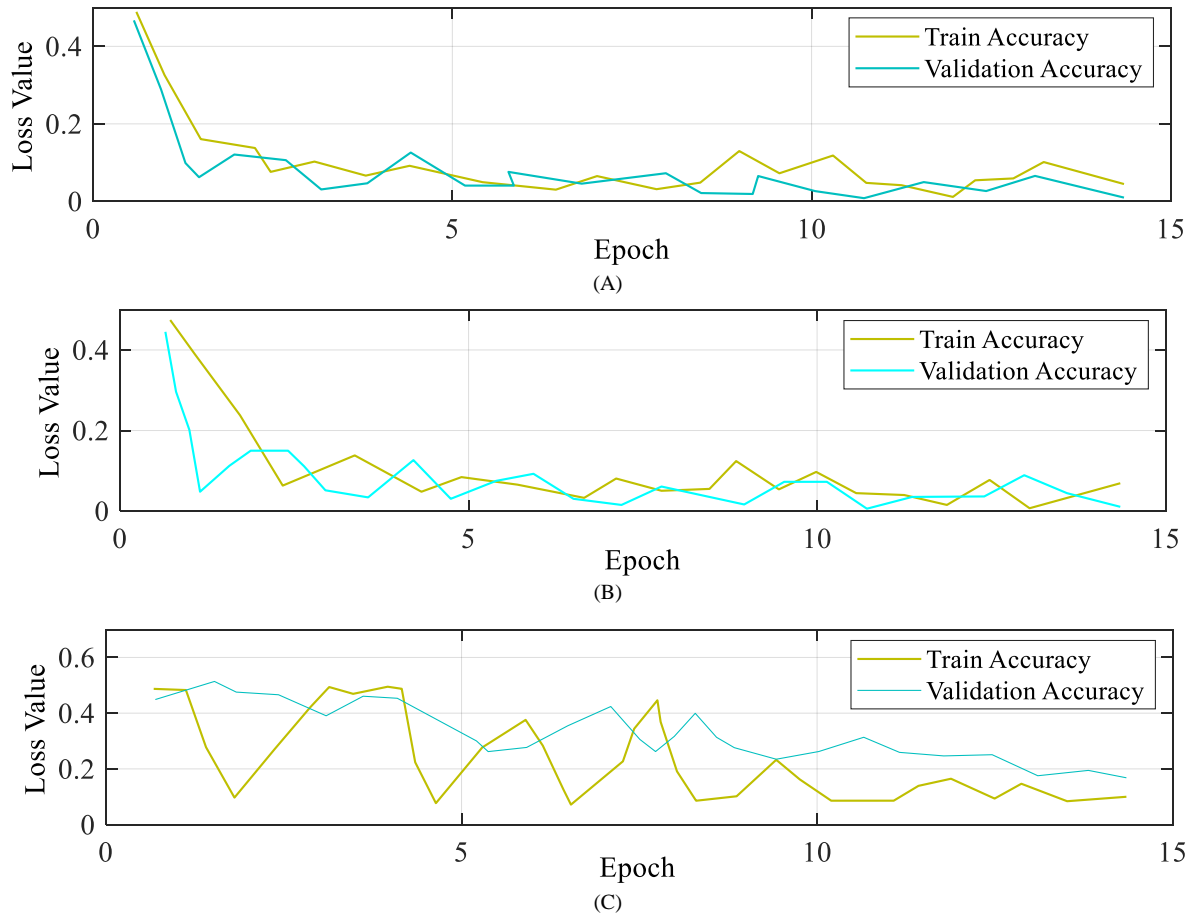


Fig. 8. Loss value of (A) CNN/IGWO, (B) CNN/GWO, and (C) CNN/GWO.

According to the results from accuracy and loss diagrams in Fig. 7 and Fig. 8, it can be understood that the maximal the number of epochs, the more the precision of the CNN/IGWO method increases and the less the error in this model. Therefore, if we want to compare these two models in general, the CNN/IGWO model has a better performance

2) *Comparison of two models based on test data:* As mentioned before, the method was compared with standard CNN [18] and CNN/GWO methodology validation and analyzing the proposed method's efficiency. In another detailed comparison of the performance of the models, the comparison of the three methods by the test data is denoted in Table I.

We obtained 100% sensitivity and a value of 100% specificity, 86% accuracy value for the proposed which is the best performance among the methods in the CNN/IGWO model. The lowest performance is achieved by the standard CNN with of 87% sensitivity value, 86% specificity value, and 86% specificity value accuracy. As a result, the CNN/IGWO method offers an advantage over the other two models in both the training and test phases. As can be observed, the highest level of accuracy belongs to the proposed CNN/IGWO method toward the other two aforesaid methods. The results show the effect of using the IGWO algorithm on the deep learning framework.

TABLE I. ANALYZING THE EFFICACY OF COVID-19 DETECTION USING PERFORMANCE METRICS

Method/Fold		Sensitivity	Specificity	PPV	NPV	Accuracy
CNN [18]	F1	0.87	0.86	0.87	0.86	0.86
	F2	0.90	0.91	0.88	0.87	0.89
	F3	0.85	0.83	0.84	0.83	0.85
	F4	0.92	0.93	0.90	0.92	0.89
	F5	0.86	0.85	0.86	0.88	0.87
	Mean	0.88	0.87	0.87	0.87	0.87
CNN/PSO	F1	0.88	0.87	0.86	0.87	0.87
	F2	0.92	0.93	0.89	0.88	0.89
	F3	0.87	0.84	0.86	0.84	0.86
	F4	0.92	0.94	0.92	0.93	0.89
	F5	0.85	0.84	0.87	0.89	0.88
	Mean	0.89	0.88	0.88	0.88	0.87
CNN/GWO	F1	0.94	0.90	0.91	0.94	0.92
	F2	0.95	0.93	0.92	0.95	0.94
	F3	0.90	0.87	0.84	0.83	0.88
	F4	0.96	0.94	0.93	0.95	0.95
	F5	0.93	0.89	0.88	0.86	0.90
	Mean	0.93	0.90	0.89	0.90	0.91
CNN/IGWO	F1	1.00	0.98	0.98	1.00	0.99
	F2	1.00	0.99	0.99	1.00	0.99
	F3	0.86	0.87	0.85	0.88	0.86
	F4	1.00	0.98	0.98	0.99	0.98
	F5	0.87	0.88	0.86	0.89	0.87
	Mean	0.94	0.94	0.93	0.95	0.93

## V. CONCLUSION

The new coronavirus (Covid-19) is an infectious agent that causes severe respiratory illness in humans. Initially identified in Wuhan, China, in late 2019, the virus has since spread worldwide. Common indications of Covid-19 infection are fever, cough, dyspnea, muscle pain, malaise, and impaired olfaction or gustation. Diagnosis can be confirmed through laboratory testing for the virus or through medical imaging techniques such as sample chest radiography and calculated tomography (CT) scans. Generally, supportive care, hydration, rest, and symptom observation are the treatments for Covid-19. Computer-aided detection (CAD) is a method employed to identify Covid-19 in clinical imaging. This entails using artificial intelligence algorithms to discover infection in X-ray, computed tomography (CT) scans, and ultrasounds. The algorithm examines the image and locates any patterns correlated with the disorder. If a pattern is observed, it is flagged as a potential suggestion of Covid-19. This approach has been beneficial for the early detection of the virus and has improved the precision of diagnosis. This paper introduces a modified convolutional optimal neural network by an Improved Gray Wolf version (IGWO) Algorithm as a new technique for the optimal analysis of COVID-19 in medical imaging. The proposed method was tested on the Joseph Cohen

dataset, and its performance was compared with that of other methods, including CNN and CNN/GWO, to demonstrate its effectiveness.

One potential future direction for further research in the field of medical imaging and disease detection is the development of a versatile and adaptable framework that can detect not only COVID-19 but also other respiratory diseases or conditions. While the focus of the current research is on COVID-19, expanding the framework to encompass a broader range of diseases would enhance its clinical utility and impact. To achieve this, researchers can explore the possibility of incorporating a wider variety of training data and expanding the dataset to include images of various respiratory diseases such as pneumonia, tuberculosis, lung cancer, and other pulmonary conditions. By training the model on a diverse dataset, it can learn to identify unique features and patterns associated with different diseases, enabling it to provide accurate and specific diagnoses.

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# Automated Epileptic Seizure Detection using Improved Crystal Structure Algorithm with Stacked Autoencoder

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**Abstract**—Epilepsy can be referred to as a neurological disorder, categorized by intractable seizures with serious consequences. To forecast such seizures, Electroencephalogram (EEG) datasets should be gathered continuously. EEG signals were recorded by using numerous electrodes fixed on the scalp that cannot be worn by patients continuously. Neurostimulators can intervene in advance and ignore the seizure rate. Its productivity is increased by using heuristics such as advanced seizure prediction. In recent times, several authors have deployed various deep learning approaches for predicting epileptic seizures, utilizing EEG signals. In this work, an Automated Epileptic Seizure Detection using Improved Crystal Structure Algorithm with Stacked Auto encoder (AESD-ICSASAE) technique has been developed. The presented AESD-ICSASAE technique executes a three-stage process. At the initial level, the AESD-ICSASAE technique applies min-max normalization approach to normalize the input data. Next, the AESD-ICSASAE technique uses ICSA based feature selection method for optimal choice of features. Finally, the SAE based classification process takes place and the hyperparameter selection process is performed by Arithmetic Optimization Algorithm (AOA). To depict the enhanced classification outcomes of the AESD-ICSASAE technique, series of experiments was made. Furthermore, the proposed method's results have been tested utilizing the CHB-MIT database, with results indicating an accuracy of 98.9%. These results validate the highest level of accuracy in seizure classification across all of the analyzed EEG data. A full set of experiments validated the AESD-ICSASAE method's enhancements.

**Keywords**—Deep learning; EEG signals; epileptic seizure detection; hyperparameter tuning; stacked autoencoders

## I. INTRODUCTION

Epilepsy is a disease of the central nervous system caused by irregularities in brain electricity [1]. Seizures occur often and often without notice, making this a diagnosis. Epilepsy manifests itself with episodes of temporarily diminished or suspended consciousness, brief periods of unconsciousness, and abrupt, severe convulsions [2]. Epilepsy has a significant effect on people's life since it may result in catastrophic events, mental decline, and restrictions on routine tasks. Patients with epilepsy would benefit more from a method to predict when they will have seizures so that they can avoid injury and begin treatment immediately [3]. In addition, it lays the way for seizure intervention mechanisms to be used to prevent impending seizures and individualized epilepsy treatment (tailored medicine with minimal side-effects). Numerous

studies have recently shown that the onset of epileptic seizures may be predicted with some degree of accuracy [4], suggesting that individuals with epilepsy might benefit from seizure prediction methods. The EEG is now the most widely used instrument for seizure detection [5]. Examining pre-seizure EEG activity for specific patterns that signal future seizures was the key challenge, and this was overcome in the reported study [6]. Epileptic seizures lead to a rapid increase in electrical disturbances in brain of patients, which is measured utilizing the EEG approach [7]. Generally, EEG signal recordings were scrutinized by neurologists for determining different levels of epilepsy such as interictal (in-between seizures), ictal (on-going seizures), post-ictal (after seizure onset period), and preictal (just before seizure onset) [8]. But this process can be time-taking, and arduous, which results in the need for automated epileptic seizure predictive mechanism. Deep learning (DL) was another pattern in this regard, which can manage the large signal dataset produced by wearable IoT sensing gadgets such as EEG headsets for epilepsy [9]. The methods depend on DL methods solve the restrictions of conventional Machine Learning (ML) methods by providing less processing duration and ability of managing big data of multichannel biomedical signals. Accordingly, such methods serve promising roles in offering real time solutions in healthcare field [10].

In this paper, an Automated Epileptic Seizure Detection using Improved Crystal Structure Algorithm with Stacked Auto encoder (AESD-ICSASAE) technique has been developed. The presented AESD-ICSASAE technique executes a three-stage process. The AESD-ICSASAE methodology begins with a min-max normalization stage to standardize the input data. After that, an ICSA-based feature selection methodology is used by the AESD-ICSASAE method to choose the best features. In the end, the SAE-based method of classification is carried out, and the AOA is the one responsible for carrying out the hyperparameter selection procedure. Multiple computations have been performed to show how the AESD-ICSASAE technique improves classification accuracy.

## A. Key Contributions

The work presented here introduces an automated system for identifying epileptic seizures termed AESD-ICSASAE. The methodology employed by the authors involves the utilization of deep learning methodologies, particularly stacked autoencoders (SAEs), for the purpose of examining EEG data.

Here we propose using the AOA to choose appropriate the hyperparameters and a modified version of the crystal structure algorithm (ICSA) to choose appropriate attributes. The AESD-ICSASAE approach greatly enhances classification accuracy, providing a possible choice for real-time seizure forecasting and tailored epilepsy therapy, according to the experimental findings.

The following outline describes how the remaining parts of this work are structured: Section II demonstrates current and significant work. The conceptual design of the proposed system is presented in Section III. Both findings and analysis of the simulations are discussed in Section IV. Challenges and limitations are discussed in Section V. The work is concluded in Section VI.

## II. RELATED WORKS

In [11], Epilepsy convulsions using EEG recordings were detected using the wavelet transform and then classified using ML algorithms as either not a seizure or a seizure. In all, 48 occurrences were selected from the collected EEG signals obtained via the CHB-MIT scalp EEG data. Hence, this data was segmented using Tuneable Q-Wavelet Transform (TQWT), and time-frequency characteristics like entropy were extracted, and temporal parameters were extracted to provide a huge dataset for accurately identifying epilepsy occurrences. Utilizing Random Forest (RF) and Support Vector Machine (SVM) classifiers, the dataset is further processed for classifying epilepsy. Jaiswal and Banka [12] proposed 2 effectual methods including Subpattern related PCA (SpPCA) and cross-subpattern correlation-related PCA (SubXPCA) includes SVM for automated seizure recognition in EEG signals. Feature extraction has been executed utilizing SubXPCA and SpPCA. Both methods explore sub pattern relation of EEG signals, which aids in making decisions.

By focusing on what makes seizures unique, Qureshi et al. [13] were able to develop a system for Epileptic Seizure Detection (ESD) that uses both traditional ML algorithms and fuzzy-based approaches. In this work, the raw input divides unknown EEG input segments into interictal and ictal groups. Bairagi and Harpale [14] introduced a novel technique, Singular Spectrum Empirical Mode Decomposition (SSEMD) for effectual categorization of Epileptic and Normal EEG Signals. For classifying EEG signals in normal and epileptic classes, high-performance ML classifiers were employed. In [15], an end-to-end ML method was modelled for recognition of epileptic seizures utilizing the pretrained deep 2D-CNN and concept of Transfer Learning (TL).

In [16], a Principal component analysis (PCA) with Genetic Algorithm (GA) related ML method can be advanced for classifying binary epileptic seizures out of EEG dataset. The presented method leverages PCA for minimizing the count of attributes for binary classification of epileptic seizures and can be implemented in the prevailing ML techniques for assessing model performance compared with more features. In this study, GA was used for tuning the hyperparameters of ML methods to detect the optimal ML method. To find the best SVM parameters for categorizing EEG recordings, Subasi et al. [17] develop a hybrid strategy for ESD using GA and Practical Swarm Optimization (PSO). SVMs are one of robust ML

approaches and were widely leveraged in several application zones. The kernel parameter's setting for SVMs in training effects the classifier accuracy. The authors employed GA- and PSO-related techniques for optimizing the SVM parameters.

The AESD-ICSASAE method represents a notable advancement over prior methodologies for the automated detection of epileptic seizures, exhibiting superior performance in multiple aspects. The approach employed involves the utilization of deep learning techniques, particularly stacked autoencoders (SAEs), to more efficiently capture intricate patterns present in EEG signals compared to conventional ML methods. The utilization of an enhanced crystal structure algorithm (ICSA) facilitates superior feature selection, thereby tackling the difficulty of discerning pertinent features from voluminous EEG datasets. Furthermore, the AOA facilitates the optimization of hyperparameter selection, thereby augmenting the efficacy of the overall model. The suggested system exhibits superiority over prior approaches due to its ability to achieve greater categorization accuracy, enhanced computational efficiency, and increased interpretability, all of which are attributed to the recent advances.

## III. THE PROPOSED MODEL

A novel AESD-ICSASAE technique for reliable ESD on EEG data was developed in this paper. The presented AESD-ICSASAE technique executes a three-stage process.

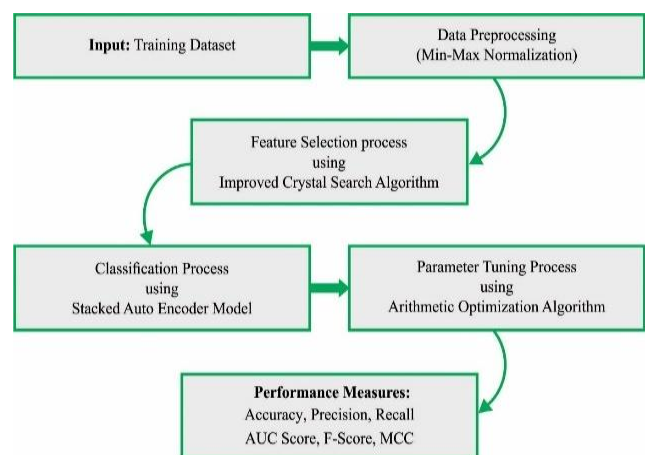


Fig. 1. Structure of the AESD-ICSASAE scheme.

As a first step, the AESD-ICSASAE method uses a min-max normalization methodology to standardize the input data. After that, an ICSA-based feature selection strategy is used by the AESD-ICSASAE method to choose the most relevant characteristics. At last, the AOA with SAE based classification process takes place. Fig. 1 represents the workflow of AESD-ICSASAE model.

### A. Data Normalization

In the beginning, the AESD-ICSASAE method utilizes a min-max normalization strategy in order to standardize the input data. The process of Min-Max normalization involves applying a linear transformation to the original dataset.  $MaxA$  and  $MinA$  represent the upper and lower bounds of attribute  $A$ , accordingly. The process of Min-Max normalization involves mapping the value of variable  $A$  to a



new value, denoted as  $v'$ , within a specified range. This is achieved by computing the difference between the  $new\_MinA$  and  $new\_MaxA$ . The threshold value for Min-Max range was fixed as  $[0,1]$

$$V' = \frac{V - \text{Min } A}{\text{Max } A - \text{Min } A} (\text{new\_Max } A - \text{new\_Min } A) + \text{new\_Min } A \quad (1)$$

### B. Feature Selection using ICSA Technique

The AESD-ICSASAE method currently employs an ICSA-based strategy for selecting features. The mathematical modeling of CSA is developed where the aim is to utilize crucial modification [18]. Now, all the candidate solutions of optimization technique are considered as a single CSA in the space. CSA counts are determined at random for the initialization of iteration purposes.

$$Cr = \begin{bmatrix} Cr_1 \\ Cr_2 \\ \vdots \\ Cr_i \\ \vdots \\ Cr_n \end{bmatrix} = \begin{bmatrix} x_1^1 & x_1^2 & \dots & x_1^j & \dots & x_1^d \\ x_2^1 & x_2^2 & \dots & x_2^j & \dots & x_2^d \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_i^1 & x_i^2 & \dots & x_i^j & \dots & x_i^d \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_n^1 & x_n^2 & \dots & x_n^j & \dots & x_n^d \end{bmatrix} \begin{cases} i = 1, 2, \dots, n \\ j = 1, 2, \dots, d \end{cases} \quad (2)$$

In Eq. (2),  $n$  indicates the CSA count and  $d$  designates the problem dimension. The initial location of CSA can be determined at random in the searching space as follows:

$$x_i^j(0) = x_{i,\min}^j + \xi(x_{i,\max}^j - x_{i,\min}^j), \begin{cases} i = 1, 2, \dots, n \\ j = 1, 2, \dots, d \end{cases} \quad (3)$$

Now,  $x_i^j(0)$  correspondingly represents the initial CSA position,  $x_{i,\min}^j$  and  $x_{i,\max}^j$  shows the minimal and maximal permissible values for  $j^{th}$  variable of  $i^{th}$  solution candidate and  $\xi$  indicate random number within  $[0, 1]$ . All the CSA at the corner can be assumed as the main CSA related to the concept of 'basis' in CSAlography, in which  $Cr_{main}$  is determined at random by assuming the initially made CSA. Note that arbitrary selection for every step can be determined by ignoring current  $Cr$ . The CSA with optimum formation can be determined as  $Cr_b$  while mean value of arbitrarily selected CSA is signified by  $F_c$ .

In order to upgrade the location of solution candidate in searching space, fundamental principle was deliberated:

a) Simple cubicle:

$$Cr_{new} = Cr_{old} + rCr_{main}, \quad (4)$$

b) Cubicle with the best CSAs:

$$Cr_{new} = Cr_{old} + r_1Cr_{main} + r_2Cr_b, \quad (5)$$

c) Cubicle with the mean CSAs:

$$Cr_{new} = Cr_{old} + r_1Cr_{main} + r_2F_c, \quad (6)$$

d) Cubicle with the best and mean CSAs:

$$Cr_{new} = Cr_{old} + r_1Cr_{main} + r_2Cr_b + r_3F_c, \quad (7)$$

Now, the novel location is denoted by  $Cr_{new}$ , the older location can be represented by  $c_{r_{old}}$ , and  $r$ ,  $r_1$ ,  $r_2$  and  $r_3$

denotes the random number. To provide the best possible results from the classifier, the CSO technique includes a fitness function (FF) whose values are skewed towards the positive to highlight the superiority of the candidates.

$$\text{fitness}(x_i) = \text{ClassifierErrorRate}(x_i) = \frac{\text{number of misclassified samples}}{\text{Total number of samples}} * 100 \quad (8)$$

The fitness function (FF) employed in the ICSA method was developed to have a balance between classifier accuracy (maximum) and the number of chosen features in all solutions (min) obtained by using such selected features, Eq. (9) denotes the FF for evaluating solutions.

$$\text{Fitness} = \alpha\gamma_R(D) + \beta \frac{|R|}{|C|} \quad (9)$$

Whereas  $\gamma_R(D)$  signifies the classifier error rate of presented techniques.  $|C|$  is total number of features in the dataset,  $|R|$  denotes the cardinality of the selected subset,  $\alpha$  and  $\beta$  were two parameters that match the importance of subset length and classification quality.  $\alpha \in [1, 0]$  and  $\beta = 1 - \alpha$ .

In order to create the ICSA, the chaos theory was used in the design process. The evolution of chaos exhibits regularity, nonrepeat ergodicity, and unpredictability, and it is a nonlinear process that may be sensitive to the starting state. Such attributes enable particles to hasten the convergence speed of method, escape from local optimization, and establish good spatial distribution. To participate in population initialization, chaotic series related to Tent map was employed and it can be formulated below.

$$f(x) = \begin{cases} 2x & 0 \leq x \leq 0.5 \\ 2(1-x) & 0.5 < x \leq 1 \end{cases} \quad (10)$$

The formula of Tent map afterward Bernoulli transform can be expressed:

$$f(x) = \begin{cases} 2x & 0 \leq x \leq 0.5 \\ 2x - 1 & 0.5 < x \leq 1 \end{cases} \quad (11)$$

### C. Seizure Recognition using Optimal SAE

In this work, the SAE based classification process takes place. The SAE method obtains the feature vector as input to assign appropriate class labels. AE was a kind of unsupervised learning framework which has 3 states namely input, hidden states and output [19]. The process of AE trained includes encoded and decoded parts. Fig. 2 depicts the infrastructure of SAE. The encoded part is used for mapping the input dataset to hidden demonstration and decoded part is used to regenerate input dataset in hidden demonstration. To give the unlabeled source dataset  $\{x_n\}_{n=1}^N$ , while  $x_n \in R^{m \times 1}$ ,  $h_n$  signifies hidden encoded vector analyzed in  $x_n$ , and  $\hat{x}_n$  indicates decoded vector of final state and encoder procedure can be defined in such a way:

$$h_n = f(W_1x_n + b_1) \quad (12)$$

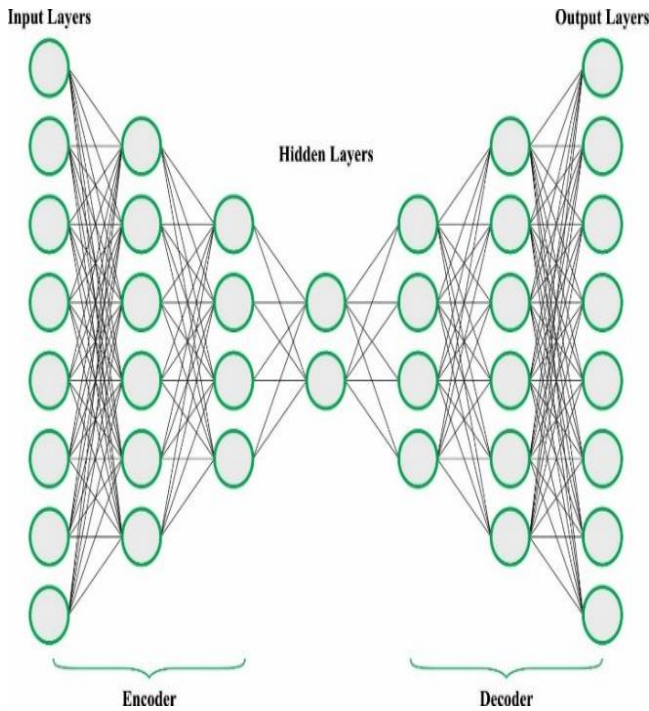


Fig. 2. Architecture of SAE.

While  $f$  represents the encoded operation,  $W_1$  stands for the weighted matrix associated with the encoded, and  $b_1$  displays the bias vector. This method of decoding may be characterized as follows:

$$\hat{x}_n = g(W_2 h_n + b_2) \quad (13)$$

The decoded perform is denoted by  $g$ , while the weighted matrix of decoding are represented by  $W_2$ , and the bias vector is denoted by  $b_2$ . To reduce the amount of inaccuracy in the reconstruction, AE's collection of variables was fine-tuned.

$$\varnothing(\theta) = \arg \min_{\theta, \theta'} \frac{1}{n} \sum_{i=1}^n L(x^i, \hat{x}^i) \quad (14)$$

While  $L$  denotes a loss function  $L(x, \hat{x}) = \|x - \hat{x}\|^2$ .

SAE uses a stacking technique to map  $n$  AEs to  $n$  hidden states using an unsupervised state-wise learning approach, before tuning using a supervised technique. Because of this, we may classify the SAE-based technique in the following ways:

- 1) The first step was to train the first AE using the input dataset to produce a feature vector;
- 2) The second phase was to use that feature vector as input for the next stage, and so on, until the process stopped.
- 3) Afterwards, all hidden states are trained, and the BP technique is used to minimize the cost function and improve the weight using labelled trained sets to achieve tuning.

Finally, the hyperparameter selection process is performed by the AOA resulting in enhanced performance. This optimization technique primarily relies on exploration and development stages [20]. The searching space for candidate solutions can be covered generally to break deadlock of method falling into search stagnation in exploration stage.

In the preliminary step of AOA's optimized approach, the sequence of potential solutions was constructed randomly.

$$X = [\chi_{N-1,1} \chi_{N,1} \chi_{2,\dots,1} \chi^1, 1 \chi_{N-1,j} \chi_{N,j} \chi_{2,j} \chi^1, j \chi_{N,n-1} \chi_{1,\dots,n-1} \chi_{N-l,n} \chi_{1,n} \chi_{N,n} \chi_{2,\dots,n}']$$

$$X = \begin{bmatrix} x_{1,1} & \dots & \dots & x_{1,j} & x_{1,n-1} & x_{1,n} \\ x_{2,1} & \dots & \dots & x_{2,j} & \dots & x_{2,n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{N-1,1} & \dots & \dots & x_{N-1,j} & \dots & x_{N-1,n} \\ x_{N,1} & \dots & \dots & x_{N,j} & x_{N,n-1} & x_{N,n} \end{bmatrix} \quad (15)$$

Before the AOA can put the optimized method into action, it must complete the searching phase based on the resultant value of the Math Optimizer Accelerated (MOA) functioning, which may be calculated using the formula below.

$$MOA(C\_Iter) = \text{Min} + C\_Iter \times \left( \frac{\text{Max} - \text{Min}}{M\_Iter} \right) \quad (16)$$

We may see the function's value after  $Iter$  iterations by looking at  $MOA(C\_Iter)$ ;  $C\_Iter$  shows the existing iteration;  $M\_Iter$  indicates the maximal iteration amount; Min and Max stand for the minimum and maximum values of the accelerated function, respectively.

The exploration phase is realized mainly by the two operators namely Division (D) and Multiplication (M). In mathematical computation, these two operators are accomplished tremendously distributing value, for the considerable amount of candidate solutions were covered. In exploration technique, the position of candidate solution can be considerably upgraded by the following expression:

$$x_{i,j}(C\_Iter + 1) = \begin{cases} \text{best}(x_j) / (MOP + \varepsilon) \times ((UB_j - LB_j) \times \mu + LB_j) & r_2 < 0.5 \\ \text{best}(x_j) \times MOP \times (UB_j - LB_j) \times \mu + LB_j & \text{otherwise} \end{cases} \quad (17)$$

Now  $\chi_{i,j}(C\_Iter + 1)$  denotes the  $j^{th}$  location of  $i^{th}$  solution in  $(C\_Iter + 1)^{th}$  iteration;  $\varepsilon$  represents the small value; The  $UB$  and  $LB$  indicate the maximum and minimum possible distances to a proposed solution;  $\mu$  is applied to regulate exploration stage that was set to 0.5.

$$MOP(C\_Iter) = 1 - \frac{C\_Iter^{\frac{1}{\alpha}}}{M\_Iter^{\frac{1}{\alpha}}} \quad (18)$$

The variable  $\alpha$  is utilized to establish the degree of effectiveness of the exploitation process during each iteration, where  $\alpha$  is assigned a value of 5. The utilization of the exploitation process is contingent upon two operators, specifically Addition (A) and Subtraction (S), which are conducive to minimizing dispersion in candidate solutions and can be implemented through extensive search techniques with a heightened likelihood of approximating the best possible solution.

$$x_{i,j}(C\_Iter + 1) = \begin{cases} \text{best}(x_j) - MOP \times ((UB_j - LB_j) \times \mu + LB_j), & r_3 < 0.5 \\ \text{best}(x_j) + MOP \times ((UB_j - LB_j) \times \mu + LB_j), & \text{otherwise} \end{cases} \quad (19)$$

**Algorithm 1:** Pseudo code for AOA

```

Populace size (N) and maximum iterations (T) are set to their
default values.
The starting position of each individual searching agent,
 $X_i(i = 1,2, \dots, N)$ 
Input values are  $\alpha, \mu, \text{Min},$  and  $\text{Max}$ 
While ( $t \leq T$ )
Assess the fitness of every search agent, Upgrade best Fitness,
 $X_b$ 
Assess the MOP
Assess the  $MOA$ 
For every search agents
If  $\text{rand} > MOA$ 
Upgrade position
Else
Upgrade position
End if
End for
                                 $t = t + 1$ 
End While
Return best Fitness,  $X_b$ 
    
```

The flexible changes between the exploration and utilization steps enable the AOA approach to finding the best answer and remain to offer a wide range of options for a broad search.

IV. RESULTS AND DISCUSSION

In this section, we verify the AESD-ICSASAE technique's experimental outcome evaluation on a dataset [21,22], of 40000 observations and two categories of classes, illustrated in Table I. The AESD-ICSASAE method has chosen a set of 7 features out of 23 features.

TABLE I. A COMPREHENSIVE OVERVIEW OF THE DATASET

Type of Classes	Total number of Observations
Seizure	20,000
NonSeizure	20,000
<b>Overall Observations</b>	<b>40,000</b>

In Fig. 3, the confusion matrices of the AESD-ICSASAE model are demonstrated. The results demonstrated that the AESD-ICSASAE model has shown accurate classification of seizure and no seizure class samples.

Table II presents the comprehensive outcomes of detecting seizures achieved by the AESD-ICSASAE approach, utilizing 60% of the Training set (TR) and 40% of the Testing set (TS) records. The AESD-ICSASAE method's brief findings for classification using 60% of the TR dataset are shown in Fig. 4. Samples belonging to the seizure and no seizure classes were correctly recognized using the AESD-ICSASAE methodology. In addition, it is noticed that the AESD-ICSASAE model at training phase has attained overall  $\text{accu}_{bal}$  of 98.70%,  $\text{prec}_n$  of 98.70%,  $\text{reca}_1$  of 98.70%,  $F_{score}$  of 98.70%,  $AUC_{score}$  of 98.70%, and MCC of 97.41%.

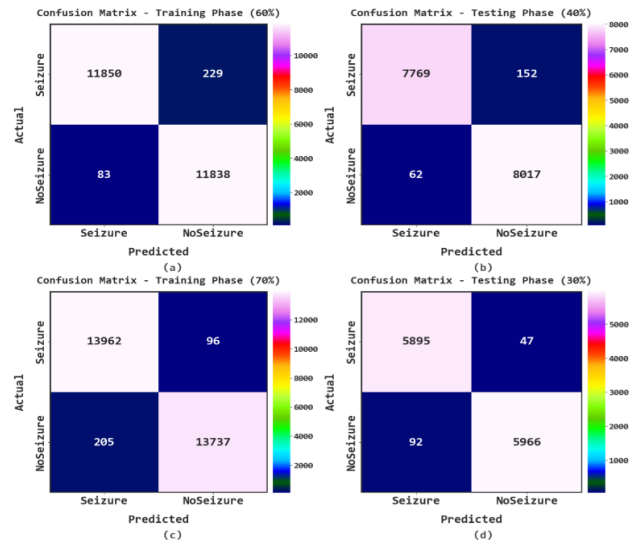


Fig. 3. Confusion matrix of the AESD-ICSASAE approach for the training (TR) and testing (TS) databases with a ratio of 60:40 and 70:30, respectively.

TABLE II. PRESENTS THE FINDINGS OF DETECTING SEIZURES USING THE AESD-ICSASAE APPROACH WITH A 60:40 RATIO OF TRAINING TO TESTING DATABASES

Training / Testing (60:40)						
Class	$\text{Accu}_{bal}$	$\text{Prec}_n$	$\text{Reca}_1$	$F_{score}$	Score of AUC	MCC
<b>Training Set</b>						
Seizure	98.10	99.30	98.10	98.70	98.70	97.41
NoSeizure	99.30	98.10	99.30	98.70	98.70	97.41
<b>Average:</b>	<b>98.70</b>	<b>98.70</b>	<b>98.70</b>	<b>98.70</b>	<b>98.70</b>	<b>97.41</b>
<b>Testing Set</b>						
Seizure	98.08	99.21	98.08	98.64	98.66	97.33
NoSeizure	99.23	98.14	99.23	98.68	98.66	97.33
<b>Average:</b>	<b>98.66</b>	<b>98.67</b>	<b>98.66</b>	<b>98.66</b>	<b>98.66</b>	<b>97.33</b>

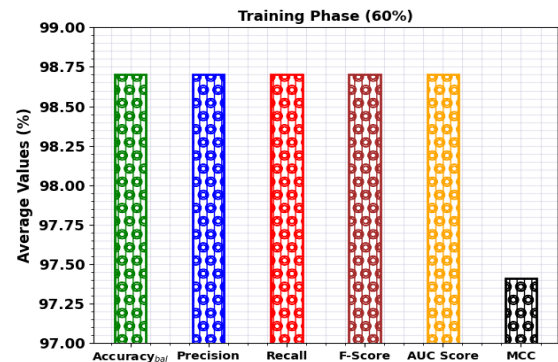


Fig. 4. Average outcome of AESD-ICSASAE approach under 60% of TR.

Table II presents the comprehensive outcomes of detecting seizures achieved by the AESD-ICSASAE approach, utilizing 60% of the Training set (TR) and 40% of the Testing set (TS) records. Fig. 5 presents the detailed classification outcomes of the AESD-ICSASAE method with 40% of TS database. The AESD-ICSASAE technique has properly identified the seizure and no seizure class samples. Moreover, it is visible that the AESD-ICSASAE methodology at testing phase has attained an average  $\text{accu}_{bal}$  of 98.66%,  $\text{prec}_n$  of 98.67%,  $\text{reca}_1$  of 98.66%,  $F_{score}$  of 98.66%,  $AUC_{score}$  of 98.66%, and MCC of 97.33%.

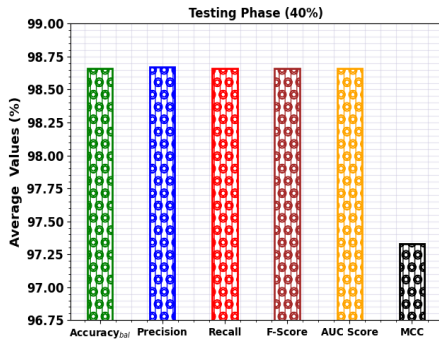


Fig. 5. Average outcome of AESD-ICSASAE approach under 40% of TS database.

Table III provides an overview of the AESD-ICSASAE method's detection findings for seizures using 70% of TR and 30% of TS datasets. The AESD-ICSASAE approach's quick classification results using 70% of the TR dataset are shown in Fig. 6. The AESD-ICSASAE technique has properly recognized the seizure and no seizure class samples. Also, it is noted that the AESD-ICSASAE method at training phase has acquired average  $accu_{bal}$  of 98.92%,  $prec_n$  of 98.93%,  $reca_l$  of 98.92%,  $F_{score}$  of 98.92%,  $AUC_{score}$  of 98.92%, and MCC of 97.85%.

TABLE III. SEIZURE DETECTION OUTCOMES OF AESD-ICSASAE APPROACH UNDER 70:30 OF TR/TS DATASET

Training / Testing (70:30)						
Type of Class	$Accu_{bal}$	$Prec_n$	$Reca_l$	$F_{score}$	Score of AUC	MCC
<b>Seizure Training Set</b>						
Seizure	99.32	98.55	99.32	98.93	98.92	97.85
NoSeizure	98.53	99.31	98.53	98.92	98.92	97.85
<b>Average</b>	<b>98.92</b>	<b>98.93</b>	<b>98.92</b>	<b>98.92</b>	<b>98.92</b>	<b>97.85</b>
<b>Seizure Testing set</b>						
Seizure	99.21	98.46	99.21	98.83	98.85	97.69
NoSeizure	98.48	99.22	98.48	98.85	98.85	97.69
<b>Average</b>	<b>98.85</b>	<b>98.84</b>	<b>98.85</b>	<b>98.84</b>	<b>98.85</b>	<b>97.69</b>

Fig. 7 portrays brief classification outcomes of the AESD-ICSASAE methodology with 30% of TS database. The AESD-ICSASAE technique has properly identified the seizure and no seizure class samples. Additionally, it is noted that the AESD-ICSASAE technique at testing phase has achieved average  $accu_{bal}$  of 98.85%,  $prec_n$  of 98.84%,  $reca_l$  of 98.85%,  $F_{score}$  of 98.84%,  $AUC_{score}$  of 98.85%, and MCC of 97.69%.

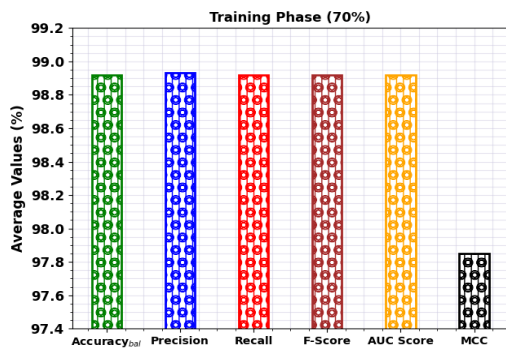


Fig. 6. Average outcome of AESD-ICSASAE technique under 70% of TR database.

Examining the AESD-ICSASAE approach's Training Accuracy (TACC) and Validation Accuracy (VACC) for seizure detection efficiency is shown in Fig. 8. The graph shows that greater TACC and VACC values result in greater efficiency for the AESD-ICSASAE method. The AESD-ICSASAE model is clearly the most successful in terms of TACC results.

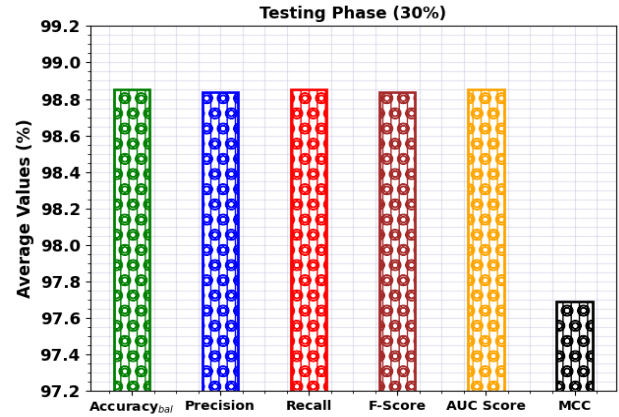


Fig. 7. Average outcome of AESD-ICSASAE approach in 30% of TS database.

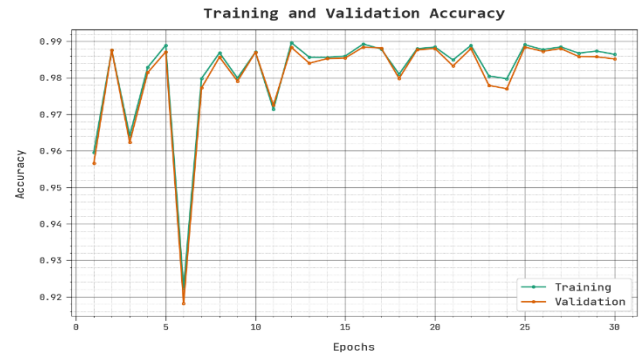


Fig. 8. Depicts the TACC and VACC analyses of the AESD-ICSASAE approach.

In Fig. 9, the TLS and VLS of the AESD-ICSASAE model is put to the test in terms of their ability to identify the onset of a seizure. Based on the graph, it seems that the AESD-ICSASAE method performs better when TLS and VLS are kept to their absolute minimums. It has been shown that the AESD-ICSASAE method leads to diminished VLS results.



Fig. 9. TLS and VLS analysis of AESD-ICSASAE approach.



Fig. 10 presents the results of a clear precision-recall analysis of the AESD-ICSASAE database used to evaluate the tested methods. The results showed that the AESD-ICSASAE method improved precision-recall values across the board.

Fig. 11 displays the results of a comprehensive ROC analysis performed on the AESD-ICSASAE test database. That number meant the AESD-ICSASAE algorithm had successfully clustered together a number of different types.

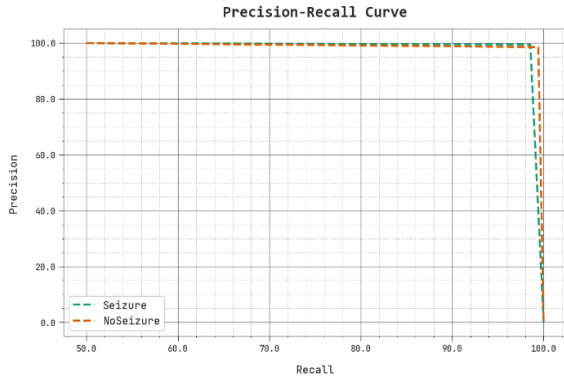


Fig. 10. Precision-recall analysis of AESD-ICSASAE method.

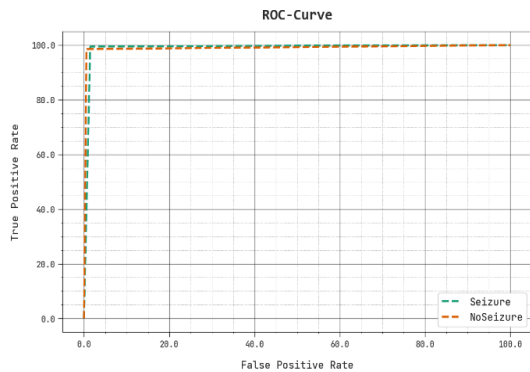


Fig. 11. ROC curve analysis of AESD-ICSASAE method.

Finally, the AESD-ICSASAE strategy superior accuracy may be verified at the ending phase through a comparative analysis, as depicted in Table IV and Fig. 12. The depicted figure indicates that the AESD-ICSASAE approach has exhibited enhanced efficacy, achieving an accuracy of 98.92%.

TABLE IV. COMPARISON OF THE AESD-ICSASAE SYSTEMS TO ALTERNATIVE METHODOLOGIES

Methodology used	Accu <sub>y</sub> (%)
<b>AESD-ICSASAE</b>	<b>98.92%</b>
DCAE-MLP	98.17%
SVM Model	82.39%
LR Model	81.32%
ResNet-152	90.63%
Inception-V3 Model	91.89%
EESC Model	93.92%

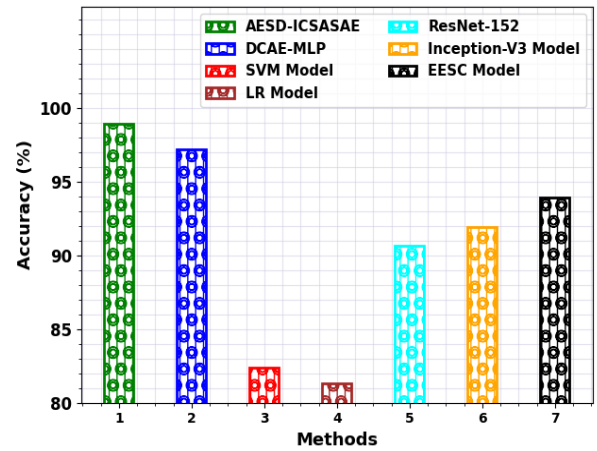


Fig. 12. Comparative analysis of AESD-ICSASAE system with other approaches.

In contrast, the existing models such as DCAE-MLP, SVM, LR, ResNet-152, Inception-v3, and EESC models have demonstrated certainly reduced accuracy of 97.17%, 82.39%, 81.32%, 90.63%, 91.89%, and 93.92% respectively. These results assured the supremacy of the AESD-ICSASAE model on seizure detection and classification.

#### V. CHALLENGES AND LIMITATIONS OF PROPOSED WORK

There are currently a number of restrictions and difficulties in the area of automated epileptic seizure identification. Several challenges arise in the application of EEG data analysis, such as inter-individual variability, the trade-off between sensitivity and specificity, poor generalization of current methods across different datasets and patient groups, the requirement for immediate implementation with high accuracy, interpretation of deep learning models, and a lack of data for training and evaluation purposes. To surmount these obstacles, it is necessary to undertake investigation efforts that are geared towards developing the applicability of findings, minimizing erroneous positive and negative outcomes, refining instantaneous being processed, augmenting comprehensibility, and broadening the availability of varied and inclusive datasets.

#### VI. CONCLUSION

This paper presents the AESD-ICSASAE algorithm, a novel method for performing precise ESD on EEG data. The described AESD-ICSASAE method is a three-step procedure. The first step of the AESD-ICSASAE method is to normalize the input data using a min-max normalization strategy. After that, an ICSA-related feature selection procedure is used by the AESD-ICSASAE method to choose the best features. Finally, improved performance is achieved by the AOA's hyperparameter selection process and categorization of SAE-related data. Experiments were conducted to illustrate the improved classification results achieved using the AESD-ICSASAE method. The simulations covered every possible scenario, ensuring that the AESD-ICSASAE method would improve. To boost the efficiency of the AESD-ICSASAE method, a fusion system based on ensemble voting may be developed in the future.

Additionally, there exist numerous elements that could be examined in the work. Initially, an inquiry into the generalizability of the AESD-ICSASAE methodology across diverse datasets and patient cohorts would offer valuable perspectives on its potential utility above the particular dataset employed. Furthermore, conducting an analysis of comparison with established methodologies could simplify an analysis of the merits and limitations of the suggested approach. Improving the comprehensibility of the outcomes through the identification of the influential characteristics or trends could improve its medical significance. Enhancing the real-time validity of the approach could be achieved through enhancing its efficiency in computing, particularly in managing substantial amounts of EEG data. Performing verification tests on additional data sets would confirm the efficacy and dependability of the aforementioned. Ultimately, an evaluation of the viability of executing the proposed methodology in real-time will determine its practicability in facilitating prompt seizure forecasts and strategies. Incorporating considerations related to generalization, effectiveness, comprehension, productivity, verification, and real-time accessibility would enhance the effectiveness of the AESD-ICSASAE methodology.

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# Evaluation of the Effects of 2D Animation on Business Law: Elements of a Valid Contract

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**Abstract**—This article presents an evaluation of Business Law 2D Animation: Elements of a Valid Contract. The developed application was produced to assist business law students to understand the contents of the topic Elements of a Valid Contract. An experiment was carried out to assess the usability of the application as a learning and review material for business law students. This study comprised five major evaluation components, including learnability, usability, accessibility, functionality, and effectiveness, to investigate user involvement and satisfaction with the proposed educational learning system. To acquire user testing results, online questionnaires were issued. There was a total of 63 respondents, including multimedia experts, students, and subject matter experts. The findings of the current study revealed that the majority of respondents were pleased with the outcomes of the animation. The results may assist in improving the teaching of the topic Elements of a Valid Contract for business law students as it provides visually appealing method of learning.

**Keywords**—2D Animation; business law; elements of a valid contract; evaluation

## I. INTRODUCTION

‘Elements of a Valid Contract’ is a fundamental topic in corporate law that is essential for business law students to remember. The topic necessitates a correlation between a multitude of components and case studies, thereby making the process of understanding and retaining each element and its relevant cases difficult for students. As the topic progresses, lecturers also may encounter challenges in simplifying appropriate teaching materials.

The objective of this paper was to present a thorough evaluation of the usability of a visual animation project named ‘Business Law 2D Animation: Elements of a Valid Contract’. This animation provided simplified descriptions of the Elements of a Valid Contract to facilitate the retention of important case studies among business law students and to assist lecturers in delivering interactive and comprehensive lessons. To evaluate user involvement and satisfaction with animation as a learning platform, five evaluation components were employed. The research question of this proposed research work is how can the best intervention and teaching material for effective business law course delivery in educational setting be constructed.

It is envisaged the proposed work would assist in providing an effective teaching delivery to the students and lecturers in the form of 2D animated video. The contribution of this study is obvious as the resulting outcomes can be

capitalised as guidelines to increase an understanding and learning motivation to the business law students.

## II. LITERATURE REVIEW

Animation is a technique that involves the manipulation of figures to create the illusion of movement. Most contemporary animations are predominantly produced through computer-generated imagery, which has allowed multiple storytellers to deliver their narratives in a more creative and enjoyable manner and visual designers can expand their creativity far beyond what the world allows them to do through liveliness. In addition to presenting a novel means of expression and innovation, animation possesses a practical advantage in that the movement attracts more attention than static images [1]. Several studies in the literature have reported on the use of animation, particularly for teaching and learning purposes [2-5]. Though there are educational materials for law subjects [6-8], these products are delivered in non-interactive videos and instructional manuals, wherein multimedia elements have not been fully utilised.

The topic Elements of a Valid Contract consists of six elements, namely: (i) offer, (ii) acceptance, (iii) consideration, (iv) intention of making legal relation, (v) certainty of the contract, and (vi) capacity and legality [9]. Accordingly, the Two-dimensional (2D) Animation for Business Law: Elements of a Valid Contract [10] was developed. This application explains the elements of the topic in more accessible terms in order to help students remember relevant case studies and allow lecturers to teach students in an easier and more interactive way. Fig. 1, Fig. 2, and Fig. 3 present the screenshots of the developed Business Law 2D Animation: Elements of a Valid Contract. A comprehensive explanation of the design and development phases of the application and the comparison of the existing products with the proposed application are presented in [10]. The current study further elaborated on prior studies presented in [10] by focusing on the evaluation of the Business Law 2D Animation: Elements of a Valid Contract. This study elaborated on five evaluation components for system testing, namely: learnability, usability, accessibility, functionality, and effectiveness. Numerous researchers have explored and employed usability testing, as evidenced by the works of [11] to [19]. Usability is described as the capacity of a product or service to provide maximum satisfaction, efficiency, and effectiveness across various users [20].



Fig. 1. Screenshot of the main page.



Fig. 2. Screenshot of the offer module page.



Fig. 3. Screenshot of the memorisation module.

### III. METHODOLOGY

The testing plan, comprising the test user, test schedule, test strategy, test implementation is elaborated in this section.

The current study was conducted on students enrolling in business law at Politeknik Melaka, Malaysia. The details of the respondents are presented in Table I. The respondents were given a link to begin the system testing by their lecturers, who were also the targeted end users of this animation. The lecturers observed the testing and assessed the content of the Business Law 2D Animation: Elements of a Valid Contract to ascertain the level of animation accuracy.

1) *Multimedia experts*: In the current study, multimedia experts evaluated the Business Law 2D Animation: Elements of a Valid Contract. Multimedia experts are those possessing expertise and competence in the field of multimedia and

information technology. In this study, multimedia experts consisted of the Chief of Technology Officer and the lecturers of multimedia courses. They conducted a system testing with an emphasis on the interface, interactivity, design, multimedia elements, and content layouts.

TABLE I. TESTING RESPONDENTS

	Multimedia Expert	Subject Matter Expert	Students
<b>General Information</b>	Lecturers in UTeM who has working experience from less than 3 years to more than 5 years	Lecturers in Politeknik Melaka who has working experience from less than 3 years to more than 5 years	Students in Politeknik Melaka age 18 to 20 years
<b>Description</b>	This testing is being done to test the technicalities of this animation in terms of multimedia principles	This testing is being done to verify the accuracies of the animation's content and provides coverage of the proposed topic.	This testing is being done to see the effectiveness of this animation.

2) *Subject matter experts*: Subject matter experts are individuals who have knowledge and expertise in a subject matter. In the current study, the subject matter experts had specialised knowledge of the Elements of a Valid Contract topic. They were lecturers of Business Law courses at Politeknik Melaka. They were given the link to the Business Law 2D Animation: Elements of a Valid Contract. They conducted a system testing to determine the content accuracy of animation and provide feedback and recommendations through a questionnaire.

3) *Business law students*: The current study focused on business law students at Politeknik Melaka. The test was administered to them through an online platform and overseen by their lecturers, who were the subject matter experts. After the system testing, student respondents were given a link to the questionnaire to facilitate the analysis.

#### A. Test Description

The test description clarifies the testing aim and projected test outcome. During the system testing, a questionnaire on user acceptance was administered to the respondents.

The respondents were required to watch the Business Law 2D Animation: Elements of a Valid Contract. They took the test using the animation link provided to them and filled out the form provided by the researchers.

#### B. Test Data

The test data of the user testing are explained in Table II, while Table III, Table IV, and Table V represent the data gathered from subject matter experts, multimedia experts, and students, respectively.

TABLE II. TEST DATA FOR USER TESTING

General Information	Number of Respondents
Lecturers in Politeknik Melaka who has working experience from less than 3 years to more than 5 years	3
Lecturers in UTeM and multimedia expert who has working experience from less than 3 years to more than 5 years	4
Students in Politeknik Melaka age 18 to 20 years	56

TABLE III. DETAILS OF SUBJECT MATTER EXPERT

No	Respondent	Position
1	Respondent 1	Principal Lecturer, Politeknik Melaka
2	Respondent 2	Law Lecturer, Politeknik Melaka
3	Respondent 3	Lecturer, Politeknik Melaka

TABLE IV. DETAILS OF MULTIMEDIA EXPERT

No	Respondent	Position
1	Respondent 1	Lecturer, FTMK UTeM
2	Respondent 2	Lecturer, FTMK UTeM
3	Respondent 3	Lecturer, FTMK UTeM
4	Respondent 4	Chief Technology Officer, SiagaX Industries (M)

TABLE V. DETAILS OF STUDENTS

Institution	Total	Age	Gender
Politeknik Melaka	56	18 – 20 years old	Male Female

#### IV. DATA ANALYSIS AND RESULTS

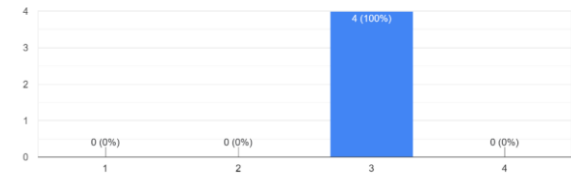
The current study includes diagrams and charts based on the findings of the overview and testing measures to summarise the outcomes of the system testing.

1) *Multimedia experts*: The current study involved four multimedia experts: three were lecturers in Fakulti Teknologi Maklumat dan Komunikasi (FTMK) at UTeM and one from SiagaX Industries (M). The questionnaire was administered on Google Forms and was given to multimedia experts together with as well as the Business Law 2D Animation: Elements of a Valid Contract. After they experienced the animation, they evaluated the animation in terms of functionality, learnability, and the user-interface of the animation. The data collected were then analysed and compiled into graphs.

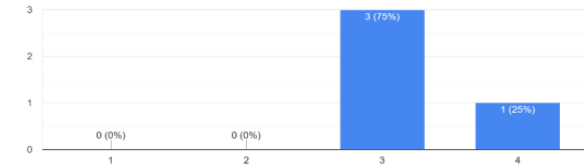
a) *Chart of Functionality for Multimedia Experts*: Fig. 4 presents the data gathered from the functionality section. The functionality section evaluated the effectiveness of content delivery through multimedia functions. According to the test results, all experts agreed on the effectiveness of animation in terms of its functionality as it followed the principles of

multimedia. Fig. 5 shows the overall mean value for the functionality section and the number of experts who participated in this section. The data indicated that all experts agreed on the animation’s functionality and its practicality for student use.

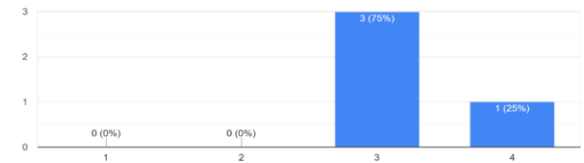
This animation follows the principles of multimedia.  
4 responses



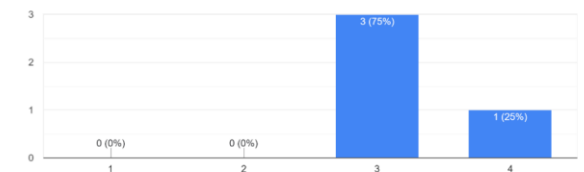
The graphic materials used in this animation is obtainable.  
4 responses



The transitions used in this this animation is smooth and clear.  
4 responses



The audio and narrations in this animation is clear and appropriate.  
4 responses



The content arrangements make the delivery of information more effective.  
4 responses

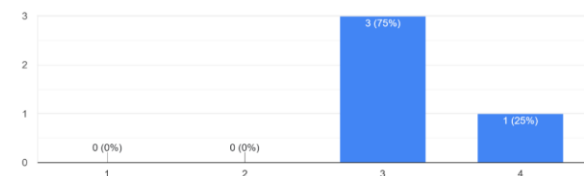
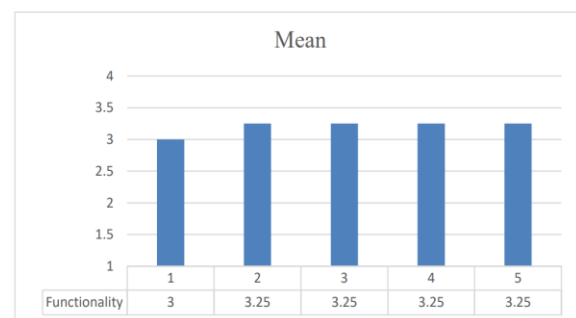


Fig. 4. Results of functionality by multimedia experts.



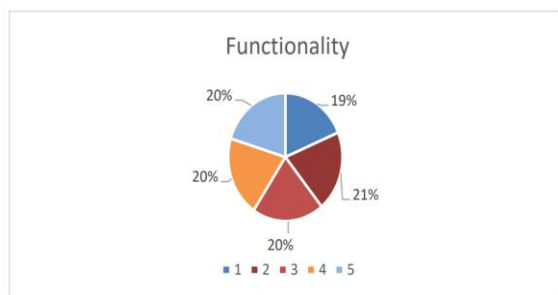


Fig. 5. Overall mean for functionality by multimedia experts.

b) *Chart of Learnability for Multimedia Experts:* As illustrated in Fig. 6, all experts agreed that the content of the animation was easy to follow despite the lack of student knowledge on the topic. More than half of the experts agreed that the audio component of the content was clear and comprehensible. However, one expert disagreed due to the presence of a narrator and accompanying background music, which intercepted the delivery of the content.

Nonetheless, all the experts agreed that the utilisation of animation positively impacted business law students and that the content was presented in a straightforward approach, thereby improving student learnability. Also, half of the experts expressed a favourable impression towards the animation's learnability. They agreed that this animation had the potential to enhance the learning efficacy of business law students.

Fig. 7 provides the overall results of the learnability section and the number of experts who participated in this test. The figure proves that the mean percentage of experts agreed that this animation helped with students' learnability as they believed that the animation could be utilised with ease by business law students.

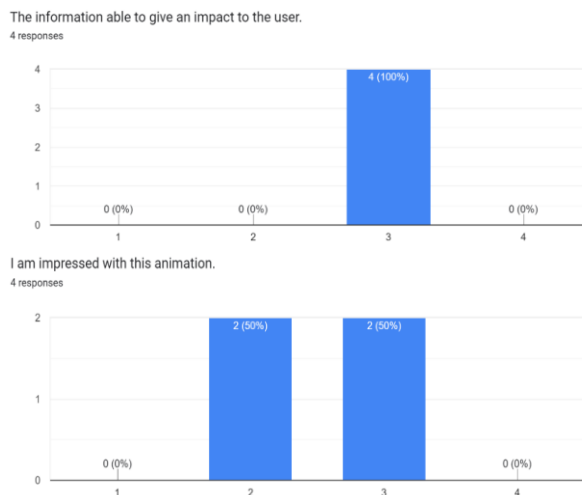


Fig. 6. Results of learnability by multimedia experts.

c) *Chart of User-Interface for Multimedia Expert:* As depicted in Fig. 8, the results of Question 1 revealed all experts agreed that the graphics and textual components used in this animation were appropriate and attractive for business law students. It was determined by over 70 per cent of experts that the colours utilised in this animation were aesthetically attractive and appropriate. The colours employed in this animation made the user interface livelier and more attractive, thereby increasing the learnability of business law students.

It is evident in Fig. 8 that all experts agreed that the multimedia forms of the animation had successfully aided learning. The use of multimedia was important to elevate the functionality of the user interface. Even though the data revealed that 50 per cent of the experts agreed that the texts were clear and comprehensible, the remaining 50 per cent perceived the animation as having poor readability. Considering that the textual components used in this animation complemented the audio narration of the content, poor text readability may result in an unclear and unintelligible user interface.

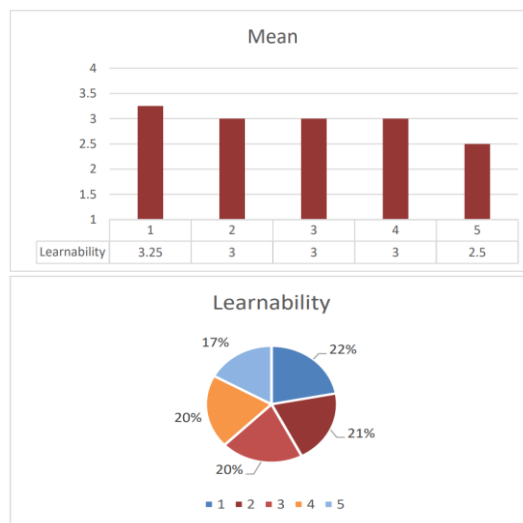
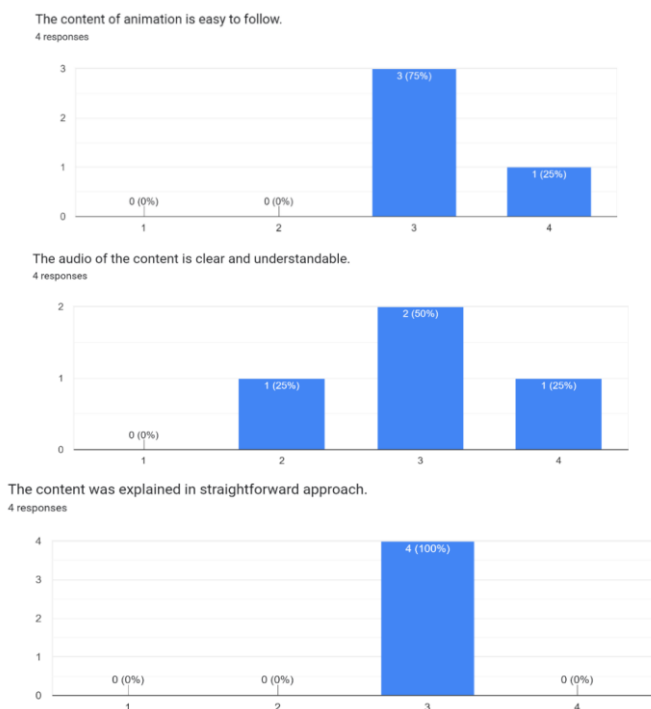
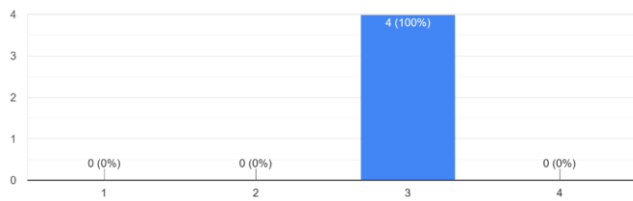


Fig. 7. Overall Mean for learnability by multimedia experts.

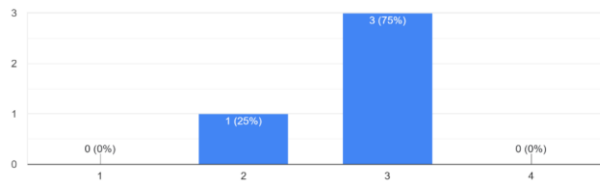
Nevertheless, all experts agreed that the Business Law 2D Animation: Elements of a Valid Contract was user-friendly as its user interface was appropriate and attractive. This helped business law students to better understand the Elements of a Valid Contract.

The data presented in Fig. 9 indicate significant variability in the overall mean of the user interface section. Specifically, Question 2 and Question 4 exhibited the lowest average scores among the five questions analysed. However, it was evident that a majority of the experts agreed that the user interface employed in this animation was attractive with the aid of multiple multimedia components. The interactive design and user-friendly interface of this animation facilitated the learning process of business law students.

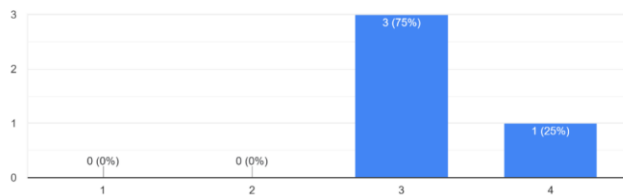
The graphics and text used are appropriate and attractive.  
4 responses



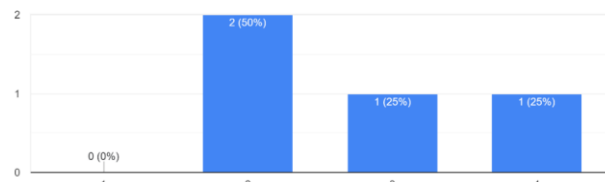
The colors used in this animation are attractive and appropriate.  
4 responses



This animation is successfully aided with multiple multimedia forms (i.e., audio, text, images, and video).  
4 responses



Readability of text in this animation is clear and easy to understand.  
4 responses



This animation is user-friendly.  
4 responses

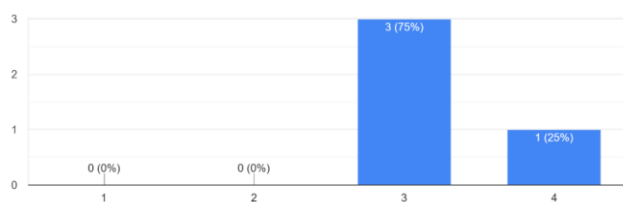


Fig. 8. Results of user interface by multimedia experts.

The summary responses of Multimedia Expert are presented in Table VI.

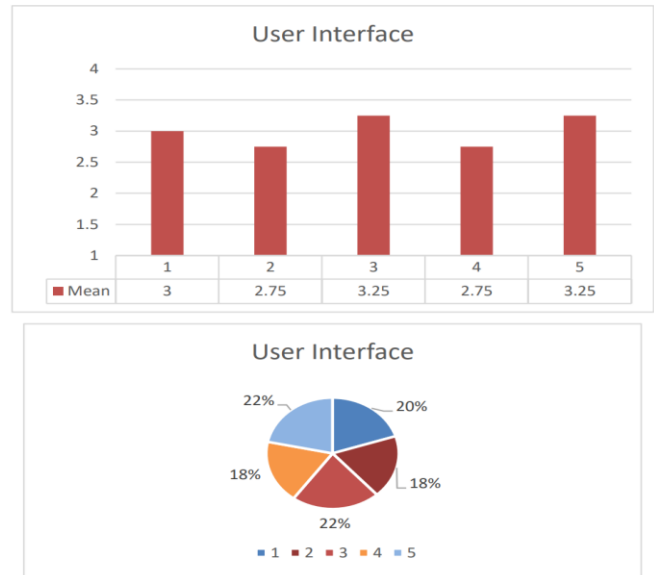


Fig. 9. Overall mean for user interface by multimedia experts.

TABLE VI. RESULT SUMMARY FOR MULTIMEDIA EXPERT

Question Type	Strongly Disagree	Disagree	Agree	Strongly Agree	Total
Functionality			80%	20%	100%
Learnability		15%	75%	10%	100%
User-Interface		15%	70%	15%	100%
<b>Total</b>		<b>10%</b>	<b>75%</b>	<b>15%</b>	<b>100%</b>

*d) Suggestion for Improvement from Multimedia Expert:*

Based on the responses from the questionnaire obtained from multimedia experts, four (4) suggestions for improvement were proposed.

- i. The character design should vary according to the different character names.
- ii. The video explanation was good and comprehensible, the graphics use was extensive, and the placements of each animation component were satisfactory. However, the multimedia components were too crowded and the colour theme used in the animation was not good enough. The selection of typeface was also unpopular.
- iii. Voice-over can be improved to engage and interact with users.
- iv. The instructional video should be accompanied by an audio or a textual introduction to explain the purpose of the video before explaining the cases.

2) *Subject matter expert:* Three respondents consisting of subject matter experts who were lecturers at Politeknik Melaka, Malaysia were involved in this testing through

interviews. The animated video and a questionnaire were given to them. After they experienced the animation, they were asked to evaluate the animated video in terms of its content, effectiveness, and flexibility. The data collected were then analysed and compiled into graphs.

a) *Chart of Content for Subject Matter Expert:* The subject matter experts evaluated the accuracy of the animation content of the 2D Animation for Business Law: Elements of a Valid Contract and whether it was in accordance with the syllabus of Elements of a Valid Contract. Based on the test results, all the experts strongly agreed on the accuracy of the content in this animation aligned with the syllabus in Elements of a Valid Contract. Also, they agreed with the narrator's explanation in this animation and that the explanation was straightforward and easy to understand. The cases used as examples for each element in the topic were also relevant and appropriate. Overall, subject matter experts agreed that the content used in this animation was accurate and precise. They believed that this animation facilitated the understanding of the content of the Elements of a Valid Contract among business law students.

b) *Chart of Effectiveness for Subject Matter Expert:* The subject matter experts evaluated the effectiveness of the animation in helping the learning of business law students and its use as teaching material. Based on the test results, all experts found this animation effective in conveying the content and serving as teaching material. For example, all subject matter experts agreed that the content layout of the animation improved the delivery, thereby being useful as teaching material.

Subject matter experts also believed that the use of this animation could help business law students improve their learning efficiency on the topic. The respondents also agreed that the use of this animation could improve student learning and may serve as revision material due to the accuracy of the content.

In short, the 2D Animation for Business Law: Elements of a Valid Contract was effective for students as well as lecturers. This was evidenced by experts agreeing that this animation may serve as revision material to facilitate the learning process of business law students, as revision material and facilitate the teaching process of lecturers, as teaching material.

c) *Chart of Flexibility for Subject Matter Expert:* In the last section, the subject matter experts evaluated the flexibility of the 2D Animation for Business Law: Elements of a Valid Contract as a new learning method. Table VII summarises the findings of the study on subject matter experts.

The experts strongly agreed that the materials used in the animation were appropriate for the topic of Elements of a Valid Contract, specifically because the materials could aid the understanding of the topic among business law students. The experts believed the animation was presented in a comprehensive and effective manner, featuring good visualisation and narration. In addition, the content arrangement of relevant cases in Elements of a Valid Contract

exhibited a satisfactory flow. The results also show that all the experts agreed on the use of this animation as their teaching material for the convenience of students in the future. This is due to the flexibility of the system being appropriate and suitable for their students.

In conclusion, all experts agree on the flexibility of the 2D Animation for Business Law: Elements of a Valid Contract, to be implemented effectively as teaching material to aid the process of delivering the content of Elements of a Valid Contract to business law students.

TABLE VII. RESULT SUMMARY FOR SUBJECT MATTER EXPERT

Question Type	Strongly Disagree	Disagree	Agree	Strongly Agree	Total
Content				100%	100%
Effectiveness			19.98%	80.02%	100%
Flexibility			13.32%	86.68%	100%
<b>Total</b>			<b>11.1%</b>	<b>88.9%</b>	<b>100%</b>

d) *Suggestion for Improvement from Subject Matter: Expert* Based on the responses from the questionnaire obtained from subject matter experts, three (3) suggestions for improvement were proposed.

- i. Each element is accompanied by separate animation, therefore enabling profound content explanation.
- ii. Add more content to the animation.
- iii. A very good effort and approach of using an interactive method to attract students to memorise cases. The video is very clear and helpful for students.

3) *Students:* The present study involved a sample of 56 respondents from Politeknik Melaka, Malaysia. The data collection method employed in this research was a questionnaire. An online questionnaire, through the Google Forms platform, was administered to the respondents along with the 2D Animation for Business Law: Elements of a Valid Contract. Upon completion of the animation testing phase, respondents evaluated the animation with regard to their preferred method, as determined by the questions posed in each of the three sections: efficiency, effectiveness, and user interface. The data collected were then analysed and compiled into graphical representations.

a) *Chart of Efficiency for Students:* This section presents the findings of the evaluation of the efficacy of the animation in terms of attractiveness, simplicity, and comprehension of the narrator's explanation. Student respondents were required to choose between two methods in this section.

According to the data presented in Fig. 10, 46 respondents (82.1 %) expressed a preference for the animation as it was a more appealing mode of learning compared to slide presentations and textbooks. This indicates that students were more interested in learning through interactive pedagogical



approaches as opposed to textbooks. A total of 75 per cent of the student respondents decided that the animation provided a simpler explanation, whereas the remaining 25 per cent disagreed. The present evidence indicates that the narrator provided a comprehensive explanation that facilitated student understanding of the Elements of a Valid Contract and the corresponding pertinent cases. A total of 43 students agreed that the content of the animation was easier to comprehend than slide presentations and textbooks. This accounted for up to 76.8 per cent of the chart. This indicated that students agreed that the animation, though more compact, provided a straightforward comprehension.

In response to the question of whether animation, slide presentation, or textbooks helped students revise the topic of Elements of a Valid Contract more effectively, 71.4 per cent of the respondents agreed animation was the most effective method. They agreed that animation was more entertaining, thereby more effective at capturing their attention while studying. Lastly, based on Fig. 11, the majority of the respondents agreed that animation helped them learn the Elements of a Valid Contract and its relevant cases more efficiently because of the proficiency of the animation in terms of content delivery and attractive graphics.

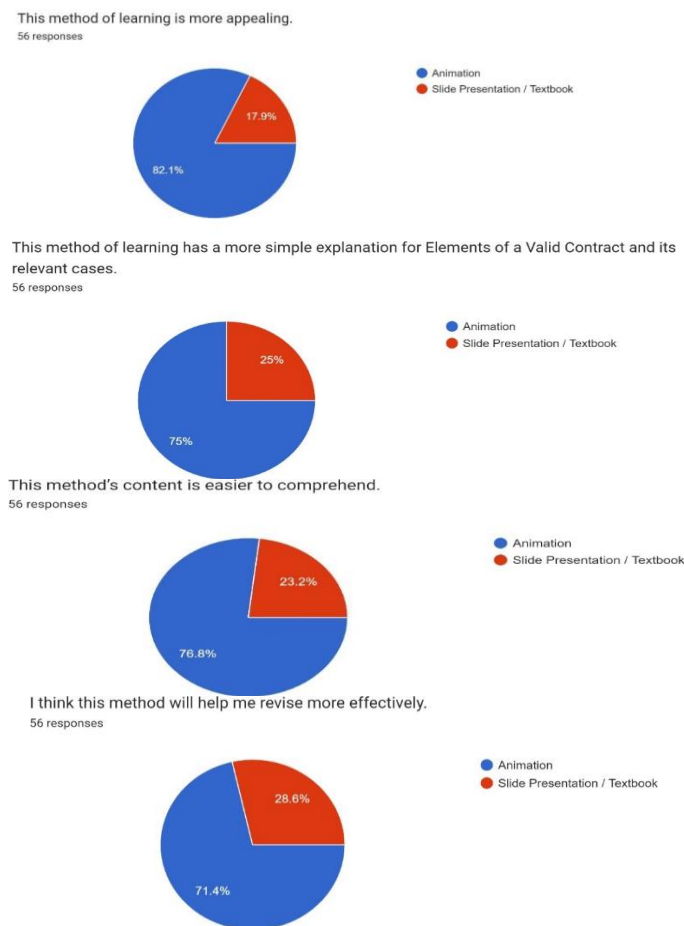


Fig. 10. Results of efficiency by students.

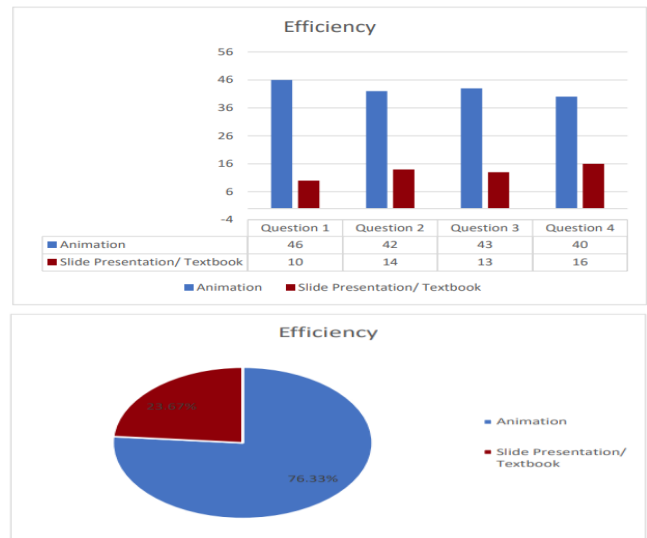


Fig. 11. Overall results of efficiency by students.

b) *Chart of Effectiveness for Students:* The respondents also evaluated the effectiveness of 2D Animation for Business Law: Elements of a Valid Contract for their learning process of Elements of a Valid Contract. They were required to choose one of two methods: (i) animation or (ii) slide presentation/textbook, in terms of approach, retrieval of information, and learning impact.

Based on Fig. 12, 73.2 per cent of the student respondents agreed that animation employed a straightforward approach to aid their understanding of the topic Elements of a Valid Contract, whereas the other 26.8 per cent agreed that same was provided by slide presentations or a textbook. Fig. 12 also demonstrated that animation assisted 71.4 per cent of student respondents in memorising the relevant cases of Elements of a Valid Contract, followed by slide presentations and textbooks with 28.8 per cent of students. It is concluded that the simple explanations provided by the narrator and the colourful graphics aid in faster memorisation.

The integrated multimedia used in animation helped 80.4 per cent of the respondents to retrieve information on the topic of Elements of a Valid Contract more effectively compared to slide presentations and textbooks. The integrated multimedia elements were believed to help users extract information more easily. Based on Fig. 12, 37 (66.1 %) respondents preferred animation as the method was more impactful because the animation facilitated their comprehension of abstract concepts and processes by making them more relatable and understandable. Nevertheless, 19 students (33.9 %) preferred slide presentations or textbooks.

Based on Fig. 13, 70 per cent of the respondents agreed that the animation made learning Elements of a Valid Contract with its relevant cases more interesting. The animation was able to help them memorise cases and assisted them in retrieving information more effectively due to its straightforward explanations.

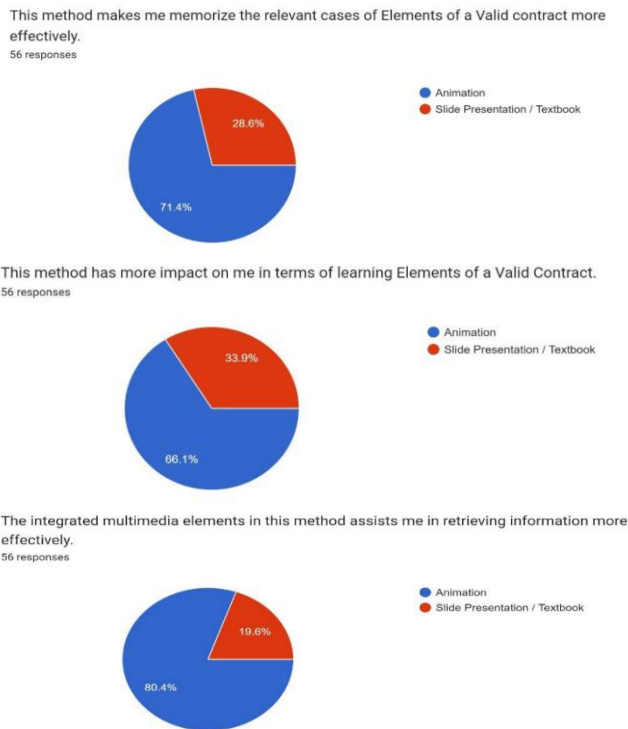


Fig. 12. Results of effectiveness by students.

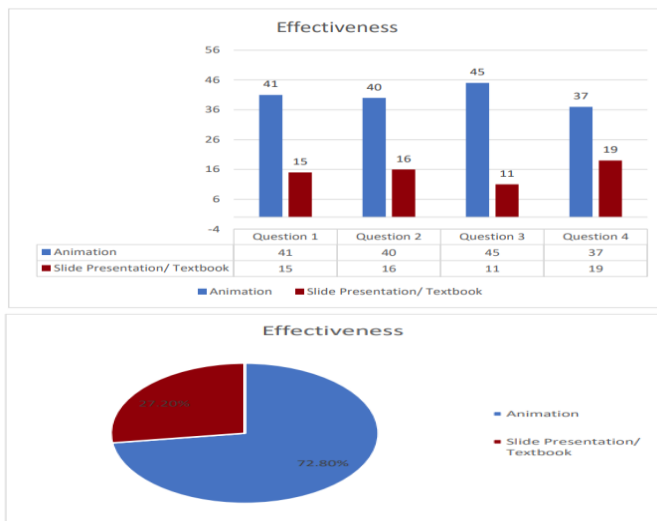


Fig. 13. Overall results of effectiveness by students.

c) *Chart of User-Interface for Students:* In the last section, student respondents evaluated the user interface of the 2D Animation for Business Law: Elements of a Valid Contract. The questions in this section required the participants to choose the interface of a learning method which was more attractive, user friendly, and piqued their interest in learning the topic Elements of a Valid Contract.

Based on Fig. 14, 73.2 per cent of the respondents chose animation as a more visually appealing and comprehensible method of learning. This was attributed to the effective use of graphics, colours, and typeface. The features also resulted in the animation to be an effective tool for capturing attention. In

addition, 82.1 per cent of student respondents agreed that the arrangement flow of relevant cases of the topic Elements of a Valid Contract in the animation provided them with a more effective way of visualising and memorising compared to reading them on slide presentations and textbooks. While the 78 cases were presented in long sentences in the conventional methods of reading, the use of graphics and concise sentences with straightforward explanations in the animation improved their visualisation, thereby enhancing the effectiveness of memorisation.

Moreover, 83.9 per cent of the student respondents agreed that animation's overall interface was more attractive in catching their attention and fostering their interest in learning the Elements of a Valid Contract. Thus, using the 2D Animation for Business Law: Elements of a Valid Contract, had the potential to aid the revision process and serve as an effective learning material. Also, 89.3 per cent of the student respondents agreed that the layout and overall graphics of the animation piqued their interest in the Elements of a Valid Contract. This is because the simple and short explanation helped them better understand the topic.

Fig. 15 shows that 80 per cent of student respondents agreed that the user interface of the 2D Animation for Business Law: Elements of a Valid Contract helped them in their learning, memorising, and revising the topic Elements of a Valid Contract better than the user interface of slide presentations and textbooks which were characterised with long sentences and lack of graphics.

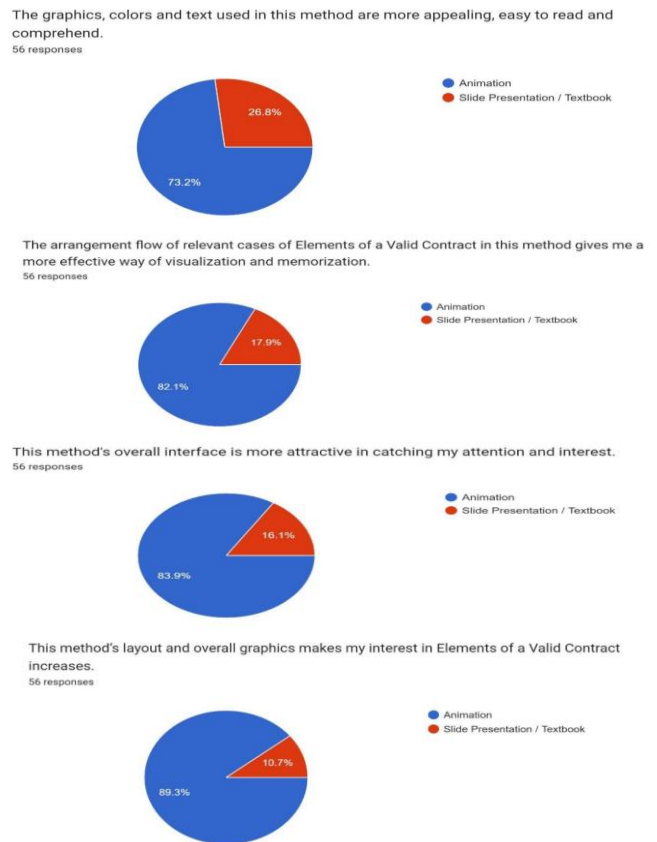


Fig. 14. Results of user interface by students.

Table VIII summarizes the testing summary for students.

TABLE VIII. RESULT SUMMARY FOR STUDENTS

Question Type	Animation	Slide presentation/ Textbook	Total
Efficiency	76.33%	23.67%	100%
Effectiveness	2.8%	27.2%	100%
User-Interface	2.13%	17.87%	100%
<b>Total</b>	<b>77.1%</b>	<b>22.9%</b>	<b>100%</b>

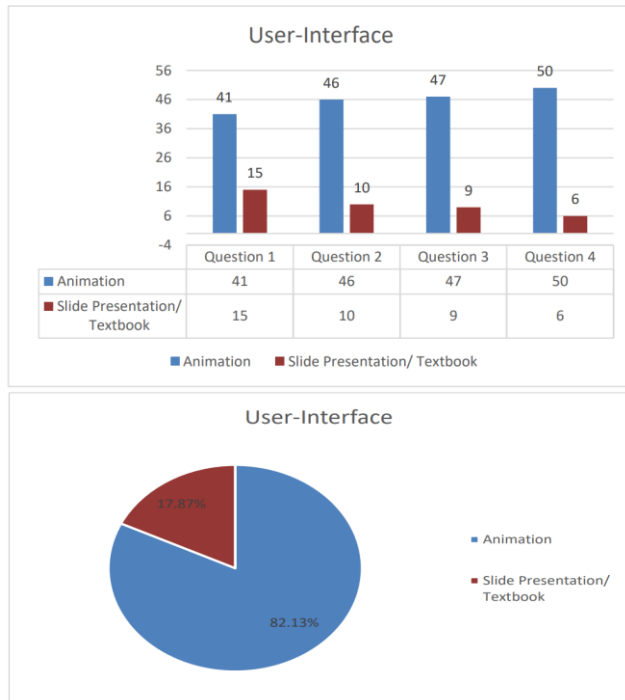


Fig. 15. Overall results of user interface by students.

d) *Summary for Improvement from Students:* Based on the responses from the questionnaire obtained from student respondents, two (2) suggestions for improvement were proposed.

- i. The audio was unclear in some parts of the animation.
- ii. This animation was lacking in content. It was compiled with one relevant case for each element of the topic Elements of a Valid Contract. Students preferred more pertinent examples because the animation was too brief. There should be multiple videos for each element rather than a single video compilation.

## V. DISCUSSION

One of the more significant findings to emerge from this study is the proposed application received positive feedbacks from the target users. From the testing performed, it is found that the sound quality of the 2D Animation for Business Law:

Elements of a Valid Contract should be improved as it was unclear. Also, the pace of the narration should be slowed down to improve the explanation. There should also be an interaction with users to engage them. In addition, an audio introduction should be included to explain the purpose of a video before diving into case explanations. As there are a lot of relevant cases in each element of the topic, it is expected that the videos be separated into different explainer videos. This allows for more relevant cases and explanations to be inserted for deeper explanations. Despite the extensive use of graphics in this animation, different character designs could be used for the various character names that are featured in each case to avoid the mix-up of characters.

The primary objective of this research was to improve the comprehension of business law students on the topic of Elements of a Valid Contract. The inability of many students to memorise the lengthy cases in each element of a valid contract prevented them from scoring well on their examinations. The findings of the testing indicate that the outcomes of the 2D animation may facilitate and overcome the limitation from the current work proposed by other researchers in [6-9]. The 2D Animation for Business Law: Elements of a Valid Contract was designed to enhance students' comprehension of the topic and facilitate their ability to recall pertinent cases through the use of graphics. This research also aimed to assist lecturers teaching business law by enhancing their understanding of the subject and making it easier for them to engage students during class.

## VI. CONCLUSION

The objective of this study was to evaluate the usability of animation: 2D animation for Business Law: Elements of a Valid Contract. The primary objective of the current study was to assist students in gaining a deeper understanding of the Elements of a Valid Contract topic and in memorisation of the relevant cases for each element. The animation proved to be a success as the findings indicate that the animation is engaging and trustworthy. Among the significant findings of this study is that the animation received positive feedback from the intended audiences. Such improvements are intended to facilitate the use of the 2D animation for Business Law: Elements of a Valid Contract as a resource for student review and as teaching material for lecturers. The research question of this proposed research work has been answered as the intervention of an effective teaching material for business law course delivery in educational setting has been successfully constructed. In a nutshell, the current study has demonstrated that animation facilitates students' understanding of the Elements of a Valid Contract by aiding their retention of pertinent cases, thereby reaching its objective.

## ACKNOWLEDGMENT

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# A Novel Approach to Multi-Layer-Perceptron Training using Quadratic Interpolation Flower Pollination Neural Network on Non-Binary Datasets

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**Abstract**—Machine Learning (ML) algorithms are widely used in solving classification problems. The biggest challenge of classification lies in the robustness of the ML algorithm in various dataset characteristics. Quadratic Interpolation Flower Pollination Neural Network (QIFPNN) is categorised into ML algorithm. The new QIFPNN's extraordinary capabilities are measured on binary-type datasets. This research ensures that the remarkable ability of QIFPNN also applies to non-binary datasets with balanced and unbalanced data class characteristics. Flower Pollination Neural Network (FPNN), Particle Swarm Optimisation Neural Network (PSO), and Bat Neural Network (BANN) were used as comparisons. The QIFPNN, FPNN, PSO, and BANN were used to train Multi-Layer-Perceptron (MLP). The test results on five datasets show that QIFPNN obtains an average classification accuracy higher than its comparison in three datasets with balanced and unbalanced data class characteristics. The three datasets are Iris, Wine, and Glass. The highest classification accuracy obtained by QIFPNN in the three datasets is 97.1462%, 98.6551%, and 73.1979%, respectively. Based on the F1-score test from QIFPNN, it is higher than all the comparisons in four datasets: Iris, Wine, Vertebral column, and Glass. Sequentially, 96.4599%, 98.7155%, 90.7517%, and 60.2843%. It proves that QIFPNN can also classify datasets with non-binary data types with balanced and unbalanced data class characteristics because they are more consistently tested on various datasets and are not susceptible to the influence of variations in dataset characteristics so that they can be applied to various types of data or cases.

**Keywords**—Quadratic interpolation; flower pollination algorithm; neural network; non-binary dataset; multi-layer-perceptron

## I. INTRODUCTION

The field of Machine Learning (ML) is a subsection of Artificial Intelligence (AI) [1] that allows computers to recognise patterns in data and make predictions based on that information [2,3]. Practical ML algorithms can provide precise results, even when dealing with datasets that present various real-world problems. The UCI Machine Learning Repository [4] is a database offering a range of datasets the AI community uses to evaluate ML algorithms.

ML algorithms are classifiers, meaning they can predict an unknown sample's class based on previous training data. A challenge in classifying data is the variation in dataset

characteristics, such as sample size, number of attributes, class count, sample distribution in each class, missing data, and data type. Traditional classification algorithms can sometimes be unreliable, mainly when dealing with datasets with an uneven distribution of class samples or an unbalanced class distribution [5].

Optimisation algorithms are frequently utilised to tackle optimisation problems and have had positive outcomes in optimising Machine Learning (ML) algorithms, such as Neural Networks (NN) [6]. The NN, also known as Multi-Layer Perceptron (MLP), is considered one of the most effective ways to solve classification problems in real-world scenarios [7,8]. The training process of NN involves feedforward and backward procedures. The backward procedure, in which weight adjustment occurs through the conventional gradient method, can be weak and often gets stuck at local optima [9,10]. The metaheuristic algorithm can take the place of this backward procedure. The success of these algorithms lies in their capability to explore the search space through both exploration and exploitation. Exploration involves finding various solutions in the search space, while exploitation involves finding the best solution to improve existing ones. A proper balance between exploration and exploitation can quickly lead to identifying the search space with the optimal solution [11], avoiding any wasted time in areas with insufficient solutions [12,13].

The Flower Pollination Algorithm (FPA) is a metaheuristic approach that balances exploration and exploitation by regulating global and local pollination in each iteration of the population. FPA has been extensively used in classification tasks using public datasets. For instance, in a study by Senthilnath et al. [14], FPA was used to adjust the class centre weights in Euclidean distance training and was compared to other algorithms such as Harmony Search, Bat Algorithm, Differential Evolution, Spider Monkey Optimization, Grey Wolf Optimization, Cuckoo Search, Particle Swarm Optimization, Genetic Algorithm, and K-means. The results showed that FPA performed better, with the lowest Classification Error Percentage, on all tested datasets. Additionally, FPA was applied to update the Probabilistic Neural Network (PNN) weights in classification problems and produced better results than PNN on all 11 datasets [7]. Yazid

et al. [15] used FPNN, which combines FPA and PNN, to classify heart diseases and found it to have higher accuracy than a standard backpropagation neural network based on results from four UCI datasets.

In recent research, Polly et al. [16] looked into classifying real-world swine disease cases. The dataset comprised 158 samples, 68 attributes, a binary data type, and an unbalanced data distribution in 11 classes. The Quadratic Interpolation Flower Pollination Neural Network (QIFPNN) increased accuracy by 22.40% and training speed by 7.61% compared to the Flower Pollination Neural Network (FPNN). QIFPNN is a modification of FPA where the Levy vector is replaced with a random vector based on the step length of quadratic interpolation (QI). The effectiveness of QIFPNN in increasing accuracy and speeding up training time on datasets with binary data types needs to be extended to datasets with non-binary data types. So it needs to be tested on various dataset characteristics with various data types, then compare the results with FPNN, PSONN, and BANN, which are other metaheuristic algorithms. The goal is to prove that QIFPNN can also classify datasets with non-binary data types. As a result, QIFPNN provides better classification accuracy and F1-score on datasets with non-binary data types than its comparators. It proves that QIFPNN is not susceptible to variations in dataset characteristics so that it can be applied to various data types or cases.

This research is structured as follows: in the theory section, we present the Quadratic Interpolation Flower Pollination Neural Network (QIFPNN). In the experimental setup section, we describe the dataset and parameter settings. In the results and discussion section, we present the accuracy measurement and F1-score of the QIFPNN and its comparators, followed by the conclusion section.

## II. THEORY

### A. Quadratic Interpolation Flower Pollination (QIFP)

Polly et al. [16] introduced QIFP, an improvement from FPA [17]. The improvement lies in the step vector of global pollination and the search space technique. In the first improvement, the step vector  $\gamma L$  is replaced with a quadratic interpolation step vector  $Q$ , so (1) can be written as (2).

$$x_i^{t+1} = x_i^t + \gamma L(g^* - x_i^t) \quad (1)$$

$$x_i^{t+1} = x_i^t + Q(g^* - x_i^t) \quad (2)$$

where  $x_i^t$  represents the  $i$ -th pollen in iteration  $t$ ,  $g^*$  is the best pollen,  $\gamma$  is the scaling factor, and  $L$  is the random step vector with Levy distribution. The pollen represents the solution vector.

The derivative of the polynomial quadratic function is used to get  $r^*$  which gives the minimum or maximum fitness. The illustration can be seen in Fig. 1. Next; the step vector  $Q$  is formed by:

- 1) Generate a vector  $Q$  with the normal distribution  $Q \sim N(\mu, \sigma)$ , where the mean  $\mu = r^*$ , deviation standard  $\sigma = f_i$ , and the  $f_i$  are fitness value of objective functions of  $g^*$ .
- 2) Replace the element value of the vector  $Q$  by 20% from  $d$  by using (3).

$$Q_c = \begin{cases} 0, & c=l \\ Q_c, & \text{otherwise} \end{cases} \quad (3)$$

where  $l \in \text{randi}[1, d]$ ;  $\text{randi}$  is *rand integer*,  $c=1, 2, \dots, d$  and  $d$  is the dimension of the solution vector.

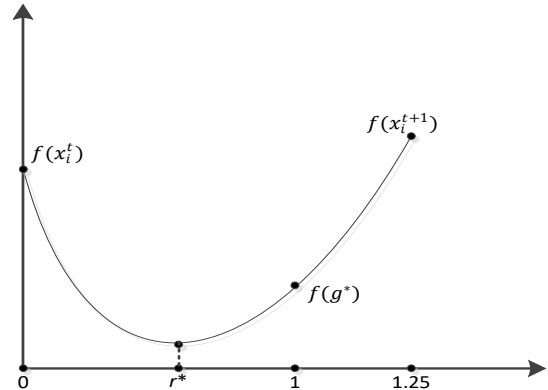


Fig. 1. Illustration of a polynomial quadratic function.

The second improvement, the FPA search space is directly carried out in the natural search space  $[LbReal, UbReal]$ . The QIFP search space starts from a small search space, which is then expanded gradually. Expansion is done by:

- 1) Identify search space first:

$$[Lb, Ub]^d = [-1, 1]^d \quad (4)$$

- 2) Expanding the next search space:

$$[Lb, Ub]^d = \begin{cases} [Lb-1, Ub+1]^d & t \text{ MOD } 50 = 0 \\ [Lb, Ub]^d & \text{otherwise} \end{cases} \quad (5)$$

- 3) Repeat step 2) until  $Lb = LbReal$  and  $Ub = UbReal$ .

where the value of  $LbReal$  and  $UbReal$  has an integer type, and zero is the result of the sum of  $LbReal$  and  $UbReal$ .

### B. Quadratic Interpolation Flower Pollination Neural Network (QIFPNN)

The evaluation of weights for classification problems in MLP is to minimise the mean square error (MSE) value. In QIFPNN, QIFP is used as a weight adjustment [16]. The flowchart of QIFPNN can be seen in Fig. 2, which represents the QIFPNN algorithm. The novelty can be seen in the two rectangles marked with bold lines. The first rectangle refers to (2), while the second rectangle refers to (4) and (5).



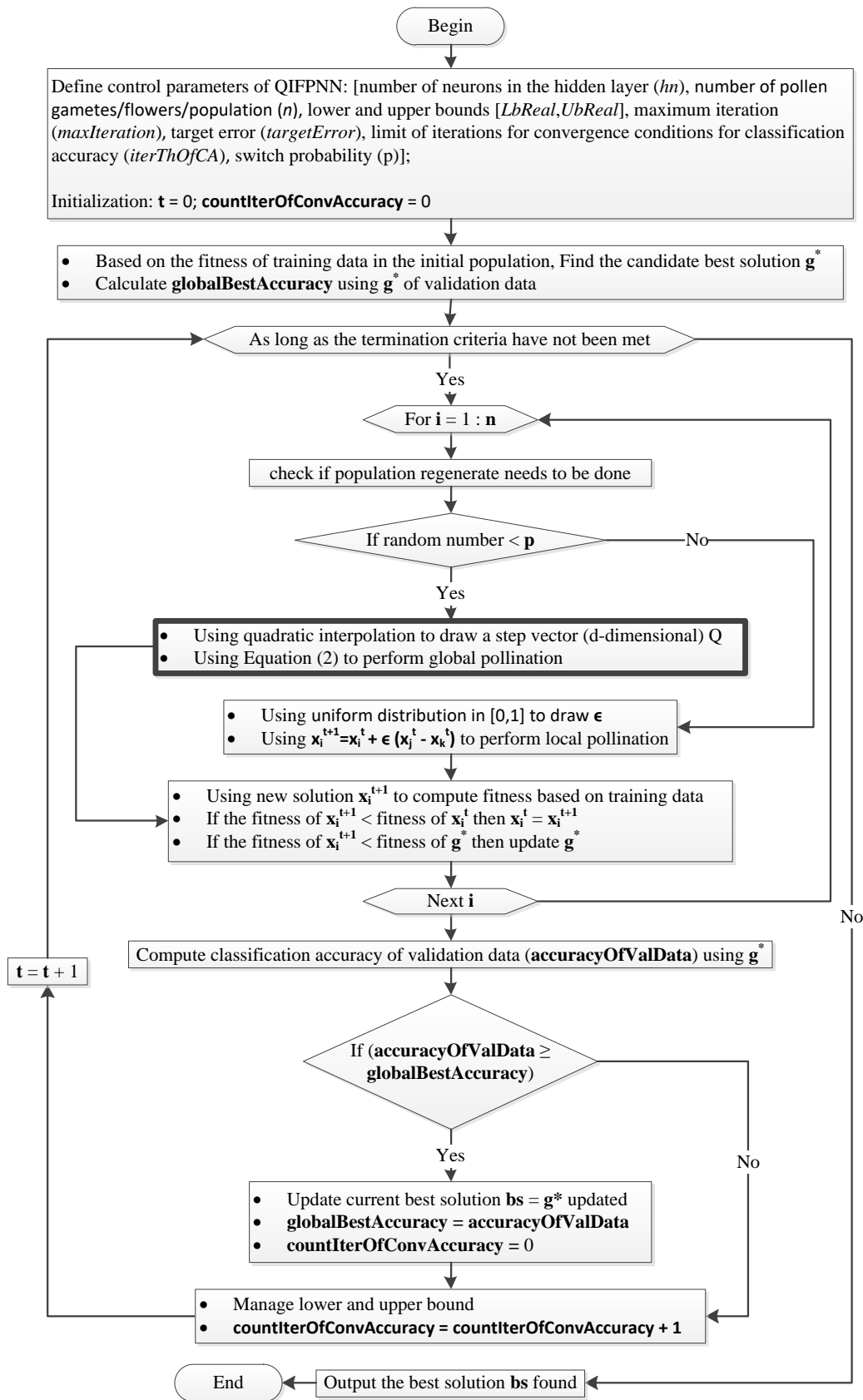


Fig. 2. QIFPNN flowchart.

### III. EXPERIMENTAL SETUP

#### A. Dataset Description

This section briefly overviews the five UCI datasets used in the study. The datasets were divided into three parts: training, validation, and testing, with 90% of the data used for training and validation (using 10-fold cross-validation) and 10% for testing

The classification process took place in two stages:

1) *The training stage aimed to find the optimal weights and determine the length of the training process. This stage used both training and validation subsets to prevent overfitting.*

2) *In the testing stage, the weights found in the training stage were applied to the test subsets to measure classification accuracy.*

Table I displays the sample size, number of input attributes and classes, missing sample size, and data type of each dataset. Table I can be categorised into datasets with balanced data classes (Iris) and unbalanced data classes (Wine, Lung cancer, Vertebral column, Glass). The Lung cancer dataset has many input attributes but a small sample size (known as a singularity problem) [18]. The Vertebral column dataset has two classes with approximately equal amounts of data in each class. The Glass dataset has six classes with varying amounts of data in each class.

#### B. Parameter Settings

The parameters used to configure each algorithm consist of four parts, namely:

- Parameters that apply to all algorithms, including (1) the number of neurons in the hidden layer ( $hn$ ), (2) the population ( $population$ ), (3) the lower and upper bounds of the actual search space [ $LbReal, UbReal$ ], (4) the maximum iteration ( $maxIteration$ ), (5) the target

error ( $targetError$ ), (6) the limit of iterations for convergence conditions for classification accuracy ( $iterThOfCA$ );

- Parameters specific to QIFPNN and FPNN, namely the switch probability ( $p$ );
- Parameters specific to PSONN, namely the learning parameters ( $\alpha$  and  $\beta$ );
- Parameters were specific to BANN: the loudness ( $loudness$ ) and the pulse rate ( $pulseRate$ ).

The QIFPNN, FPNN, PSONN, and BANN use MLP architecture with one hidden layer by determining the number of neurons in that layer according to (6) [16]. One hidden layer can approximate any function with arbitrary accuracy [19].

$$hn = \sqrt{(si+so)+ii} \quad (6)$$

Where, respectively,  $hn$ ,  $si$ , and  $so$ , are the number of neurons in the hidden, input, and output layers, while  $ii$  is an integer set to be 1. The determination of  $ii = 1$  aims to simplify the size of the MLP architecture in order to expedite the learning process.

It is essential to control parameters in each iteration of a metaheuristic algorithm to obtain an optimal solution. However, there is no known effective strategy to produce a variety of parameters [20]. All parameters are set based on Polly et al. [16], namely population  $n=30$  [16,21], [ $LbReal, UbReal$ ] $=[-80,80]$ , maximum iteration  $maxIteration=4000$ , target error  $targetError=0.001$ , and limit of iterations for convergence conditions for classification accuracy  $iterThOfCA=700$ . Three variables control the stopping criteria:  $maxIteration$ ,  $targetError$ , and  $iterThOfCA$ . Another parameter set for QIFPNN and FPNN is switch probability  $p=0.8$  [16,17,22–24]. Specifically for PSONN, the learning parameters are  $\alpha \approx \beta \approx 2$ , while for BANN, the parameter  $loudness=0.25$  and the parameter  $pulseRate=0.5$  [25].

TABLE I. CHARACTERISTICS OF THE DATASETS

Dataset	Sample Size	Number of Input Attributes	Sample Size in Each Class	Missing Sample Size	Data Type
Iris	150	4	<ul style="list-style-type: none"> <li>Class 1 Iris Setosa = 50 data (33.3%)</li> <li>Class 2 Iris Versicolour = 50 data (33.3%)</li> <li>Class 3 Iris Virginica = 50 data (33.3%)</li> </ul>	-	Real
Wine	178	13	<ul style="list-style-type: none"> <li>Class 1 = 59 data (33.2%)</li> <li>Class 2 = 71 data (39.9%)</li> <li>Class 3 = 48 data (26.97%)</li> </ul>	-	Integer, real
Lung Cancer	27	56	<ul style="list-style-type: none"> <li>Class 1 = 8 data (29.6%)</li> <li>Class 2 = 10 data (37.04%)</li> <li>Class 3 = 9 data (33.3%)</li> </ul>	5	Integer
Vertebral Column	310	6	<ul style="list-style-type: none"> <li>Class 1 Abnormal = 210 data (67.7%)</li> <li>Class 2 Normal = 100 data (32.3%)</li> </ul>	-	Real
Glass	214	9	<ul style="list-style-type: none"> <li>Class 1 Building windows float processed = 70 data (32.7%)</li> <li>Class 2 Building windows non-float processed = 17 data (7.9%)</li> <li>Class 3 Vehicle windows float processed = 76 data (35.5%)</li> <li>Class 4 Vehicle Windows non-float processed = 0 data (0%)</li> <li>Class 5 Containers = 13 data (6.1%)</li> <li>Class 6 Tableware = 9 data (4.2%)</li> <li>Class 7 Headlamps = 29 data (13.6%)</li> </ul>	-	Real

This study set the population parameter to 30, referring to Chakraborty et al. [21], as the four datasets used in this research were also employed in their study. Furthermore, the findings of Polly et al. [16] provided additional support by utilising the same population size and yielding satisfactory solutions. The rationale for determining the parameter  $[LbReal, UbReal] = [-80, 80]$  was based on an intuitive approach to solution search techniques, starting from the smallest search space and gradually expanding it. The expansion of the search space was performed every 50 iterations, and the most extensive range of the search space,  $[-80, 80]$ , was determined by setting the maximum iteration to 4000. The target error parameter was set to 0.001 to achieve high accuracy on the training data.

The parameter  $iterThOfCA$  was set to 700 based on documented test results in Table II. The row labelled "Average Training and Validation Accuracy" shows that using the  $iterThOfCA=700$  parameter yields slightly lower accuracy than the  $iterThOfCA=1000$  and 1800 parameters. However, the difference with the highest accuracy is tiny, only 0.22. In the row labelled "Training Time," the  $iterThOfCA=700$  parameter results in a shorter time than the  $iterThOfCA=1000$  and 1800 parameters. Therefore, the  $iterThOfCA=700$  parameter is selected as the appropriate option. The switch probability parameter is set to 0.8 based on preliminary parametric studies indicating that a value of  $p=0.8$  can provide better performance for most applications [17,23,24]. Expressly, for PSONN, the learning parameters (" $\alpha$  and  $\beta$ ") are set to 2, while for BANN, the normal values for the loudness parameter are 0.25, and the pulse rate parameter is set to 0.5, following standard practices in PSONN and BANN [25].

TABLE II. THE DETERMINATION OF THE  $ITERTHOFCA$  PARAMETER WAS BASED ON THE AVERAGE TRAINING ACCURACY, VALIDATION ACCURACY, AND TRAINING TIME USING 10-FOLD CROSS-VALIDATION, CONDUCTED OVER 5 REPETITIONS

	$iterThOfCA$ Parameter		
	700	1000	1800
The average training and validation accuracies (%)	87.9191	88.0872	88.1432
The average training time (seconds)	5934.45	7497.80	10555.65

### C. Testing

The experiment measures the performance of four algorithms by evaluating their average classification accuracy and training time. The tests were repeated 20 times in each fold of the 10-fold cross-validation method, and the results were recorded as the average of these trials. Additionally, the F1-score was also calculated as part of the testing procedure.

## IV. RESULT AND DISCUSSION

The tests were conducted on five datasets, as outlined in Table I. The results of the tests, including the average of the classification accuracy and the average of the training time, are shown in Table III and Fig. 3 to 4. Table IV shows the results of the F1-score test.

As seen in Table III, the QIFPNN algorithm produced a higher average classification accuracy in the training subset

than the other algorithms for all five datasets. It includes the Iris, Wine, Lung cancer, Vertebral column, and Glass datasets with an accuracy of 98.9103%, 99.3056%, 90.7478%, 87.6424%, and 73.855%, respectively. The QIFPNN model has the lowest mean square error and does not experience premature convergence across various datasets. The F1-score further supports this in the training subset, which was higher for all five datasets, including the Iris, Wine, Lung cancer, Vertebral column, and Glass datasets, with scores of 97.7294%, 99.3488%, 90.0801%, 90.9789%, and 64.8062% respectively, as shown in Table IV.

The average classification accuracy obtained from the training, validation, and test subsets from QIFPNN is higher than all the comparisons in the three datasets, namely the Iris, Wine, and Glass datasets. The average acquisition accuracy of the classification can be seen in Table III and Fig. 3, namely 97.1462%, 98.6551%, and 73.1979%. FPNN is only higher in two datasets than all the comparisons in the Lung cancer and Vertebral column datasets, respectively 78.7861% and 87.4692%. Still, QIFPNN ranks second highest after FPNN in both datasets, with gains of 76.5826% and 87.3895%. Based on the F1-score test from QIFPNN in Table IV, it is higher than all the comparisons in the four datasets: Iris, Wine, Vertebral column, and Glass. Sequentially, 96.4599%, 98.7155%, 90.7517%, and 60.2843%. Meanwhile, FPNN is higher than all its comparisons only in the Lung cancer dataset, namely 75.3369%, but QIFPNN ranks second highest with an acquisition of 73.1106%. It proves that the QIFPNN training model is the best among all comparisons because it is more consistently tested on various datasets and is not susceptible to the influence of variations in dataset characteristics so that it can be applied to multiple other data/cases.

The average PSONN training time is faster than QIFPNN, FPNN, and BANN on three datasets, namely Iris, Vertebral column, and Glass, with values of 384.4917 seconds, 55.6039 seconds, and 678.6673 seconds. QIFPNN is faster than FPNN, BANN, and PSONN on two datasets, namely Wine and Lung Cancer, with values of 179.7063 seconds and 135.8932 seconds, which can be seen in Table III and Fig. 4. It proves that, in general, PSONN is faster than its comparators. However, QIFPNN has a speedy training time compared to the comparison specifically for datasets that experience singularity problems, such as the Lung cancer dataset. The training time is also quick for datasets like Wine, which have unbalanced data class characteristics. This fact shows that the quadratic interpolation concept accommodated by QIFPNN works very quickly in the training process for datasets with characteristics similar to those of the Lung cancer and Wine datasets.

Based on the results of classification accuracy and F1-score measurements, it can be said that the QIFPNN is suitable for classifying non-binary datasets with balanced and unbalanced data class characteristic models. The slow training time of QIFPNN on the Iris, Vertebral column, and Glass datasets is due to the QIFPNN fitness evaluation being twice the fitness evaluation of FPNN, BANN, and PSONN in each individual (flower/pollen gamete) per iteration.

TABLE III. RECAPITULATION OF TESTS ON THE IRIS, WINE, LUNG CANCER, VERTEBRAL COLUMN, AND GLASS DATASETS BASED ON THE AVERAGE FOR CLASSIFICATION ACCURACY AND TRAINING TIME OF 20 TRIALS ON ALL FOLDS

Dataset	Method	The Average for Classification Accuracy of 10-fold on			The Average for Classification Accuracy of The Training, Validation, and Test Subsets (%)	The Average Training Time of 10 fold (seconds)
		Training subset (%)	Validation subset (%)	Test subset (%)		
Iris	QIFPNN	<b>98.9103</b>	98.4615	94.0667	<b>97.1462</b>	534.3663
	FPNN	98.3390	98.6978	92.2000	96.4123	488.9779
	BANN	89.7546	89.1566	84.3000	87.7371	508.0139
	PSOINN	82.0805	82.9890	78.8000	81.2898	<b>384.4917</b>
Wine	QIFPNN	<b>99.3056</b>	98.1875	98.4722	<b>98.6551</b>	<b>179.7063</b>
	FPNN	99.0104	99.0313	95.5278	97.8565	709.1112
	BANN	90.6319	89.5938	89.3333	89.8530	702.8217
	PSOINN	85.1424	87.0000	83.6389	85.2604	943.0891
Lung Cancer	QIFPNN	<b>90.7478</b>	70.0000	69.0000	76.5826	<b>135.8932</b>
	FPNN	87.0249	88.5000	60.8333	<b>78.7861</b>	784.5162
	BANN	71.9989	65.4167	49.0000	62.1385	640.8733
	PSOINN	63.6818	67.4167	47.6667	59.5884	826.6481
Vertebral Column	QIFPNN	<b>87.6424</b>	89.5099	85.0161	87.3895	727.1914
	FPNN	85.9383	90.3241	86.1452	<b>87.4692</b>	555.9895
	BANN	86.2841	88.0595	84.5000	86.2812	675.5812
	PSOINN	76.2325	80.8082	77.2742	78.1050	<b>553.6039</b>
Glass	QIFPNN	<b>73.8550</b>	73.0395	72.6991	<b>73.1979</b>	1199.2273
	FPNN	64.3742	71.3566	65.6212	67.1173	856.9318
	BANN	60.5766	61.9513	59.0000	60.5093	806.5957
	PSOINN	46.6498	51.8789	48.4524	48.9937	<b>678.6673</b>

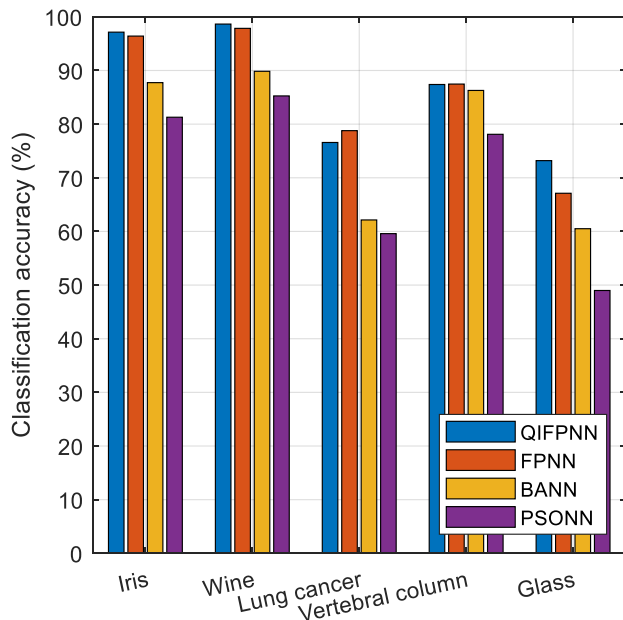


Fig. 3. The average for classification accuracy of the training, validation, and test subsets.

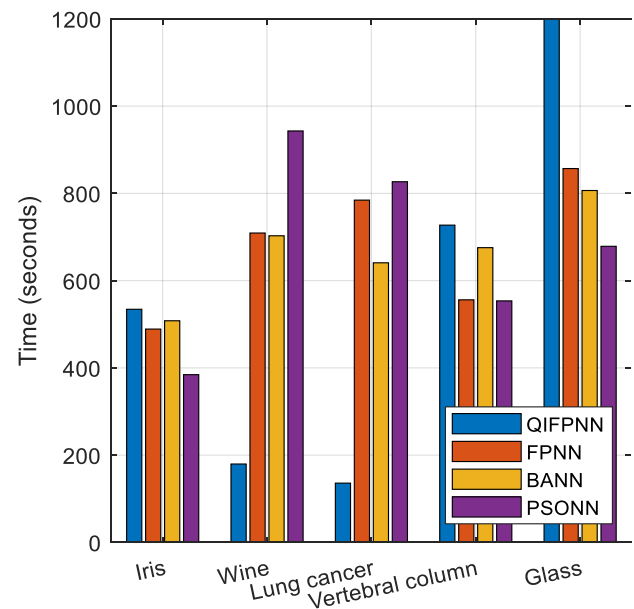


Fig. 4. The average training time of 10 fold.

TABLE IV. RECAPITULATION OF TESTS ON THE IRIS, WINE, LUNG CANCER, VERTEBRAL COLUMN, AND GLASS DATASETS BASED ON THE AVERAGE FOR F1-SCORE OF 20 TRIALS ON ALL FOLDS

Dataset	Method	The Average for F1-score of 10 Fold on			The Average for F1-score of The Training, Validation, and Test Subsets (%)
		Training Subset (%)	Validation Subset (%)	Test Subset (%)	
Iris	QIFPNN	<b>97.7294</b>	98.5092	93.1412	<b>96.4599</b>
	FPNN	96.7000	98.7036	90.7623	95.3886
	BANN	85.3531	85.9876	80.4231	83.9213
	PSOINN	75.4134	77.5504	72.9403	75.3014
Wine	QIFPNN	<b>99.3488</b>	98.2541	98.5435	<b>98.7155</b>
	FPNN	99.0587	99.0560	95.6972	97.9373
	BANN	88.4922	87.3719	87.1803	87.6815
	PSOINN	83.9748	85.7330	82.5509	84.0862
Lung Cancer	QIFPNN	<b>90.0801</b>	66.4461	62.8056	73.1106
	FPNN	86.6670	85.5936	53.7500	<b>75.3369</b>
	BANN	68.2836	62.7826	39.8333	56.9665
	PSOINN	60.7273	64.1797	38.7500	54.5523
Vertebral Column	QIFPNN	<b>90.9789</b>	92.3511	88.9251	<b>90.7517</b>
	FPNN	89.7003	92.9143	89.5973	90.7373
	BANN	89.9682	91.2794	88.4099	89.8858
	PSOINN	83.1972	86.5253	83.7587	84.4937
Glass	QIFPNN	<b>64.8062</b>	55.9833	60.0634	<b>60.2843</b>
	FPNN	45.7893	48.3887	44.9519	46.3766
	BANN	41.4919	38.9253	36.9897	39.1356
	PSOINN	23.9903	27.5101	25.1203	25.5403

However, QIFPNN is faster in obtaining solutions compared to FPNN, BANN, and PSOINN on the Lung cancer and Wine dataset, so it can be explained that the quadratic interpolation concept on QIFPNN can increase the QIFPNN training speed than the levy distribution concept on FPNN, the idea of acoustic echolocation on BANN, and the concept of adjusting the trajectories of individual agents, called particles, as the piecewise paths formed by positional vectors in a quasi-stochastic manner in PSOINN in both datasets.

## V. CONCLUSION

In previous research, the new algorithm QIFPNN was tested on real-world cases involving binary data types. Findings from that study indicated that QIFPNN significantly outperformed FPNN, PSOINN, and BANN. In this study, QIFPNN was tested using five UCI datasets with variations in data characteristics, such as non-binary data types, balanced and imbalanced classes, and singularity issues. The main objective of this research was to investigate the reliability of QIFPNN in dealing with various characteristics present in these datasets. Reliability measurements used classification accuracy, F1-score, and training time as evaluation metrics. The classification accuracy measurements on the training subset consistently showed that QIFPNN outperformed all other models across all datasets, indicating that QIFPNN did not suffer from premature convergence.

Moreover, the average classification accuracy on the training, validation, and test subsets demonstrated that QIFPNN performed superiorly on three datasets: Iris, Wine, and Glass. Although on the other two datasets, QIFPNN ranked second after FPNN; the difference was marginal. Furthermore, the F1-score test results revealed that QIFPNN significantly outperformed other models on four datasets, including Iris, Wine, Vertebral column, and Glass. However, on the Lung cancer dataset, QIFPNN ranked second after FPNN with a slight difference. These findings demonstrate that QIFPNN exhibits reliable performance in handling various dataset characteristics. Based on the measurements of classification accuracy and F1-score, it can be concluded that the QIFPNN training model is a reliable choice for various dataset characteristics in different cases.

Additionally, the training time measurements indicated that PSOINN was faster on three datasets, namely Iris, Vertebral column, and Glass, while QIFPNN was faster on two datasets. In the QIFPNN algorithm, the fitness evaluation is performed twice, resulting in excessive training time consumption. We recommend improving the Q step vector by introducing an additional parameter as a multiplier factor. The aim is to enhance the performance of QIFPNN.

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# Hamming Distance Approach to Reduce Role Mining Scalability

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**Abstract**—Role-based Access Control has become the standard of practice for many organizations for restricting control on limited resources in complicated infrastructures or systems. The main objective of the role mining development is to define appropriate roles that can be applied to the specified security access policies. However, the mining scales in this kind of setting are extensive and can cause a huge load on the management of the systems. To resolve the above mentioned problems, this paper proposes a model that implements Hamming Distance approach by rearranging the existing matrix as the input data to overcome the scalability problem. The findings of the model show that the generated file size of all datasets substantially have been reduced compared to the original datasets. It has also shown that Hamming Distance technique can successfully reduce the mining scale of datasets ranging between 30% and 47% and produce better candidate roles.

**Keywords**—Role-based Access Control; role mining; hamming distance; data mining

## I. INTRODUCTION

Role mining techniques exploit the existing user-permission assignment (UPA) to define roles that are suitable to the policies of an organization. The UPA usually involves big scale of data, which usually makes role mining difficult to process. The input data should contain at least a set of users (U), permissions (P), and user permission assignment relation (UPA) which is commonly depicted in a Boolean matrix form. A number of studies, such as in [3], [4], [5] and [6], have found that pre-processing phases are significant to be implemented, especially to simplify the scalability of the UPA matrices that work as the input to the role mining process. Furthermore, the authors also have discussed that pre-processing steps can be divided into two major classes: data cleansing and data selection. Data cleansing can be defined as a method to decrease the noise that resides in the UPA matrices, while data preparation ensures that the input data is suitable to be executed by role mining algorithms.

From the perspective of RBAC, when an organization's existing UPA includes numerous permissions and users, or when the size of UPA becomes excessively large, it increases the likelihood of the UPA to contain overlapping permissions and an unnecessary number of roles. To address these challenges and to uncover roles that are of high quality and meaningful, data mining techniques, specifically clustering techniques, are required. Eventually, it can produce reliable and optimal candidate roles that would be forwarded to the next stage or phase. In addition, the migration from traditional

ACM to RBAC model usually would not result in the best RBAC states either they are too complex or not scalable enough to be passed on the next phase.

Based on the above discussion, there is a main question from RBAC's standpoint on how to overcome the scalability problem in existing system of an organization. So, the main objective of this research is to discover an approach, specifically a data mining technique in pre-processing stage, such as Hamming Distance, k-Nearest Neighbor (k-NN) or deep learning algorithm as in [7] to be implemented to rearrange the matrix to overcome the huge scale of UPA as input data to produce more scalable, optimal and accurate datasets that can be used into the next phase. Furthermore, the selection of data mining methods for this research must be suitable for binary or Boolean data type.

The output of pre-processing stage is optimal candidate roles. A candidate role in a RBAC system contains a set of permissions that is connected to a user-to-role assignment that can be visualized as a row in matrix PA, a column in matrix UA, and a user is permitted with permissions if he/she is appointed with a role that includes the designated permissions. This stage is the most meaningful process because this phase usually produces a big pool of candidate roles [4], [8], [9], therefore appropriate techniques are needed to recover optimal candidate roles by exploiting appropriate data mining techniques or heuristics algorithms.

This paper proposes an approach that can manage the conversion from traditional and existing ACM in an organization to RBAC that contains large data since the large data can be complicated and unscalable and consist of redundant data with immoderate permissions and roles. The approach has utilized data mining technique particularly Hamming Distance, prior to the role mining process that can cluster a more accurate RBAC system.

The remainder of the paper is structured as follows. Section II presents a background study of this work, specifically on clustering techniques. Section III discusses the general methodology developed for the proposed approach; Section IV elaborates the experimental results and discussion on the proposed approach; lastly Section V sums up the research with conclusion and future works.

## II. RELATED WORK

The fast growth of internet technologies has created extreme escalation of data gathering, storing, and analysis of large datasets and data mining can be described as a method to

obtain informative patterns from these datasets. One of a common data mining task that is appropriate for role mining is clustering. Generally, clustering can be expressed as a process of combining items that have the same attributes, specifically in role mining. Clustering is the act of grouping similar users and permissions to produce a common set of roles. Clustering techniques have been comprehensively reviewed in many applications, such as the pattern recognition field. According to the authors, clustering technique offers many advantages as the following features [10], [11]:

- 1) Firstly, it can be utilized as a pre-processing technique to obtain related groups within the datasets.
- 2) Secondly, it can decrease the cost that involved in data mining technology.
- 3) Thirdly, it is effective to get information regarding the properties of the datasets.

Many clustering techniques have been proposed for different datasets, and most of the conventional clustering algorithms are unsuitable for handling categorical datasets, such as in role mining. Researchers [12] have introduced a statistical method using Hamming Distance (HD) to cluster categorical datasets. In their research, HD vectors has been utilized to generate clusters for each iteration until no notable clusters can be produced. The proposed method has performed significantly better than the other algorithms. Furthermore, the application of clustering techniques in role mining has been discovered by [13], [14] and according to the authors, the dataset would be segregated into clusters based on the same characteristics that eventually would decrease size of the dataset significantly.

Moreover, the authors also have discovered, based on the simulations and analysis conducted, that the application of the Bayesian model can successfully cluster datasets that contain categorical data [15]. Most recently, [16] have effectively proposed a model to cluster categorical datasets using a mixture of distributions based on HD. Additionally, according to the authors, the role mining scales were huge that could produce results that were not easily interpreted; hence the authors have adapted the basic role mining concept into clustering problem with the application of HD to rebuild the original matrix into a compressed matrix [17].

In recent years, there has been an increasing amount of literature on role mining techniques in Role-based Access Control (RBAC). However, numerous existing role mining algorithms in RBAC do not provide any appropriate approach to overcome the huge scale of existing UPA in an organization that may contain overlapping permissions that can lead to inaccurate and too many roles that eventually overwhelmed the existing system and burdened the administrator. Researchers [18] have proposed a technique based on frequent pattern mining. However, this technique has constructed a large number of potential permission sets. Additionally, researchers [19] have discussed a feasible solution based on a constraint satisfaction problem. However, this solution still produced quite a large of number of users and permissions. Therefore, the rest of this paper will discuss on the methodology, results, and discussion on Hamming Distance approach to reduce role mining scalability.

### III. MATERIALS AND METHODS

This section presents the detailed specification of an approach or phase to restructure the huge scale of role mining input data, namely user-permission assignment (UPA), that exists in a form of Boolean matrix to produce optimal and accurate candidate roles. This approach discusses the application of data mining technique, specifically Hamming Distance (HD), to reduce the scalability of UPA input data. The process begins by grouping users with the same permissions and considering them as a user group. Then each user group can be depicted as different user clusters. The output of this process is a less complex matrix UPA.

#### A. Datasets

The dataset that has been used in this research is the benchmark access control datasets, as shown in Table I and the datasets comprise of the numbers of users  $|U|$ , the number of permissions  $|P|$ , the size of user-permission assignment  $|UPA|$ , number of roles  $|R|$  and density that can be described as the number of entries equivalent to one with the respect to its size in an unrestricted setting. The Apj dataset was acquired from the network access control rules used in Hewlett Packard (HP) and the profile was obtained from the Cisco firewalls and used to authenticate the users with the related network access [20]. Furthermore, the healthcare dataset was collected from the US Veteran's Administration [21]. Additionally, the firewall1 and firewall2 datasets were gained from Checkpoint firewalls and lastly the domino dataset came from a set of user and access profiles for a Lotus Domino server [20].

TABLE I. REAL WORLD DATASETS

Dataset	$ U $	$ P $	$ UPA $	$ R $
Apj	2044	1164	6841	453
Domino	79	231	730	20
Firewall1	365	709	31951	64
Firewall2	325	590	36428	10
Healthcare	46	46	1486	14

#### B. Measurements

This approach needs data mining technique such as Hamming Distance to rearrange the matrix to overcome the huge scale of UPA as input data to produce more scalable, optimal and accurate datasets. Moreover, the selection of data mining methods for this research must be suitable for binary or Boolean data type. For this research, the successful implementation of such technique can be determined by size of generated files and the size should be reduced (smaller size) compared to the original dataset

#### C. Hamming Distance Approach

An effective transition from a conventional access control model to a role-based model needs to define an appropriate dataset that enables to capture the security policies of an organization. The complexity of the RBAC system can be quantified by parameters such as number of roles, permissions, hierarchy size, constraints, and user-permission assignment (UPA). Although the process may seem uncomplicated to

accomplish when the roles can be defined from the beginning, for an organization with existing user-permission assignments, this procedure can be complicated to produce stable candidate roles, especially when the existing UPA contain a huge number of permissions and users. This enormous UPA may deteriorate the functionality of the RBAC system and become challenging to handle appropriately.

For a RBAC system, role mining is a method that can be implemented to cluster or group users who have the same or comparable permissions and role mining can be utilized to create various roles with these permissions. Users are commonly given roles with numerous duplicate permissions and this method can simplify the management and maintenance of RBAC system. Therefore, in order to reduce the complexity of the generated roles, it is necessary to cluster users who share the same attributes. However, implementing traditional role mining techniques resulting enormous mining scales and burdens the administration of the systems due to the miscellany of permissions and users [22].

Therefore, a pre-processing technique is needed to reduce the scalability of the UPA to produce more precise candidate roles. For this paper, basic role mining has been converted into a clustering problem using the Hamming Distance (HD) approach and basic role mining can be defined as the following:

Definition 1. Given a set of users (U), a set of permissions (PRMS), a user permission assignment (UPA), a set of roles (ROLES), a user-to-role assignment (UA), and a role-to-permission assignment (PA), 0-consistent with UPA and minimizing the number of roles, k.

Hamming Distance (HD) approach has been applied to decrease the scales of UPA. This approach can decrease the size of initial dataset by grouping users with the same permissions in the existing UPA to generate an initial set of roles. As input data of RBAC model is user-permission assignments (UPA) in a form of Boolean matrix, it can be observed that the matrix is at the same length, and it is a common practice to calculate the distance between two separate but similar length vectors applying Hamming Distance calculation. Generally, the approach to find the distance can be done by calculating the number of positions between two similar length vectors namely Distance (x, y).

#### IV. EXPERIMENTAL RESULTS AND DISCUSSION

This section presents the results and discussion on the pre-processing model as discussed in previous sections. The algorithms have been implemented in Python 3.6 through Visual Studio Code and tested on a MacBook Air running macOS Monterey Version 12.6.1 on Apple M2 and CPU having 8 GB memory. Five real-world datasets have been widely employed in literature to evaluate the framework to analyze the performances of various unconstrained role-mining heuristics.

The effectiveness of pre-processing model that works to restructure role mining input data (UPA) that exists in the form of a Boolean matrix to produce optimum candidate roles can be demonstrated in the following subsection. The measurement that has been used is size of generated files and the size should

be reduced (smaller size) compared to the original dataset. More precisely, the size of the generated files can be expressed as clustered size that can determine how well UPA are clustered. The dataset that has been used in this research is the benchmark access control datasets, as shown in Table I and the datasets comprise of the numbers of users |U|, the number of permissions |P|, the size of user-permission assignment |UPA| and number of roles |R| in an unrestricted setting.

Fig. 1 describes the model of pre-processing approach to generate candidate roles or can be described as optimal candidate role set identification, and this model can be divided into three main steps. In the first step, rows in the original dataset have been applied with Hamming Distance formula to find a distance value between two identical length rows. Furthermore, in the second step, based on the values of Hamming Distance, the generated dataset is divided into partitions according to similar clusters of users. Lastly, the generated dataset is rearranged in the third step to produce a meaningful smaller set of users that signify each cluster. Thus, these steps can be viewed as processes that can reduce the scalability of UPA, resulting in a compressed dataset containing final candidate roles or optimal candidate to be used in the next phase.

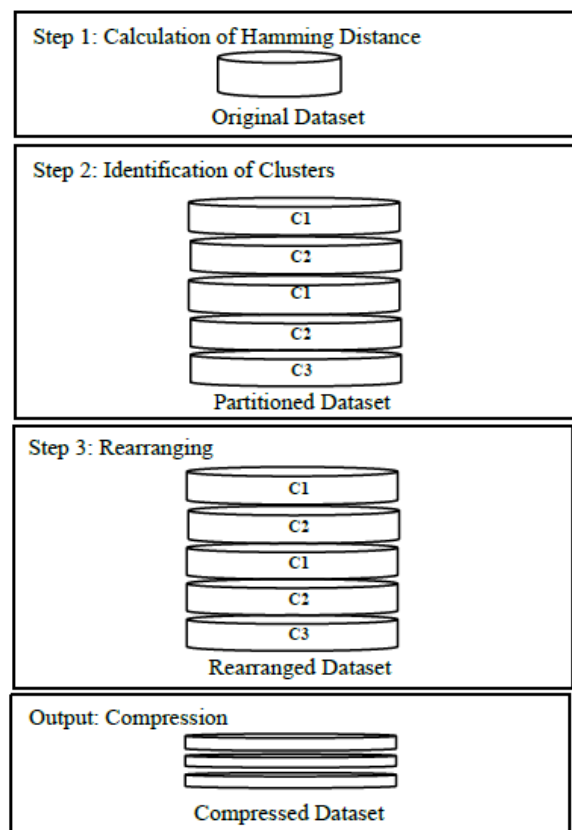


Fig. 1. Role selection and assignment phase.

Table II compares the original files size and generated files size that have been applied with Hamming Distance computation. Meanwhile, Fig. 2, Fig. 3, Fig. 4, Fig. 5 and Fig. 6 show the contrast between both sizes that are represented in form of a graph. Each graph can be designated by blue and red bar, the blue bar signifies the original file size, and

correspondingly, the red bar symbolize generated file size, which are computed by Hamming distance computation. Furthermore, Fig. 7 shows the comparison of file sizes between both original datasets and generated datasets in the directory of the computer.

TABLE II. ORIGINAL VS EXTRACTED FILES SIZE

Dataset	Original File Size	Generated File Size
Apj	144 KB	68 KB
Domino	15 KB	6 KB
Firewall1	671 KB	273 KB
Firewall2	765 KB	319 KB
Healthcare	31 KB	10 KB

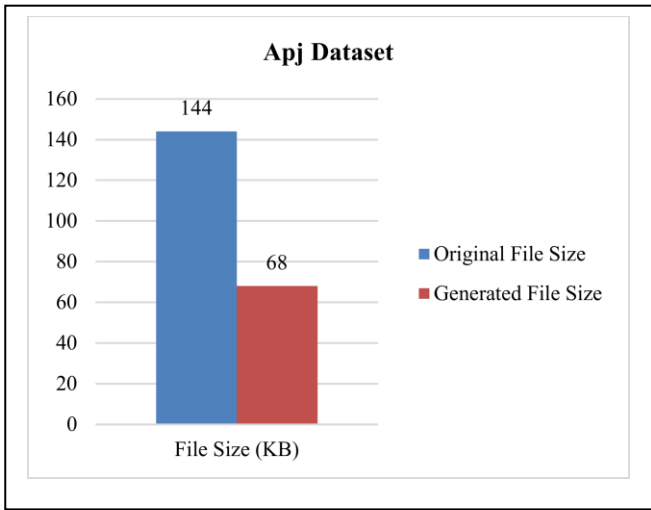


Fig. 2. Initial vs. extracted file size comparison of apj dataset.

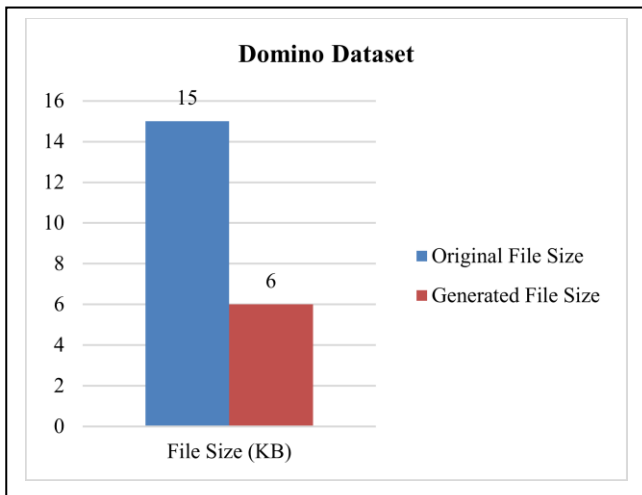


Fig. 3. Initial vs. extracted file size comparison of domino dataset.

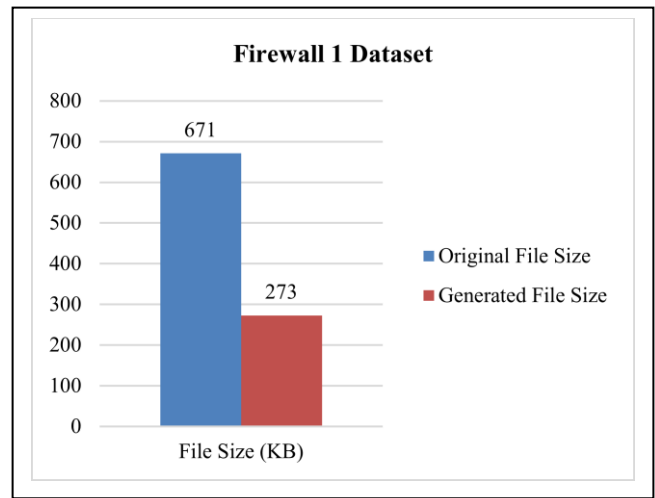


Fig. 4. Initial vs. extracted file size comparison of firewall 1 dataset.

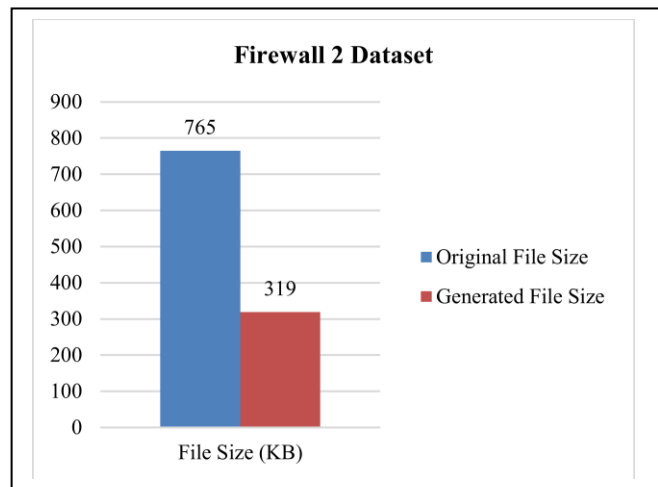


Fig. 5. Initial vs. extracted file size comparison of firewall 2 dataset.

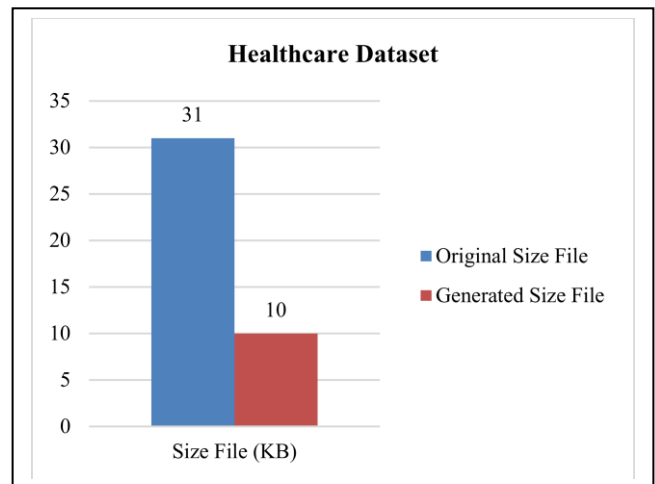
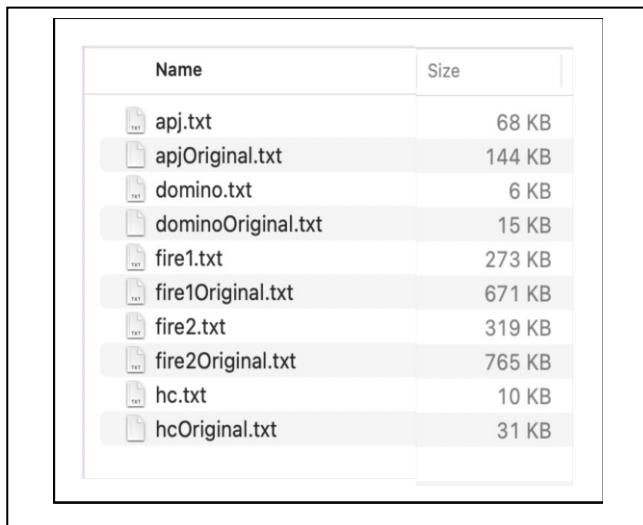


Fig. 6. Initial vs. extracted file size comparison of healthcare dataset.



Name	Size
apj.txt	68 KB
apjOriginal.txt	144 KB
domino.txt	6 KB
dominoOriginal.txt	15 KB
fire1.txt	273 KB
fire1Original.txt	671 KB
fire2.txt	319 KB
fire2Original.txt	765 KB
hc.txt	10 KB
hcOriginal.txt	31 KB

Fig. 7. Comparison of original and generated file size.

TABLE III. REDUCED FILES SIZE

Dataset	Original File Size	Generated File Size	Reduced Size (%)
Apj	144 KB	68 KB	47.2%
Domino	15 KB	6 KB	40.0%
Firewall1	671 KB	273 KB	40.7%
Firewall2	765 KB	319 KB	41.7%
Healthcare	31 KB	10 KB	32.3%

Significantly, based on Table II and Fig. 2 to Fig. 7, the generated file size of all five datasets substantially have been reduced compared to the initial or original datasets showing that Hamming Distance (HD) approach is successfully can be utilized to reduce the mining scale of datasets and eventually can produce better candidate roles. Thus, the three steps as in Fig. 1 can effectively recognize as processes that can reduce the scalability of UPA and resulting a compressed dataset that contains final candidate roles to be used in the next phase. Table III displays the percentage of reduced file size and indicates that HD enables to compress the original dataset to become a smaller generated dataset between 32% to 47%. The Apj dataset has disclosed the highest percentage of 47.2%. In the meantime, the Healthcare dataset has shown the lowest percentage of 32.3%.

## V. CONCLUSION AND FUTURE WORKS

In conclusion, the generated file size of all five datasets has been significantly reduced compared to the original using Hamming Distance approach. The process begins by grouping users that have the same permissions and considering them as a user group, and then each user group can be depicted as different user clusters. The output of this process is a less complex UPA matrix.

For future works, two directions can be considered. The first direction is to consider other possible data mining techniques to be combined with role mining technique, particularly clustering techniques that can produce more

accurate candidate role sets, and the second direction is to explore role-engineering optimization potential in other applications or environments such as in Internet of Thing (IoT) environment.

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# Towards Path Planning Algorithm Combining with A-Star Algorithm and Dynamic Window Approach Algorithm

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**Abstract**—In the Automated Guided Vehicle (AGV) warehouse automatic guided vehicle system, the path planning algorithm for intelligent logistics vehicles is a key factor to ensure the stable and efficient operation of the system. However, the existing planning algorithms have problems such as single designing a route and the inability to intelligently evade moving barriers. The academic community has proposed various solutions to these problems, although they have improved the efficiency and quality of path planning to some extent, they have not completely solved problems such as poor safety in planning, the high number of path inflection points, poor path smoothness, easily getting stuck in deadlocks, and have not fully considered the running cost and practical implementation difficulty of algorithms. To address these issues, the article deeply researched traditional A\* scheme and Dynamic Window Approach (DWA) technology and proposed designing a route method according to the fusion of the A\* algorithm and DWA technology. The algorithm improved the A algorithm by introducing a sub-node optimization algorithm to solve problems for instance poor global path planning safety and easy deadlock. Moreover, the algorithm reduced the amount of global route reversal locations and increased path consistency by improving the evaluation function and removing redundant points of the A algorithm. Finally, by integrating the DWA algorithm, the intelligent logistics vehicle achieved dynamic obstacle avoidance capabilities for moving objects in the real world. Our simulations-based results on MATLAB framework show that the algorithm significantly improves path smoothness, path length, path planning time, and environmental adaptability compared to traditional algorithms, and basically meets the path planning requirements of the AGV system for intelligent logistics vehicles.

**Keywords**—AGV; path planning; A\* algorithm; dynamic window approach

## I. INTRODUCTION

In recent years, with the major breakthroughs in the P.R. China-Europe Railway Express, the China-Japan-Korea Free Trade Zone, and the Belt and Road Initiative (BRI) in Pakistan, China's flagship economic corridor economy has ushered in new development, and at the same time stimulated the rapid growth of the logistics industry. According to statistics from relevant departments, the total volume of China's logistics industry in 2022 will reach 347.6 trillion, a year-on-year increase of 3.4% [1]. At the same time, due to the continuous development of Artificial Intelligence (AI), warehouse-

automated guided vehicles (automated guided vehicles, AGV) are commonly utilized in warehousing and distribution, logistics distribution, and other industries [2]. But at this stage, the AGV control system has a single path planning and fixed-point pickup, and cannot dynamically avoid dynamic obstacles [3]. The dynamic path planning of the AGV control system needs further research.

At present, many experts and scholars put forward different solutions. J Borenstein's team proposes a virtual stand that considers the dynamic behavior of fast-moving robots and solves the local minimum trap problem. Hao W's team used neural networks for path planning [4]. Chang et al. presented the SPEA2 method into the genetic algorithm to distribute the fitness of the population individuals and realized the balance of path smoothness, path length, and path difficulty [5], Xiong Lijun et al. introduced the initial grid transfer rule and changed the information The method of updating elements, deleting redundant nodes, DWA algorithm [6] for the design for regional paths and other methods can improve the rate of integration of the ant colony algorithm, the smoothness of the planned path, and the safety and reliability. Performance indicators such as smoothness, safety, and reliability are improved compared with traditional algorithms [7]. The K Dan team proposed the A\* algorithm for the first time [8]. Yang Guihua and others adopted the method of cleaning the Close list to optimize the total quantity of vertices in the route that the A\* method designed [9], while Yang Mingliang and others tried to integrate the A\* algorithm and The DWA algorithm into achieves the global optimality of the planned route via avoiding obstacles the objective is to arrive [10]. Although the above method has improved the efficiency and quality of path planning to a certain extent, it has not completely solved the problems of too many vertices in the path planning, is not smooth, and is easy to fall into a deadlock, and has not considered the cost of algorithm operation and the difficulty of the actual implementation. Focusing on the real-world issues of adaptive obstacle-resistant routing for stored robotics, this study suggests a route modeling technique utilizing DWA and the typical A\* technique.

The main contribution of this research work is as follows:

1) *Firstly*, the problems of the A\* algorithm such as long search time, readily prone to global optimal, traversing obstacle vertices, and insufficient path smoothness are improved; a

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globally optimal path is planned, and then combined with DWA to analyze the dynamic obstacle part.

2) *Secondly*, we create an adjacent adaptive obstacle-avoiding route to arrive at the desired route.

3) *Finally*, we conduct three sets of comparative computer simulations to verify that the method which is suggested performs superior to the traditional algorithm and the existing improved algorithm in both stationary and dynamic settings where the obstacle movement direction is known and unknown superiority.

The paper is structured into several sections. Section I introduces the field of automated guided vehicles for guided vehicle systems. Section II provides an environment model construction. Section III presents the basic algorithm. Section IV leads to the improved safety and reliability of the improved A\* algorithm. Section V focuses on simulation-based experimental results. Finally, Section VI concludes this research work and stipulates future research directions in Section VII.

## II. ENVIRONMENT MODEL CONSTRUCTION

As shown in Fig. 1, the grid map is used to construct the virtual working environment map of the robot. In this two-dimensional map, the black grids represent obstacles, respectively S1, S2, ..., Sn, and the white grids represent no obstacles, while Point N and Point T represent the beginning and ending points, respectively. The serial numbers of grids are 1, 2, 3... from bottom to top and from left to right. What needs to be paid is that a distinct identification and associated two-dimensional dimensions are assigned for every grid, and the conversion method is the following:

$$\begin{cases} x_i = (\text{mod}(i, MM) - 0.5) * \beta \\ y_i = (NN + 0.5 - \text{rup}(20 - i/NN)) * \beta \end{cases} \quad (1)$$

Among them,  $x_i$  and  $y_i$  are the coordinates of the  $i$ -th grid in the two-dimensional graph;  $\beta$  represents the unit length of the grid;  $\text{mod}$  represents rounding;  $MM$  and  $NN$  are the grids in the row direction and column direction of the grid respectively number;  $\text{rup}$  is a custom function, representing rounding up.

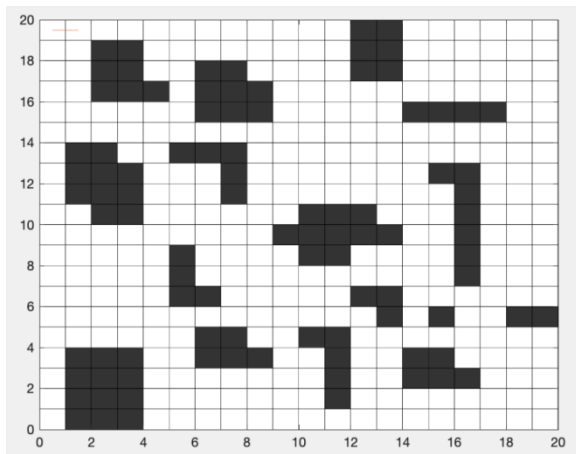


Fig. 1. Grid map of robot working environment.

## III. BASIC ALGORITHM

### A. Traditional A\* Algorithm

The shortest route among the two locations is determined by the most common methods are the Dijkstra algorithm [11] and A\* algorithm. Compared with the Dijkstra algorithm, the A\* method predicts the projected utility from the present location to the objective position in addition to recording the utility of getting to the beginning place. It has the advantages of faster speed and higher efficiency. It is a heuristic depth-first algorithm [12]. The assessing parameter of the conventional A\* method is typical:

$$f(n) = g(n) + h(n) \quad \# \quad (2)$$

Among them,  $f(n)$  depicts the car's assessment process in its present grid,  $g(n)$  indicates the actual utility value of the mobile robot from the initialing dot to the current dot, and  $h(n)$  denotes the heuristic performance [13], Euler distance was employed as the heuristic in the research [14].

$$H(n) = \sqrt{(N1_x - N2_x)^2 + (N1_y - N2_y)^2} \quad \# \quad (3)$$

The A\* technique's pathfinding strategy is displayed in the following Fig. 2:

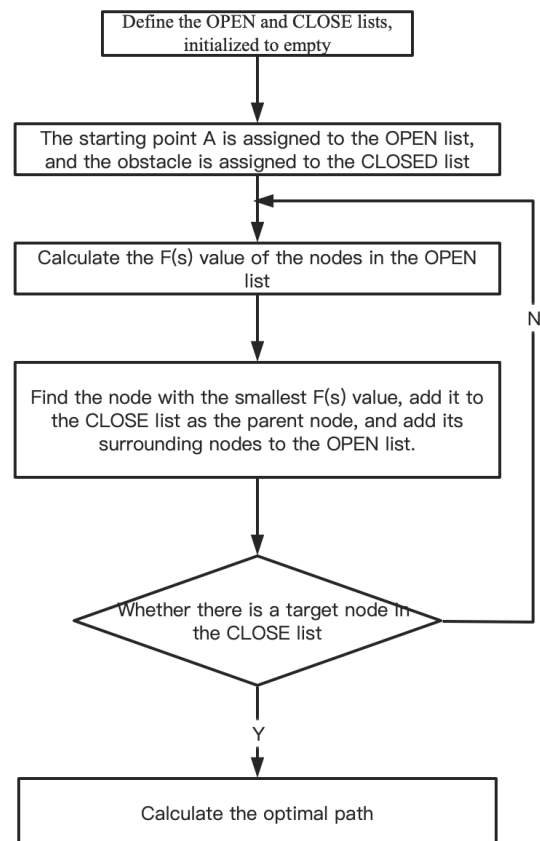


Fig. 2. A\* Algorithm flow chart.

Step 1: Open the list and close the initial transmission of the list.

Step 2: Fill out the unfilled list with the initial location, then get the set of surrounding points and add it to the open list, and then the beginning spot should be taken off the list that is vacant and added to the closing condition of the closed list.

Step 3: Judging whether these surrounding point sets are already in the open list or not, then update the F and father points of these points and add them to the open list; if they are, then update G, F, and father points.

Among them, G stands for the utility associated with relocating initialing point A to a certain grid tile,

F represents the prediction function value of the point, and its value is equal to G+H, and H refers to the anticipated utility of moving from the specified square to the final result, that is, the utility of the heuristic function.

Step 4: then obtain the surrounding point set, find the point with the smallest F from the surrounding point set, then remove the point that finds the smallest F from the open list, and add it to the closed list.

Step 5: judge whether the opening list is empty, if it is empty, it means that the path does not exist, if it is not empty, execute Sep3 in a loop.

Step 6: If the objective grid is in the "open list", it means that the route has been identified, the algorithm ends, and the path planning is completed.

The classic A\* algorithm has some issues, as the information mentioned shows:

1) The planned path is rough, and the inflection point is too close to static obstacles, so it cannot be directly applied to the movement of smart cars in real life.

2) It can only run in a static environment. When the working environment changes, it still plans the path according to the environmental grid map before modification, resulting in the existence of theory and failure of practice, and even causing safety hazards.

### B. Dynamic Programming (DWA) Algorithm

To address the drawbacks of the confusing decision-making introduced by the A\* technique, which only focuses on the path to the destination, and overlooks the impact of dynamic barriers on the performing route's track on the vehicle's route selection, the DWA (dynamic window technique) algorithm is a more suitable solution plan [15].

The fundamental idea is to collect different sets of rates in the velocity domain (v, w), and model the course of these velocities over a predetermined amount of time, and the rating function should be used to assess these motions, and decide on the corresponding optimal trajectory (v, w) Drive the robot to move[16].

There are three main steps in the operation of the algorithm, specifically:

1) *Smart car kinematics model*: As shown in Fig. 3, the smart car belongs to omnidirectional movement. In the robot coordinate system, there is the speed  $V_x$  in the X direction and the speed  $V_y$  in the Y direction [17]. The relationship between the position and speed at time t and time  $t + \Delta t$  is as follows:

$$\begin{bmatrix} x(t + \Delta t) \\ y(t + \Delta t) \\ V_x(t + \Delta t) \\ V_y(t + \Delta t) \\ \theta(t + \Delta t) \\ \omega(t + \Delta t) \end{bmatrix} = \begin{bmatrix} x(t) + V_x(t) * \cos(\theta(t)) * \Delta t - V_y(t) * \sin(\theta(t)) * \Delta t \\ y(t) + V_x(t) * \sin(\theta(t)) * \Delta t + V_y(t) * \cos(\theta(t)) * \Delta t \\ V_x(t) + \alpha_x(t) * \Delta t \\ V_y(t) + \alpha_y(t) * \Delta t \\ \theta(t) + \omega(t) * \Delta t \\ \omega(t) + \alpha(t) * \Delta t \end{bmatrix} \# \quad (4)$$

It is especially pointed out that this model has two coordinate systems - the world coordinate system and the smart car coordinate system.

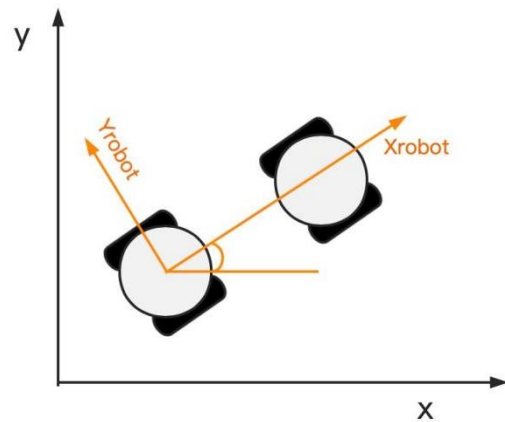


Fig. 3. Kinematics model of the smart car.

$V_x(t)$  and  $V_y(t)$  in the above formula refer to the speed of the smart car in the x and y directions in the smart car coordinate system respectively.

2) *Velocity space of the smart car*: Theoretically speaking, the acceleration of the smart car should reach the maximum value that the machine motor can bear in an instant from the moment it stops to the start of acceleration, but in the actual environment, the car is limited by various factors, mainly including the following aspects:

a) *The smart vehicle's velocity is its only constraint*:  $V_s$  represents the range of vector speeds the vehicle is capable of which is affected by angular velocity and linear velocity:

$$V_s = \{(v, \omega) | v \in [v_{min}, v_{max}] \wedge \omega \in [\omega_{min}, \omega_{max}]\} \# \quad (5)$$

b) *The moving trolley is affected by its own motor performance*: In the actual operating environment, subject to cost and safety considerations, the acceleration of the car has a range limit, and the maximum acceleration and deceleration will take a certain amount of time to reach. The expressions are as follows:

$$V_d = \{(v, \omega) | v \in [v_c - v_b * \Delta t, v_c + v_b * \Delta t] \wedge \omega \in [\omega_c - \omega_b * \Delta t, \omega_c + \omega_b * \Delta t]\} \# \quad (6)$$

c) *The mobile car is affected by obstacles:* To make the car stop before it hits an obstacle and avoid damage to goods and property, the car should satisfy the following expression under the premise of maximum deceleration:

$$V_a = \left\{ (v, \omega) \left| \begin{array}{l} v \leq \sqrt{2 \text{dist}(s, \omega) v_b \wedge} \\ \omega \leq \sqrt{2 \text{dist}(s, \omega) \omega_b} \end{array} \right. \right\} \# \quad (7)$$

Among them, distance (s, w) shows the quickest path between the vehicle and the obstruction.

After the speed of the car passes through the three restrictions, the speed space will return to a certain extent, and it will change according to the changes in the linear velocity, angular velocity, and acceleration of the motor. This is the dynamic window of the car's movement [18], When the conditions are met, a sample of the speed space of the car, and the speed range in Fig. 4, below will be obtained:

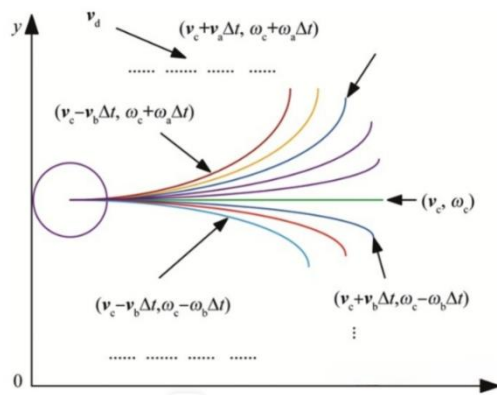


Fig. 4. Smart car speed range map [19].

3) *Evaluation function:* In general, the following is the evaluation process:

$$G(v, \omega) = \sigma \left( \alpha * \text{heading}(v, \omega) + \beta * \text{dist}(v, \omega) + \gamma * \text{vel}(v, \omega) \right) \# \quad (8)$$

Among them, heading (v, w) is the azimuth evaluation function: assess the angle between the intended location and the car's final route, given the present selected velocity; the main meaning of distance (v, w) is that the car is in the predicted. The final destination of the route is placed relative to the closest constraints on the map, and sample sites that are nearby the barrier are penalized to guarantee the car is able to prevent it and lessen the likelihood that it would collide with it; vel (v, w) is the current car, promoting the vehicle will help it swiftly reach its aim [20],  $\alpha$ ,  $\beta$ ,  $\gamma$  are the weights, and  $\sigma$  is the smoothing coefficient, which is generally 1.

After obtaining a variety of trajectories through the above methods, the current optimal speed and the best trajectory are selected through the evaluation function, to drive the car to avoid obstacles as much as possible. But this method has the blindness and randomness of path selection.

#### IV. IMPROVED A\* ALGORITHM

##### A. Improve Safety and Reliability

Although the traditional A\* scheme contains several benefits fast speed and global routing in path routing, it has the disadvantages of a large turning range, many trajectory polylines, and the initial path of turning to being close to obstacles. The following Fig. 5 shows the domain algorithm of the traditional A\* scheme for routing:

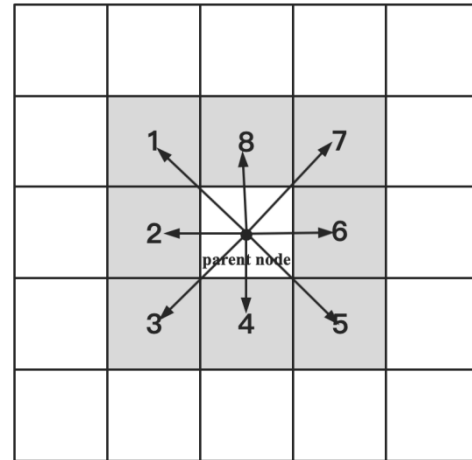


Fig. 5. Schematic diagram of the domain of the A\* algorithm.

From the analysis in Fig. 5, we know that the reason for the insufficient uniformity of the planned route is that the type A\* technology adopts one 3\*3 domain algorithm, leading to the turning range of the smart car. This causes the issue that the planned car path is insufficient near static barriers.

To fix the challenge, the improved A\* scheme needs to adopt a sub-node optimization algorithm in the route. Its core is to select an appropriate method to remove redundant nodes according to obstacles at different positions, to prevent the phenomenon in which the car traverses obliquely through the apex of obstacles and ensure that the car Safe distance from obstacles.

As shown in Table I, sub-nodes 1, 3, 5, and 7 are divided into X-type nodes, and sub-nodes 2, 4, 6, and 8 are divided into N-type nodes. According to the division method, the selection method of the sub-node optimization algorithm is:

TABLE I. SUB-NODE OPTIMIZATION ALGORITHM

Obstacle node type	Handling measures	The number of remaining child nodes
X	do not deal	8
N	removes two child nodes adjacent to the obstacle child node	6

##### B. Path Smoothness Optimization

After adopting the above-mentioned sub-node optimization algorithm, although the phenomenon of obliquely crossing the obstacle vertex can be avoided, it also strengthens another shortcoming of the A\* algorithm - the problem that the path is not smooth and the path length is not optimal. In order to solve

this problem, the improved A\* algorithm adopts the method of twice smoothness optimization.

1) *The first smoothness optimization:* The first smoothness optimization is achieved by improving the evaluation function of the A\* algorithm. By increasing the weight value of  $h(n)$  to increase the evaluation value  $G$  of the correct node, the algorithm selects a child node closer to the end position. The function expression is as follows:

$$f(n) = g(n) + \left(1 + \frac{r}{R}\right)h(n) \quad (9)$$

Where  $r$  is the space between the beginning position and the goal point, where  $R$  is the value between the present and objective locations.

2) *The second smoothness optimization:* When the classical A\* algorithm plans the path, there will be several redundant connections in enormous amounts, which will increase the length of the path and make the result not the optimal solution. Therefore, the A\* algorithm for the second smoothness improvement adopts two methods to remove redundant nodes:

a) Remove collinear nodes, such as five nodes  $N_4$ ,  $N_5$ ,  $N_6$ ,  $N_7$ , and  $N_8$  belong to collinear nodes, then the child nodes of  $N_3$ . The next step should be to change to the node with obstacles in the first domain of the collinear node, that is,  $N_8$ .

b) Eliminate the right-angle inflection point, when the next two steps of the parent node  $N_i$  are still in the domain of the parent node, it is determined that the path planning is in progress. There is a right-angle inflection point. Currently, whether the child node of the domain union of the three parent nodes is an obstacle is judged. If not, the next hop of  $N_i$  is changed to  $N_{i+2}$  instead of  $N_{i+1}$ . After two path smoothness optimizations, the path planning demonstration diagram of A\* is shown in Fig. 6.

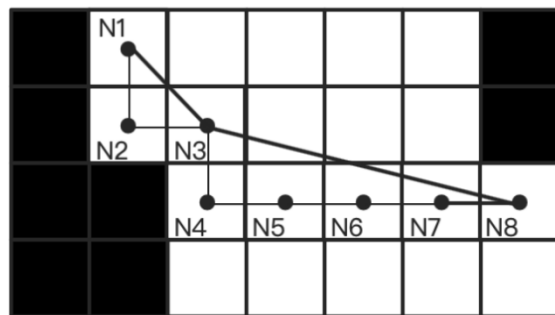


Fig. 6. A\* path planning.

### C. Integrated Obstacle Avoidance Strategy

Based on the above improvement scheme, the 9\*9 improved A\* algorithm incorporates the DWA algorithm, the A\* algorithm is used for global path planning, a reference route is provided for DWA, and points are selected for local obstacle avoidance path planning, which solves the problem of the DWA algorithm. The blindness and randomness of the path selection realize the optimal combination of the shortest path and dynamic obstacle avoidance. At the same time, in order to

ensure the path smoothness of the car at the turning point, and to ensure that the smart car can slow down in advance when encountering obstacles or turning, so as to ensure the safety of the goods and the optimization of the path length, the improved algorithm proposes a The new DWA evaluation algorithm based on the globally optimal path, its expression is as follows:

$$G(v, \omega) = \sigma(\alpha * heading(v, \omega) + \beta * dist(v, \omega) + \gamma * vel(v, \omega)) + \eta * Yheading(v, \omega, G_i) \quad (10)$$

In the formula,  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\sigma$ , and  $\eta$  are weighted, and  $\sigma$  is a smoothing coefficient, usually, its value is 1. Heading () is the azimuth evaluation function, distance () measures the separation between the course of motion and the obstruction, vel () is the evaluating process, Y heading () is the deviation function from the sub-target point to the end of the path, where  $G_i$  represents the current car The subgoal point closest to the global planning path. Therefore, this paper implements a global path planning algorithm that integrates obstacle avoidance, avoids the blindness and randomness of the classical DWA algorithm at the beginning of path selection, and effectively ensures the global route is followed in the best possible way by cutting the path's width and design time, Superiority.

## V. SIMULATION-BASED EXPERIMENTAL RESULTS

To assess how well the enhanced technique performs and verify the feasibility of the algorithm, the algorithm validity verification experiment and the algorithm comparison verification experiment were carried out. Both experiments were carried out on the Matlab R2023a simulation platform, the computer operating system version is MacOS 11, the processor is Intel Core i7-4870HQ, and the memory is 16G. In the comparative experiment, two map environments were constructed, and the size, shape, and number of obstacles of different environments were different. By setting up different environments, the performance of the proposed improved planning algorithm is analyzed and verified in terms of path length, path smoothness, running time, and obstacle avoidance ability.

### A. Improved A\* Algorithm Verification

To verify the advantages of the improved A\* algorithm in path smoothness, pathfinding efficiency, and security, this paper simulates different environments on Matlab, namely a simple environment (10\*10 grid map) and a complex environment (20\*20 grid map), where "  $\Delta$  " identifies the beginning and "  $\circ$  " identifies the finding. Compared with the simple environment, the number of map environments and obstacles has doubled in complex environments, and the number of searchable sub-nodes has expanded by 4 times. It can effectively evaluate the performance of the upgraded A\* technique. A\* algorithm shows in Fig. 7.

Fig. 7 and Fig. 8 shows that the enhanced A\* algorithm can prevent too many vertices in the path planning process, and then plan a route with a shorter path length and a higher path smoothness. Fig. 9 and Fig. 10, we can see that the improved algorithm called A\* will identify a shorter route in fewer seconds in a complex environment, which is obviously better than the traditional A\* algorithm. The direction energy parameters of path planning for different algorithms in two

different environments are shown in Table II, and the data are recorded with two decimal places:

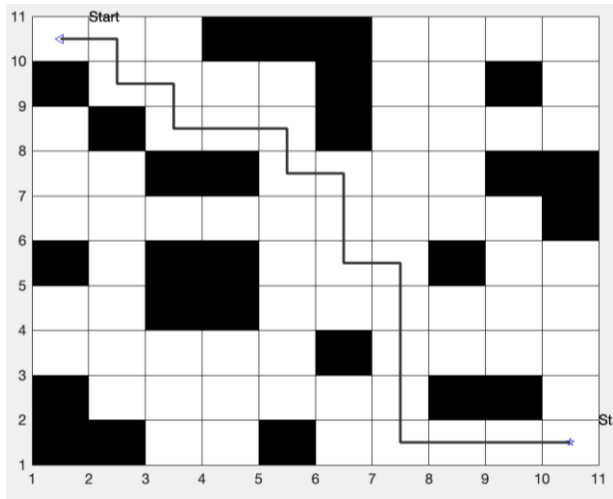


Fig. 7. Path planning of the traditional A\* algorithm in a simple environment.

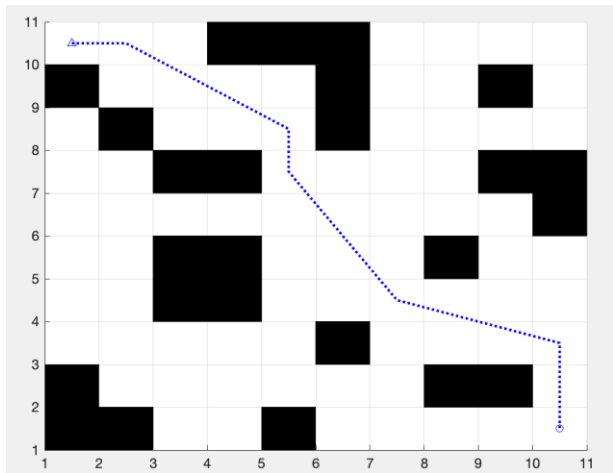


Fig. 8. Path planning of the improved A\* algorithm in a simple environment.

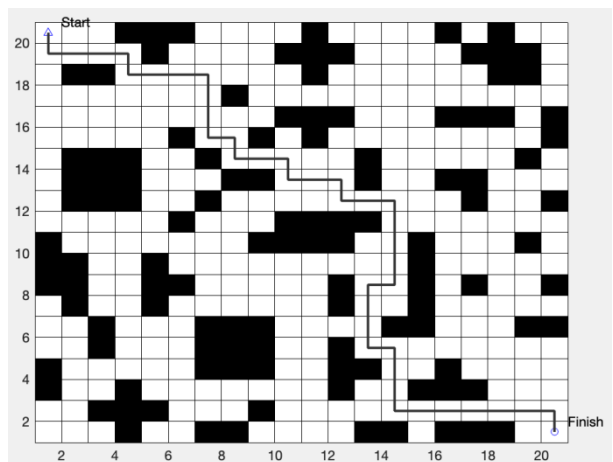


Fig. 9. Path planning of traditional A\* algorithm in a complex environment.

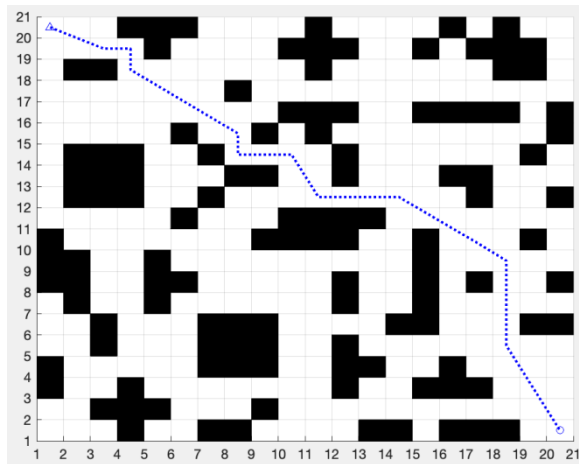


Fig. 10. Path planning of the improved A\* algorithm in complex environments.

TABLE II. PARAMETERS OF PATH PLANNING IN DIFFERENT ENVIRONMENTS

		<i>Path length</i>	<i>Vertices</i>	<i>Planning time</i>
<b>Simple environment</b>	Traditional A* algorithm	18.00	10	7.69
	Improved A* algorithm	14.83	5	5.48
<b>Complex environment</b>	Traditional A* algorithm	38.00	16	22.89
	Improved A* algorithm	29.85	10	11.03

From this, we can see that in comparison to the typical A\* algorithm, the enhanced A\* method has a comprehensive reduction in the number of breakpoints by 44%, a comprehensive reduction in path length by 17.18%, and a comprehensive reduction in planning time by 14.68%. The enhanced A\* method performs quite well regarding route length and roughness.

B. Fusion Obstacle Avoidance Function Verification

The A\* technique's minimization evaluation has to be verified for different obstacles after integrating the obstacle avoidance ability. Construct a simulation environment 3, which is a 20\*20 grid map containing movable obstacles, represented by yellow squares, whose moving coordinates are ([14, 7], [14, 11]), and contains several Unknown static obstacles represented by gray squares. Numerous factors have an impact on the efficacy as well as the efficiency of the enhanced routing technique. The experimental environment parameter settings are shown in Table III:

TABLE III. EXPERIMENTAL ENVIRONMENT PARAMETER SETTINGS

Parameter type value	
<b>Direction angle <math>\alpha</math></b>	0.05
<b>Static distance <math>\beta</math></b>	0.2
<b>Dynamic Distance <math>\gamma</math></b>	0.3
<b>Smoothing factor <math>\sigma</math></b>	1
<b>Offset term <math>\eta</math></b>	0.1



The following figure displays the experiment's findings:

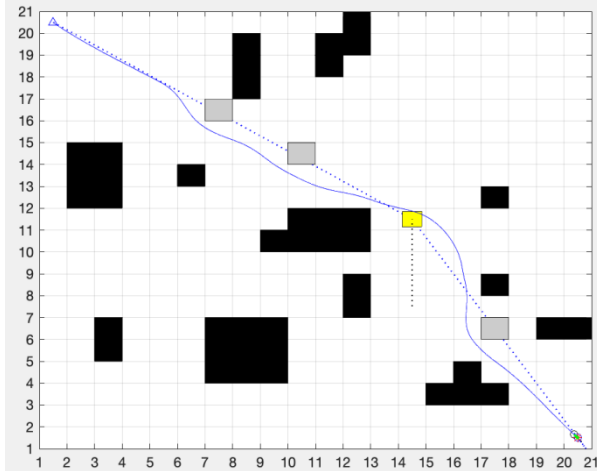


Fig. 11. Path planning of the fusion obstacle avoidance ability A\* algorithm.

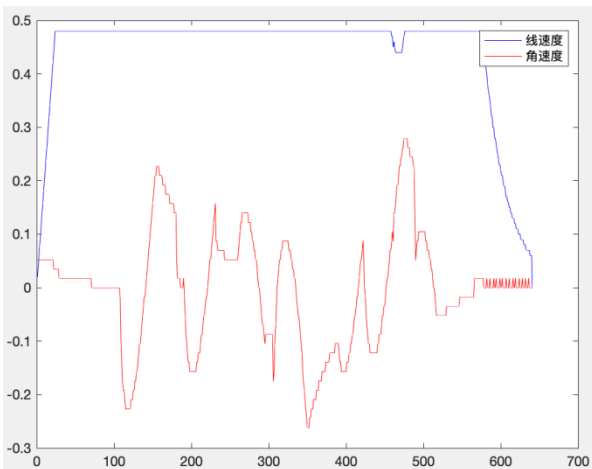


Fig. 12. The speed change diagram of the smart car.

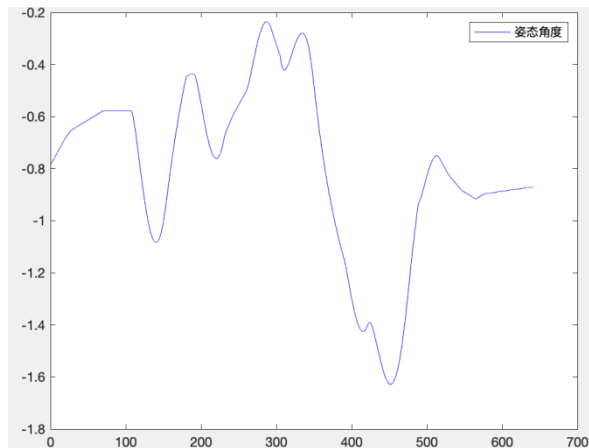


Fig. 13. The attitude angle change diagram of the smart car.

Through the analysis of Fig. 11, 12, and 13, we can conclude that for static obstacles that appear on the global planning path, when the distance between the smart car and the obstacle exceeds the calibration value, the car can change the angular velocity, thereby affecting the attitude angle. Realize

automatic obstacle avoidance. When facing a dynamic obstacle, the car slows down, changes the angular velocity value, and greatly changes the attitude angle, so as not to more violent collision with the unstable obstruction. The route routing efficiency metrics for the A\* approach when combined with the DWA technique is shown in Table IV.

TABLE IV. PATH PLANNING COMPARISON TABLE

	Number of inflection points	Path length	Planning time
Global planning path	1	29.85	11.28
Final path	0	38.60	60.50

From this, it is evident that, compared with the global route diagram drawn via the improved A\* algorithm, the path integrated with the DWA algorithm has a higher smoothness and is more suitable for the actual production and living environment when the path length is not much different. The path realizes the optimal global path and excellent obstacle avoidance ability of the intelligent logistics vehicle.

### C. Improved Algorithm Compared with Other Algorithms

The ancient route technique known as the "ant colonies program" was created by summarizing how ants forage in the wild [21-27]. The selection basis is that the shorter route has higher pheromone concentration along the route, which guides other ants to forage along the route and forms positive feedback to obtain the shortest route to find food. The ant colony algorithm can also provide global route scheduling for the fusion algorithm. The path planning of the ant colony algorithm in a complex setting (environment 2) is shown in Fig. 14:

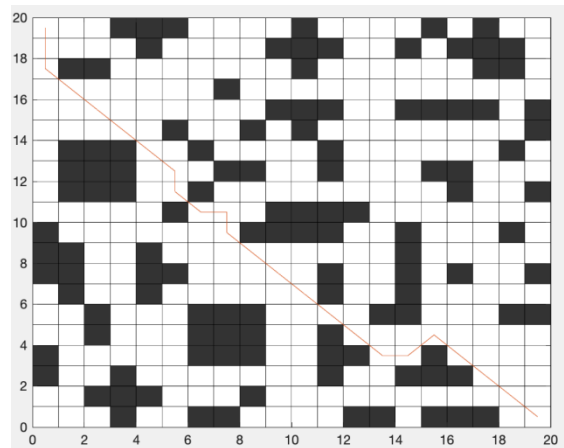


Fig. 14. Ant colony algorithm planning global path.

The path planning comparison table is shown in Table V:

TABLE V. PATH PLANNING COMPARISON TABLE OF IMPROVED A\* ALGORITHM AND ANT COLONY ALGORITHM

	Path length	Vertices	Planning time
Improved A* algorithm	29.85	10	11.03
Ant Colony Algorithm	32.04	9	12.08

From the above Table V, we can analyze that throughout the procedure of developing a global route, the ant colony scheme has the disadvantages of obliquely crossing the obstacle vertices, insufficient smoothness of the intended route, and long path length. By comparison, the high smoothness and low route size of the enhanced A\* algorithm in global scheduling is proved again.

## VI. CONCLUSION AND FUTURE WORK

Focusing on dynamic obstacle-avoiding route scheduling problems for storing robotics, the study put forward an A\* route scheduling algorithm integrated with the DWA obstacle avoidance algorithm. Fitting greatly optimizes the path smoothness and path length of the global path planning, and realizes planning a better route in a shorter time. By integrating the DWA algorithm, it realizes automatic avoidance of static and dynamic obstacles on the planned path, improves the flexibility and the method's effectiveness at finding results in complex environments, and makes up for the shortcomings of the A\* algorithm that cannot achieve dynamic obstacle avoidance.

Through MATLAB simulation experimental results, the efficacy of the enhanced method suggested in this investigation is verified in terms of route smoothness and the capacity to prevent obstacles. However, the more advanced method still has the problems of long planning time and poor adaptive proficiency of the integration technique. These are the routes for further research on the path planning of smart cars.

## VII. FUTURE WORK DIRECTIONS

In our future research work, we elaborate on an efficient global planning algorithm that can be designed and can be real-time used in different real-world environments and achieve the good goal of reducing the planning time by 80% based on the current method.

## VIII. FUNDING STATEMENT

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## CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest to report regarding the present research paper.

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# Advances in Machine Learning and Explainable Artificial Intelligence for Depression Prediction

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**Abstract**—There is a growing interest in applying AI technology in the field of mental health, particularly as an alternative to complement the limitations of human analysis, judgment, and accessibility in mental health assessments and treatments. The current mental health treatment service faces a gap in which individuals who need help are not receiving it due to negative perceptions of mental health treatment, lack of professional manpower, and physical accessibility limitations. To overcome these difficulties, there is a growing need for a new approach, and AI technology is being explored as a potential solution. Explainable artificial intelligence (X-AI) with both accuracy and interpretability technology can help improve the accuracy of expert decision-making, increase the accessibility of mental health services, and solve the psychological problems of high-risk groups of depression. In this review, we examine the current use of X-AI technology in mental health assessments for depression. As a result of reviewing 6 studies that used X-AI to discriminate high-risk groups of depression, various algorithms such as SHAP (SHapley Additive exPlanations) and Local Interpretable Model-Agnostic Explanation (LIME) were used for predicting depression. In the field of psychiatry, such as predicting depression, it is crucial to ensure AI prediction justifications are clear and transparent. Therefore, ensuring interpretability of AI models will be important in future research.

**Keywords**—*Depression; LIME; Explainable artificial intelligence; Machine learning; SHAP*

## I. INTRODUCTION

Artificial Intelligence (AI) refers to computer technology that mimics human intelligence by using logical methods to reason, learn, and make decisions. With the advancement of AI technologies such as machine learning, deep learning, and natural language processing, this technology is being applied not only in professional fields but also in our daily lives. For instance, virtual assistants such as Apple's Siri, Samsung's Bixby, and Google's Assistant use natural language processing technology to provide convenience to our lives [1].

There is a growing interest in applying AI technology in the field of mental health, particularly as an alternative to complement the limitations of human analysis, judgment, and accessibility in mental health assessments and treatments [2,3]. Traditional mental health assessments rely heavily on the subjective self-reports and interviews of patients, leading to potential inaccuracies in expert decision-making [4,5]. The misdiagnosis rate of mental health conditions (e.g. bipolar disorder) can be as high as 55~76% [6,7], even among experts

who have difficulty grasping the symptoms and information not reported by the patient.

The current mental health treatment service faces a gap where people who need help do not receive it due to negative perceptions of mental health treatment, lack of professional manpower and physical accessibility limitations [8,9,10]. There is a growing need for a new approach to overcome these difficulties, and AI technology is being explored as a potential solution.

In particular, explainable artificial intelligence (X-AI) with both accuracy and interpretability technology can help improve the accuracy of expert decision-making, increase the accessibility of mental health services, and solve the psychological problems of high-risk groups of depression [11]. In this mini-review, we examine the current use of X-AI technology in mental health assessments for depression. Additionally, we discuss the measures and limitations of applying AI to mental health services.

## II. MATERIALS AND METHODS

### A. Artificial Intelligence and Machine Learning in Depressive Disorder

Depressive Disorder is a severe psychiatric disorder that results in functional impairment [12]. Currently, the diagnosis of depressive disorder relies on the identification of a minimum number of core symptoms that cause functional impairment over a certain period of time [12]. However, this symptom-based approach can lead to diagnostic discrepancies and make it challenging to interpret the results of additional studies, such as genetic studies, neuroimaging studies, and postmortem studies.

The early detection and diagnosis of subtle clinical signs in depressive disorder require highly skilled professionals working in specialized mental health services. Hence, using more objective and reliable techniques, such as neuroimaging techniques, can aid in early detection. Machine learning has the potential to make accurate diagnoses and predict the response to treatment, beyond the conventional method of comparative analysis between a patient group and a normal control group.

Artificial intelligence was first introduced at the Dartmouth Conference in 1956 by Professor John McCarthy of Dartmouth University in the US [13]. At the technological level, it refers to Narrow Artificial Intelligence (NAI), which can perform certain tasks with better-than-human capabilities [14]. Machine

learning is a specific approach to implementing AI, in which a computer learns how to perform a task through an algorithm, rather than having specific decision criteria inputted directly by humans. In this process, defining appropriate features is critical to machine learning, and various algorithms, such as the Support Vector Machine, Gaussian Process Classifier, Linear Discriminant Analysis, and Decision Tree are used.

Deep learning, a branch of machine learning, goes further by using given data as input [15]. This end-to-end machine learning reduces errors that can occur due to human intervention, but the quality and quantity of data provided for learning is becoming increasingly important [13]. Therefore, obtaining high quality data for AI learning is becoming more important than the algorithms used.

**B. Advances in Machine Learning in Neuroimaging**

Brain imaging studies can be classified into structural and functional studies. Various studies have reported the use of machine learning techniques to predict the onset of depression. Conventional structural brain imaging studies, which compare patients with major depressive disorder (MDD) and healthy controls, often use T1-weighted images, which provide high contrast between gray matter and white matter, allowing for more accurate viewing of gray matter regions that make up the cortex. However, MDD is a complex disorder with diverse symptoms, and neuroanatomical abnormalities in MDD are not limited to morphological changes in a single local area. T2-weighted imaging and diffusion tensor images are other neuroimaging techniques used to study structure. Meanwhile, functional aspects can be studied using fMRI (functional Magnetic Resonance Imaging). There are various methods used in fMRI research to predict the diagnosis of depression, such as task-related fMRI and resting fMRI. However, studies [16,17,18] on discrimination of depression using neuroimaging techniques have shown accuracy errors that vary based on sample size. Flint et al. (2021)[16] found that a study with a small sample size (n = 20) demonstrated higher accuracy than one with a medium sample size (n = 100), while a study with a large sample size (n = 1,868) showed an accuracy of only 61%. The authors emphasized the importance of considering the impact of test set size on systematic misestimation and why an overestimation effect may occur. Therefore, researchers should not disregard their models solely based on low training data, instead they should test the models on a larger set of data to assess its performance if it exhibits good results.

**C. Advances in Machine Learning in Psychological Assessment**

Depression is diagnosed through a structured interview, which sets it apart from many other diseases. The Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (published by the American Psychiatric Association)[19] provides diagnostic criteria that are widely used across the globe. These criteria are updated periodically by the APA. One of the main features of these criteria is that they rely solely on interviews with patients and psychological assessments. For instance, Table I displays the diagnostic criteria for major depressive disorder.

TABLE I. INSTANCE OF CRITERIA FOR MAJOR DEPRESSIVE DISORDER IN THE DSM-5

Criteria	
A	If five (or more) of the following symptoms persist for two consecutive weeks and show a change from previous functional status, at least one of the symptoms must be (1) depressed mood or (2) loss of interest or pleasure. Note that symptoms due to other apparent medical conditions should not be included
1	Depressed mood most of the day and nearly every day, subjectively reported (e.g., feeling sad, empty, or hopeless) or objectively observed (e.g., tearing); note that in children and adolescents, it may present as irritable mood.
2	Significantly diminished interest or pleasure in almost all of the usual activities nearly every day.
3	Significant weight loss (e.g., weight change of 5% or more in one month) or weight gain, or decrease or increase in appetite almost every day, without weight control; note that in children, weight gain should not exceed expectations.
4	Insomnia or hypersomnia nearly every day.
5	Psychomotor agitation or retardation nearly every day, observed objectively, not just subjective feelings of restlessness or stagnation.
6	Fatigue or loss of energy nearly every day.
7	Feelings of worthlessness or excessive or inappropriate guilt (which may be delusional) almost every day, not just remorse or guilt.
8	Decreased ability to think or concentrate, or indecisiveness nearly every day, either subjectively or objectively observable.
9	Recurrent thoughts of death (not just fear of dying), recurrent suicidal thoughts without a specific plan, or a suicide attempt or specific plan to commit suicide.

This definition of major depressive disorder makes it difficult to properly differentiate whether someone is exaggerating their symptoms using these criteria or, conversely, minimizing symptoms to avoid social stigma and prejudice as a person with a mental illness [12]. Furthermore, many risk indicators for depression have been presented through numerous studies so far, but no single risk indicator can accurately diagnose or classify depression [20,21]. This is because depression is not caused by a single factor but develops through various genetic and environmental interactions. Therefore, in order to diagnose depression clearly, it is necessary to consider the importance and influence of various risk factors in one model, which should include not only the results of face-to-face counseling but also various environmental and biological results. To overcome these limitations, several studies [22,23,24] have attempted to predict depressive disorder using machine learning.

**D. Limitations of Machine Learning in Diagnosis**

Studies on machine learning in the diagnosis of depressive disorder [22,23,24] have been ongoing for more than 10 years, and accuracy, sensitivity, and specificity are used to evaluate these models. Accuracy has been reported to range from the high 60% to the mid-80%, while sensitivity and specificity have been reported to be in the high 70-80% range. However, when applying machine learning theories to actual clinical practice, several problems arise that prevent its application, such as the heterogeneity of various image data, which arises from data collection, acquisition parameters, and post-processing methods. This makes it challenging to generalize the results to other data and compare.

**E. Advancement of Decision Tree-based Ensemble Model Techniques for Depression Prediction and SHAP**

As a result of the efforts of many researchers to create ML models with high accuracy and reproducibility over the past decade, ML models have evolved into ensemble and boosting models, as follows.

**F. Random Forest**

The random forest algorithm is a machine learning methodology that predicts by deriving several decision tree algorithms. The decision tree algorithm is an analysis technique that models relationships and rules of data and does not require assumptions of linearity, normality, and equal variance [25]. Random forest derives several such decision trees and synthesizes the results. Random forest randomly selects training data and independent variables when creating each decision tree to make predictions. Although individual accuracy may be low, all decision trees are aggregated and predicted. It has the advantage of increasing accuracy and stability because it performs side-by-side measurement [26]. In other words, the random forest randomly selects N independent variables and creates T decision tree algorithms that randomly select data and use the most derived value or average value as the predicted value based on the majority rule. The concept of a random forest is illustrated in Fig. 1.

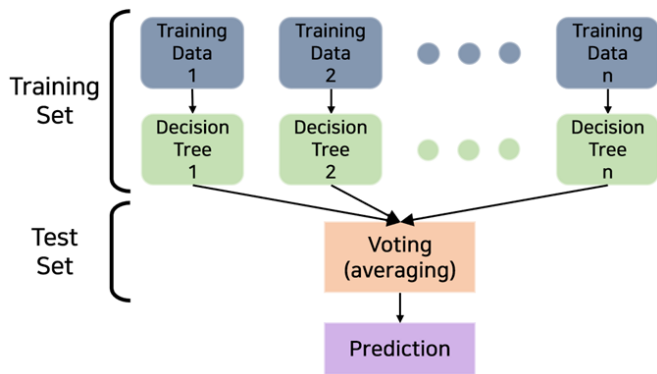


Fig. 1. The concept of a random forest.

**G. Extreme Gradient Boosting: XGBoost**

The boosting technique is an ensemble technique that creates a weak learner using initial sample data and iteratively adds new learners in the direction of reducing the error of the learning result. In particular, gradient boosting is an algorithm that continues to add new models that predict the residuals of previous learners [27]. However, it has the disadvantage of slow learning and overfitting. XGBoost is an algorithm that compensates for these drawbacks. The concept of XGBoost is shown in Fig. 2.

Introduced by Tianqi Chen in August 2016, XGBoost is a decision tree-based machine learning algorithm that uses a gradient boosting structure. It creates an optimized model that prevents overfitting while minimizing training loss through parallel processing, missing value processing, and regularization [28].

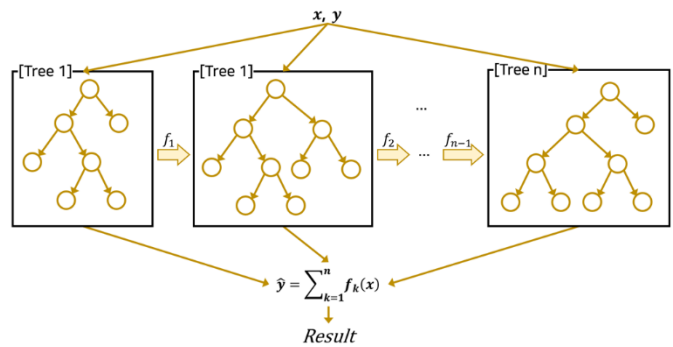


Fig. 2. The concept of XGBoost.

**H. Light Gradient Boosting Machine: LightGBM**

LightGBM is a fast and efficient GBDT (Gradient Boosting Decision Tree)-based algorithm designed by Microsoft MSRA (Microsoft Research Lab Asia) in 2016 [29]. Existing GBDT-based algorithms have a problem in that they do not perform well in large amounts of high-dimensional data because they have to scan all of the data to evaluate the information gain for all possible split points. Here, information gain refers to better discriminating data by selecting a certain attribute. LightGBM solved the problem by introducing two techniques, Gradient-based One-Side Sampling (GOSS) and Exclusive FeatureBundling (EFB) techniques.

In GBDT, data attributes with large gradients play a larger role in information gain. Therefore, GOSS is a technology that maintains data attributes with a large gradient and randomly removes data attributes with a small gradient with a certain probability. EFB is a technique for grouping mutually exclusive variables according to the characteristics of a sparse variable space to reduce the number of variables [30]. In other words, LightGBM uses this technology to reduce usage and achieve fast training speed. The concept of LightGBM is illustrated in Fig. 3.

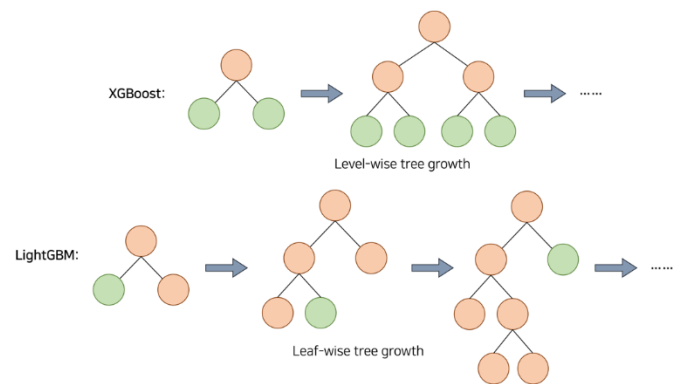


Fig. 3. The concept of LightGBM.

**I. Categorical Boosting: CatBoost**

The CatBoost algorithm is an ordered boosting technique that focuses on preprocessing categorical variables and solving overfitting problems [31]. Unlike conventional boosting models that sequentially learn all residual errors, ordered boosting creates a model by calculating residual errors with some data. After that, the technique calculates the residual error of the remaining data through the corresponding model.



In addition, overfitting is prevented by mixing the order of data through random permutation in sequential boosting. The CatBoost algorithm improves training speed through variable combinations that combine variables with the same information gain. Furthermore, unlike other ensemble algorithms that use Grid Search or Randomized Search to find the optimal hyperparameter, it optimizes the initial hyperparameter value, so the parameter adjustment procedure is unnecessary.

### J. Explainable Artificial Intelligence (XAI)

Explainable artificial intelligence (XAI) refers to helping users understand the results by explaining the outcomes predicted by artificial intelligence. This makes it possible to identify the main factors influencing the result, understand the basis of the decision based on the prediction result of the machine learning model, and provide an intuitive explanation that humans can comprehend about the prediction result [32].

### K. Local Interpretable Model-Agnostic Explanation (LIME)

LIME is a technique that uses combinations of masking or non-masking of superpixels, which are regions of interest in an image that contain important information. The goal is to create an interpretable model that checks the importance of each superpixel in the prediction of a black box model. For example, if an image is classified as a frog, LIME can help us understand why by cutting the image into explanatory units and creating multiple masked and non-masked versions of each unit. We then input these images into the black box model to determine the probability that each one is classified as a frog.

To interpret the results, we train a surrogate model that takes the number of masking cases as input values and the corresponding probabilities as output values. This model can show intuitive results and requires fewer resources than other techniques. Additionally, LIME is model-agnostic, which means it can be applied regardless of the machine learning model used.

However, LIME has some disadvantages. One is that the method used to determine the decision boundary of the model is non-deterministic, meaning that the output value may be different each time it is called. Another is that since LIME only considers one data point at a time, it may not provide a complete explanation of the entire model. The concept of LIME is shown in Fig. 4.

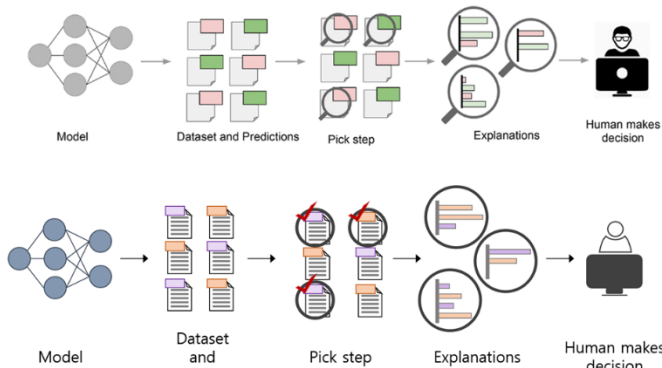


Fig. 4. The concept of LIME.

### L. Shapley Additive exPlanations (SHAP)

SHAP is an algorithm based on Shapley Values from game theory used to describe the output of a machine learning model. The Shapley value is a value obtained through the average change according to the presence or absence of a variable after constructing a combination of several variables to determine the importance of one variable [33]. An explainable model is created based on the training data and the learned model, and the Shapley value, which expresses the influence on the prediction result in terms of direction and magnitude, is calculated for the newly input data. Through this, the technique explains the contribution that the input variable has on the output value of the learned model.

Existing feature importance techniques use a permutation method to measure the effect of a variable on a model. This method has the advantage of high computational speed, but results may be distorted when variables are dependent on each other. Also, the negative (-) influence cannot be calculated, so the value of a specific variable may be set higher than its actual influence. On the other hand, the SHAP technique considers the possibility that variables affect each other and can calculate the negative (-) influence. Although it has the disadvantage of being slow, it can be seen as measuring the influence more accurately than the variable importance method [34]. The concept of SHAP is shown in Fig. 5.

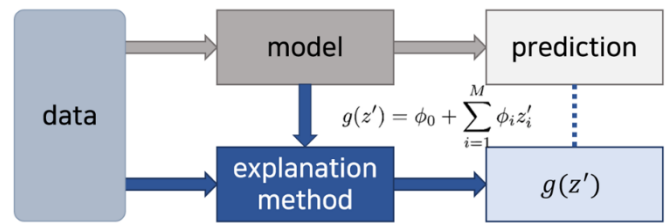


Fig. 5. The concept of SHAP.

### M. Studies of Predicting Depression based on XAI

Explainable machine learning is a relatively new field that aims to make machine learning models and their decisions more understandable and transparent. This is especially important when making decisions that could negatively impact people's lives, such as diagnosing depression. Several studies have reported that depression was predicted using SHAP, one of the techniques of X-AI (Table II). For instance, Matthew et al. (2021)[35] propose a framework for explainable machine learning called SHAP (SHapley Additive exPlanations) that can identify depressive symptoms from social media posts. SHAP is a method that assigns importance values to each feature in a model based on how much they contribute to the prediction. The framework uses natural language processing and sentiment analysis to extract features and provide explanations for the predictions. The authors assessed the model's performance on a held-out test set and found an AUC of 0.73 (sensitivity: 0.66, specificity: 0.7) and 0.67 (sensitivity: 0.55, specificity: 0.7) for GAD and MDD, respectively. Additionally, the authors used advanced techniques such as SHAP values to illuminate which features had the greatest impact on prediction for each disease.

TABLE II. SUMMARY OF X-AI STUDIES

Article	Data	Models /Algorithms	Results
Nguyen and Byeon (2022)[32]	36,000 depression participants over 60 years old	Deep neural network, LIME	Accuracy=89.92%, Precision=93.55%, Recall=97.32%
Matthew et al. (2021)[35]	4,184 undergraduate students	Natural language processing, sentiment analysis, SHAP	GAD: AUC=0.73 (sensitivity: 0.66, specificity: 0.7) MDD: AUC=0.67 (sensitivity: 0.55, specificity: 0.7)
Hueniken et al. (2021)[36]	Canadian adults (aged $\geq 18$ years, N=6021) who completed web-based surveys	Random forest, gradient boosting, support vector machine, and neural network, SHAP	Average accuracy of 85% and 88% 3 most important items predicting elevated emotional distress: increased worries about finances (SHAP=0.17), worries about getting COVID-19 (SHAP=0.17), and younger age (SHAP=0.13)
Amit et al. (2021)[37]	266,544 UK women who gave birth between 2000 and 2017	Gradient tree boosting algorithm based on SHAP	Postpartum depression: AUC=0.805 to 0.844 Sensitivity=0.72 to 0.76 Specificity=0.80
Hochman et al. (2021)[38]	A nationwide longitudinal cohort that included 214,359 births between January 2008 and December 2015	Gradient-boosted decision tree algorithm	Postpartum depression AUC=0.712 Sensitivity=0.349 Specificity of 0.905
Uddin et al. (2022)[39]	Large text-based dataset from a public Norwegian information website: ung.no. (11,807 and 21,470 posts of different length)	LSTM (Long Short-Term Memory), RNN (Recurrent Neural Network), LIME	Depression Accuracy=84.2%

### III. RESULTS AND DISCUSSION

Hueniken et al. (2021) [36] used machine learning methods to identify factors associated with anxiety and depression among Canadian adults during 8 months of the COVID-19 pandemic. The study analyzed data from repeated cross-sectional surveys conducted by Statistics Canada between May 2020 and December 2020, involving 6,021 respondents. Authors applied four machine learning algorithms (random forest, gradient boosting, support vector machine, and neural network) to predict anxiety and depression scores based on demographic, economic, lifestyle, and health risk variables [36]. Authors found that machine learning models performed well in predicting anxiety and depression scores, with an

average accuracy of 85% and 88%, respectively [36]. Authors also identified several important predictors of anxiety and depression, including age, gender, income level, employment status, physical activity level, chronic conditions, and perceived health risk related to COVID-19 infection or vaccination.

The study by Amit et al. (2021)[37] aimed to predict the risk of postpartum depression (PPD) using machine learning and electronic health records (EHR) data from primary care. PPD is a common disorder that affects mothers and their newborns. The study used data from 266,544 UK women who gave birth between 2000 and 2017 and had at least one visit to their primary care physician within a year after delivery. The machine learning algorithm used in this study was a gradient tree boosting algorithm based on SHAP. According to the findings, incorporating EHR-based forecasting with EPDS score enhanced the area under the receiver operating characteristic curve (AUC) from 0.805 to 0.844, as well as increased the sensitivity from 0.72 to 0.76 while retaining a specificity of 0.80. The study demonstrates the feasibility and value of using SHAP-based machine learning and EHR data for estimating PPD risk and improving screening and early intervention.

Hochman et al. (2021) [38] conducted a study to create and validate a model using machine learning to predict postpartum depression (PPD). The research analyzed data from a national cohort of Israeli women who gave birth between 2008 and 2015 and had a psychiatric diagnosis or prescription within a year after delivery. EHR-derived sociodemographic, clinical, and obstetric features were used with a gradient-boosted decision tree algorithm to develop the prediction model. The model's accuracy was assessed in the validation set, achieving an AUC of 0.712, with a sensitivity of 0.349 and a specificity of 0.905 at the 90th percentile risk threshold. The model identified PPDs more than three times higher than the overall set, with positive and negative predictive values of 0.074 and 0.985, respectively. The study revealed that both recognized (e.g., past depression) and less-recognized (differing patterns of blood tests) PPD risk factors were strong predictors in the model. The research demonstrated the usefulness of machine learning-based models in predicting PPD using large-scale cohort data with high accuracy.

Several studies [32, 39] have developed X-AI models to predict depression using LIME. Uddin et al. (2022) [39] developed an interpretable machine learning model that can predict depression from multi-modal data, such as speech, text, and facial expressions. The model used attention mechanisms and feature importance scores to provide insights into the factors influencing depression. Furthermore, as the attributes utilized by the system are grounded on the probable indications of depression, the system could produce purposeful justifications of the verdicts from machine learning algorithms through the use of an interpretable artificial intelligence technique named LIME. The accuracy of the developed depression prediction model was 84.2%.

Nguyen and Byeon (2022) [32] utilized a deep neural network (DNN) model to make predictions about depression in elderly individuals during the pandemic. They focused on

social factors related to stress, health status, daily changes, and physical distancing as potential predictors. To obtain data, they used the 2020 Community Health Survey of the Republic of Korea, which included more than 97,000 participants over 60 years old. After cleansing the data, the DNN model was trained on information from over 36,000 participants and 22 variables. The researchers also integrated the DNN model with a LIME-based model to make the predictions more explainable. The study found that the model achieved an accuracy of 89.92% and had high precision (93.55%) and recall (97.32%) scores, indicating its effectiveness. The researchers highlighted the potential of this explanatory DNN model in identifying elderly patients who require early treatment due to the increased likelihood of depression caused by the pandemic.

Taken together, X-AI such as SHAP and LIME have been reported to be effective in predicting depression in several previous studies. However, the predictive performance of machine learning techniques varies across studies due to differences in data imbalance (particularly in the Y variable), the nature of the features incorporated in the model, and how the outcome variable is measured. Therefore, while some studies have shown that X-AI-based machine learning algorithms perform well, additional studies are continually needed to verify the predictive performance of each algorithm since the results cannot be generalized to all data types.

#### IV. CONCLUSION

Models that are easy to interpret often have simple structures and lower accuracy, while models that are difficult to interpret typically have more complex structures and higher accuracy. In various fields, researchers are conducting studies to apply X-AI to models to ensure interpretability while using powerful learning algorithms with excellent predictive performance. In order to introduce AI into sensitive decisions such as medical diagnoses, and to support medical professionals in their decision-making, sufficient justification for AI results needs to be established. Particularly in the field of psychiatry, such as the prediction of depression, it is crucial to ensure that the justifications for AI predictions are clear and transparent. Therefore, ensuring the interpretability of AI models will be important in future research.

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# State of-the-Art Analysis of Multiple Object Detection Techniques using Deep Learning

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**Abstract**—Object detection has experienced a surge in interest due to its relevance in video analysis and image interpretation. Traditional object detection approaches relied on handcrafted features and shallow trainable algorithms, which limited their performance. However, the advancement of Deep learning (DL) has provided more powerful tools that can extract semantic, high-level, and deep features, addressing the shortcomings of previous systems. Deep Learning-based object detection models differ regarding network architecture, training techniques, and optimization functions. In this study, common generic designs for object detection and various modifications and tips to enhance detection performance have been investigated. Furthermore, future directions in object detection research, including advancements in Neural Network-based learning systems and the challenges have been discussed. In addition, comparative analysis based on performance parameters of various versions of YOLO approach for multiple object detection has been presented.

**Keywords**—Deep learning; neural networks; object detection; YOLO

## I. INTRODUCTION

Object detection involves the process of identifying the location of objects within an image (object localization) and assigning each object to its corresponding class (object classification) [1]. Commonly utilized techniques for object detection include frame difference, background subtraction, optical flow, and Hough transform [2], but they have limitations regarding accurate object detection. On the other hand, object recognition focuses on determining the presence of a specific object in visual data and often involves feature extraction [3].

Nowadays, object detection is applied in various fields such as face detection [4][5], mask detection for COVID-19 compliance [6], railway signal detection [7], and multiple object tracking for counting purposes. Many object detection methods are being developed from many years. Researchers are trying to come up with new methods which will be stable and give accurate results irrespective of the data size. The emergence of popular algorithms for object detection included R-CNN, Fast R-CNN, and Faster R-CNN. R-CNN was initially slow due to its inability to share processing, requiring a ConvNet forward pass for each proposed object [8]. To address this, spatial pyramid pooling networks (SPPNets) were introduced to accelerate R-CNN by enabling computation sharing. Subsequently, Fast R-CNN was developed, training the deep VGG16 network nine times faster than R-CNN, achieving a significantly faster testing speed (213 times faster), and higher Mean Average Precision (MAP) [9] applications requiring fast

and accurate object detection [10-13]. YOLO9000, an extension of YOLO, employs joint optimization of detection and classification to identify over 9000 object types in real time. This approach combines data from diverse sources such as ImageNet [14], [15] and COCO [16] using joint optimization techniques and Word Tree [17]. YOLO9000 significantly bridges the dataset size gap between detection and classification. [18]. YOLOv3, a combination of Darknet-19 and residual network technology, features 53 convolutional layers known as Darknet-53. YOLOv3 performs comparable to SSD variations regarding COCO's average mean average precision measure but is three times faster [19].

Real-time object detection functions enable widespread and cost-effective utilization of standard Graphics Processing Units (GPUs). While the most accurate neural networks currently available cannot operate in real-time and require multiple GPUs for training, YOLOv4 addresses these challenges. YOLOv4 is designed to run efficiently on a standard GPU in production systems, optimizing parallel calculations rather than relying solely on low computation volume theoretical indicators [20], [21]. This paper comprehensively reviews various object detection models and their evolutionary advancements. Due to the availability of lots of object detection algorithms, the question arises which is the better and most suitable for handling complex data and giving high accuracy.

The main objective of this study is to presents a detailed analysis of multiple object detection techniques using deep learning. The study is organized as follows: Section I provides introduction; Section II describes the related work. Experimental work is described in Section III. The results are analyzed and discussed in Section IV. Section V presents the conclusion of the article.

## II. RELATED WORK

In this section, the existing work based on multiple object detection techniques using deep learning has been reviewed [28]. On making a comparative study of YOLOv5 models' performance based on [31], [33], it has been observed that using YOLOv5 for object detection has gained significant popularity across diverse applications. In a prior study by P. Mishra et al., YOLOv5 was successfully employed to identify objects for agricultural monitoring [34]. The research showcased the proficiency of YOLOv5 in accurately detecting various elements such as crops, weeds, and other objects on large-scale agricultural landscapes. Another study by S. Gupta et al. utilized YOLOv5 for real-time object detection in surveillance videos, showing its efficiency and accuracy in

detecting multiple object classes [35]. These studies highlight the successful application of YOLOv5 in different domains even in detecting the more minor objects findings in the automobiles for which the YOLO5 [36] developed series

achieved a very good accuracy, indicating its versatility and performance. The network architecture and overview of YOLOv5 is shown in Fig. 1 and 2, respectively.

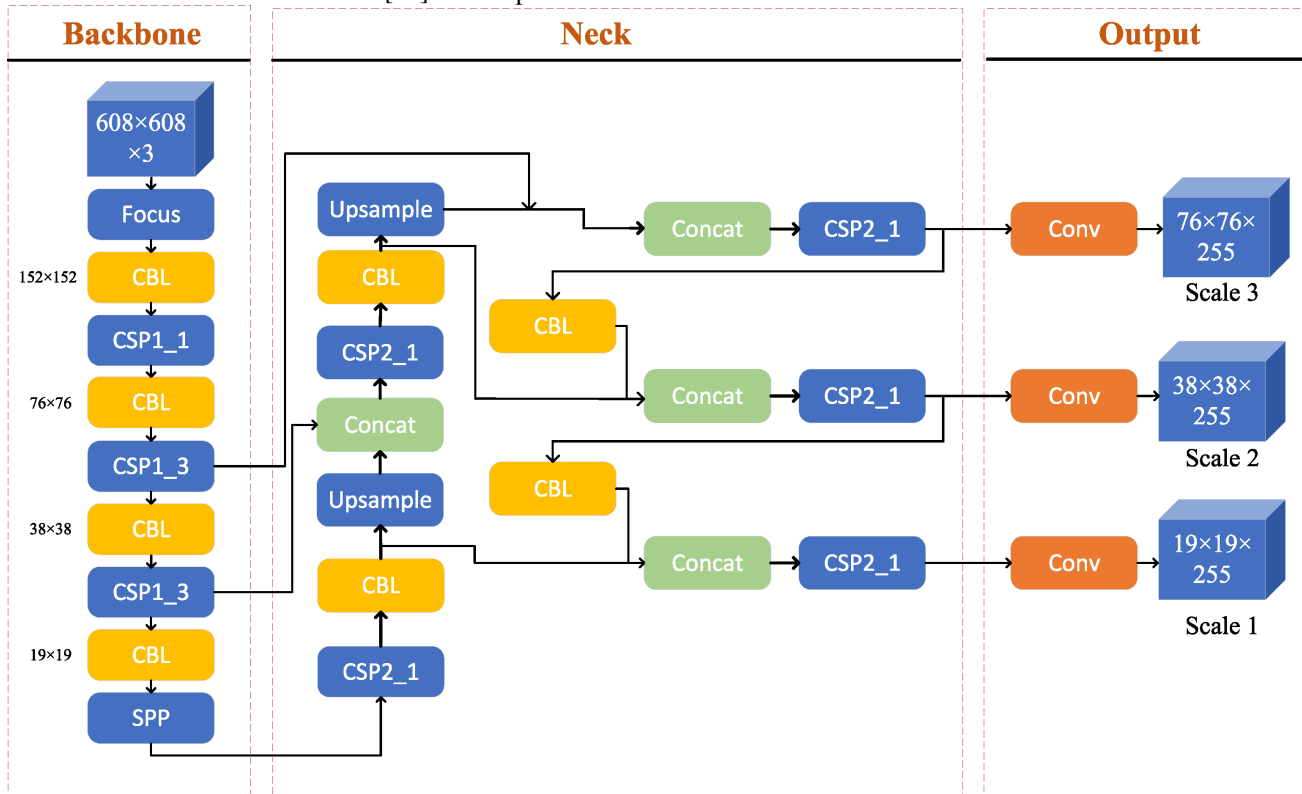


Fig. 1. The network architecture of YOLOv5. [25].

### Overview of YOLOv5

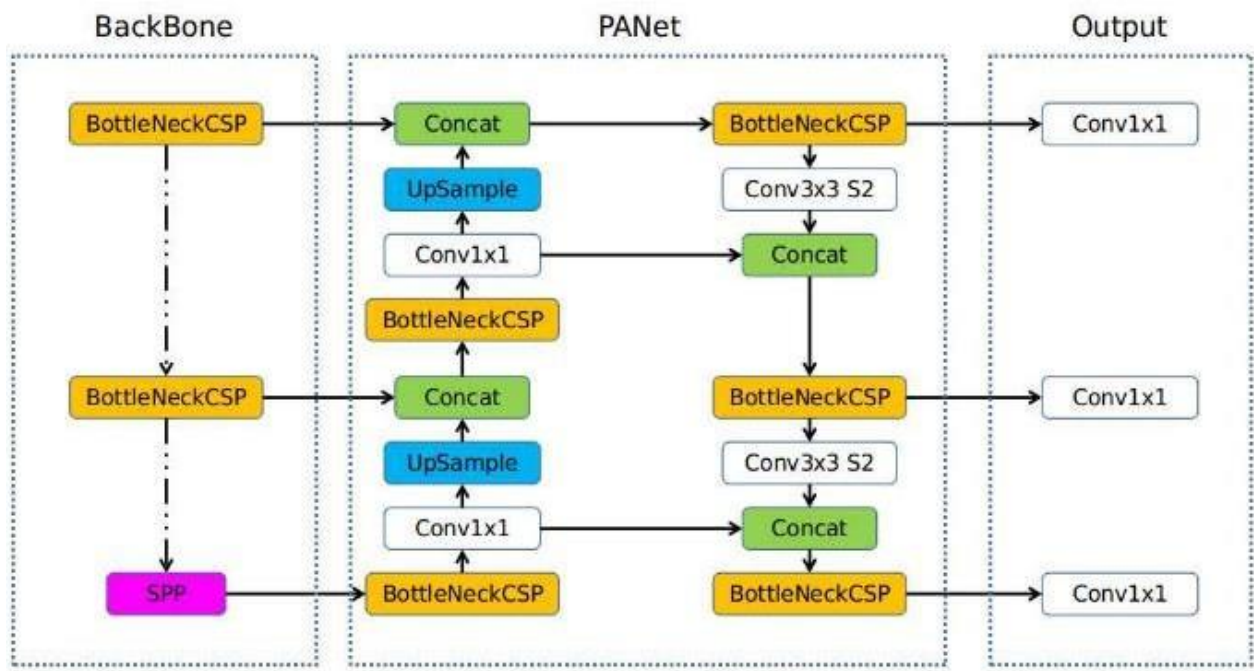


Fig. 2. The overview of YOLOv5. [26].



Data Annotation and Model Training with Roboflow, has been extensively used for data annotation and model training in various computer vision projects. In a study by L. Chen et al., Roboflow was employed to annotate images and train a YOLOv5 model for traffic sign detection [37]. The researchers leveraged the capabilities of Roboflow to generate accurate bounding box annotations, resulting in an exact and efficient traffic sign detection system. Additionally, a study by M. Rodriguez et al. utilized Roboflow for annotating medical images and training a YOLOv5-based model to detect abnormalities in lung X-rays [38]. These examples demonstrate the successful integration of Roboflow in diverse applications, emphasizing its role in facilitating data annotation and model training pipelines and in medical one of its standard applications, is detecting the Lung nodule using YOLO5 [39].

**Object Detection in Unconstrained Environments:** Object detection in unconstrained environments has been a challenging task. Previous work has leveraged YOLOv5 and Roboflow to address this challenge. In a study, YOLOv5 was used for Outdoor Navigation System for Visually Impaired People [40], [41]. Combining YOLOv5's real-time detection capabilities and Roboflow's efficient data annotation and model training workflow enabled accurate and timely object detection in dynamic environments. This work demonstrates the potential of using YOLOv5 and Roboflow in real-world scenarios with complex backgrounds and varying lighting conditions.

**Object Detection for Robotics Applications:** YOLOv5 and Roboflow have also found applications in robotics. In a research project by A. Kumar et al., YOLOv5 and Roboflow were employed for object detection in an autonomous drone system [42]. The combination of YOLOv5's fast inference speed and Roboflow's annotation capabilities allowed the drone to detect and track objects in real time, enabling autonomous navigation and interaction with the environment. This study showcases the integration of YOLOv5 and Roboflow in robotics applications, highlighting their potential for enhancing situational awareness and decision-making capabilities. These examples demonstrate the successful utilization of YOLOv5 and Roboflow in various domains, including aerial monitoring, surveillance, unconstrained environments, and robotics. The combination of YOLOv5's real-time object detection capabilities and Roboflow's annotation and model training platform has proven effective in achieving accurate and efficient object detection systems. With the improvement of the YOLOv5 framework, YOLOv6 has been developed for which a customized quantization method is introduced. The latest version of YOLOv6s demonstrates improved mean Average Precision (MAP) compared to all previous iterations of YOLOv5. Additionally, it achieves approximately twice the inference speed [43]. Roboflow for annotation and data management has streamlined the preprocessing stage, ensuring the availability of adequately labeled training data for training object detection system. This has significantly contributed to the development process by expediting the annotation process and allowing more focus on the algorithmic aspects of the system. Furthermore, keeping up-to-date with the latest research papers in the field of object detection, including YOLOv7 [44], [55].

**Deep Learning-based Object Detection:** Deep learning has revolutionized the field of computer vision, enabling highly accurate object detection. The seminal work by R. Girshick et al. introduced the R-CNN (Region-based Convolutional Neural Networks) framework [45], laying the foundation for subsequent advancements. Numerous variants, such as Fast R-CNN [46], Faster R-CNN [47], and Mask R-CNN [48], have been proposed to improve detection accuracy and processing speed. These methods have significantly influenced the development of stick-based object detection system. **Single-Shot Object Detection:** Single-shot object detection algorithms have gained popularity due to their real-time processing capabilities. Among them, YOLO family of models [49] has achieved remarkable performance. YOLO models detect objects in a single pass through the Neural Network, making them suitable for resource-constrained environments. It can be observed from literature that YOLO effectively used for object detection.

**Mobile object detection** aims to enable object detection on mobile devices with limited computational resources. MobileNet [50], is a lightweight deep neural network architecture specifically designed for mobile applications. Its efficient design and small memory footprint make it ideal for real-time object detection on low-power devices. The concepts underlying MobileNet have influenced the development of stick-based object detection system. Contextual object detection methods utilize contextual information to improve detection accuracy. Context R-CNN [51] incorporates context reasoning into the detection pipeline, leveraging the relationship between objects and their surrounding context. Stick-based object detection system also considers contextual cues to enhance object identification and classification.

**Focal Loss for Dense Object Detection:** They claim that the main barrier stopping one-stage object detectors from outperforming top-performing, two-stage techniques, including Faster R-CNN versions, is class imbalance. They developed the focused loss, which adds a modulating term to the cross-entropy loss, to focus learning on challenging examples and de-weight the many obvious negatives [52] and PointRCNN [53]. These methods leverage multi-scale feature MAPs and anchor-based strategies to improve detection performance in challenging scenarios. Stick-based object detection system integrates similar strategies to handle unconstrained environments effectively.

**Sensor-Based Object Detection:** Object detection approaches based on sensors use data captured by diverse sensors, including LiDAR, radar, and cameras, to identify and track objects. LiDAR-based methods, such as Point RCNN [54] and PIXOR [55], leverage 3D point cloud data for accurate object localization. Although primarily based on visual information, stick-based object detection systems can benefit from incorporating sensor fusion techniques to enhance detection accuracy.

### III. METHODOLOGY

The methodology below explains the object detection process using the base model as YOLOv5. Fig. 3 depicted the block diagram of object detection procedure.

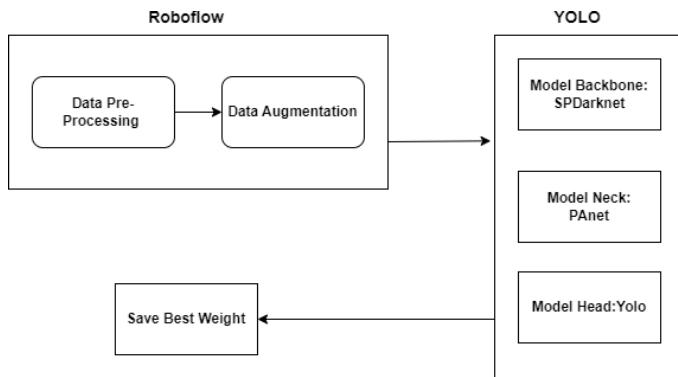


Fig. 3. Block diagram of object detection system.

#### A. Preprocessing

Roboflow has been used for Data preprocessing and data augmentation.

- It provides a platform for better data collection, pre-processing, and model training techniques.
- It can handle a variety of different annotation formats.
- The pre-processing of data includes resizing, image orientations, contrasting, and data augmentations.
- There are choices for model deployment and visualization, spanning the whole state-of-the-art.

1) *Noise*: Adding noise to a hazy photograph might help it to stand out. The picture seems to be made up of white and black dots when "salt and pepper noise" is applied.

2) *Crop*: An area of the image is picked, cropped, and resized to its original size.

3) *Flip*: Horizontally and vertically; the picture is flipped: The pixels are rearranged while the picture's characteristics are preserved when the image is flipped.

4) *Rotation*: The picture is rotated by a degree ranging from 0 to 360 degrees. Each rotated image will be different in the model. Each rotated image will be different in the model. The picture's brightness changes, resulting in a darker or brighter image. This technique allows the model to recognize photos in various illumination situations.

5) *Blur*: The image quality will vary because photographs come from various sources. Some images will be of outstanding quality, while others will undoubtedly be of terrible quality. In these circumstances, blur the original photographs, making model more resistant to the image quality used in the test data.

6) *Shear*: Shearing is rotating an image along a central axis to add or remove discriminating points. Typically, it is used to magnify images so that computers may understand how different viewpoints affect how things are perceived.

7) *Bounding boxes*: Bounding boxes are rectangles defining the boundaries of photograph items. Bounding boxes can be annotated in a variety of ways. The bounding box coordinates are represented differently in each format [22].

8) *Exposure*: Exposure refers to the quantity of light that

reaches your camera's sensor over some time, resulting in visual data. It could be a second or several hours.

9) *Model Utilized*: Three main vital parts of YOLOv5 are as follows:

a) *Model Backbone*: Model Backbone's primary goal is to extract essential features from an image. In YOLOv5, the CSPNet [23] backbone is used to extract a wealth of valuable characteristics from an input image.

b) *Model Neck*: Model Neck is preferable while developing feature strategies. Models can generalize their object marking and scaling using feature extractions. Recognizing the same object in various scales, marks, and shapes is helpful. The neck in YOLOv5 uses PANet to build feature pyramids.

c) *Model Head*: In YOLO, the detection process incorporates the Head component of the model, responsible for the final stage. Following the application of anchor boxes to the extracted features, the Head component further contributes to the detection process. Generated output vectors represent the final results of the detection process. The heads of the YOLOv5 models follow a similar structure to those found in the v3 and v4 versions. YOLOv4 is the superior architecture from this perspective. It's worth mentioning that YOLOv4 is trained in the Ultralytics YOLOv3 repository (rather than the Darknet), which includes most of the training changes in the YOLOv5 repository, resulting in MAP increases.

YOLOv5 has notably impacted by transitioning the Darknet research framework to the PyTorch framework. The Darknet framework, predominantly coded in C, offers meticulous control over the network's operations. Developed in the C language, Darknet grants extensive control over network activities. This low-level control is beneficial for research in several aspects. However, incorporating new research findings becomes more challenging as each addition requires custom gradient computations [24].

#### B. Data Augmentation Approach

While training the batch YOLOv5 use a data loader that helps add data online with each set. Data loader performs scaling, mosaic augmentation, and color space. Mosaic data augmentation, for example, mixes four photos into four random-ratio tiles. Mosaic augmentation allows the model to learn to deal with "small object problems" in which the smaller items are not detected correctly compared to more significant objects. Thus, it is an effective method for object detection identification benchmark. It's not worth experimenting with the set of augmentations to maximize performance on a specific work that is wrathful. Pre-trained models abound in YOLOv5. The trade-off between model size and inference time separates them. The received picture is first run through the YOLOv5 algorithm. The real-time snapshot in this study is partitioned into matrix grids. The image may be divided into any number of grids as the image complexity changes. After the photos have been divided, each grid holding the item undergoes classification and localization. All of the grids are given a confidence score. Depending on whether the item is spotted or not, the confidence score and the bounding box for each grid will alter. Training techniques are just as crucial as the final performance of an

object detection system while being less talked about. Data augmentation alters the base training data to expose the model to more semantic variance than the training set alone.

#### IV. EXPERIMENTAL WORK

The procedure for the experiment began with the collection of data, followed by the training of the YOLO network, and finally the testing of the output with test photos. The network was designed to detect 106 class labels and performed annotations [27] of all the images of data. A sample dataset of multi-object detection and category-wise objects in the available dataset are shown in Fig. 4 and 5, respectively.

In the dataset, augmentation is performed and improved model performance which helped to increase the size and help to generalize the model. A function is lost. IOU is a popular target detection index. It is utilized to assess the positive and negative samples and, in most anchor, -based approaches to calculate the distance between the expected and actual locations.

The research paper introduces a proposed regression positioning loss, which considers multiple factors including

overlapping, area, center point distance, and aspect ratio. These factors play a vital role in calculating the loss for regression positioning and are deemed crucial in the proposed approach.

1) *Network output analysis:* The output must be viewed as a feature MAP or a vector onto which the features are being Mapped. If  $N$  = no of bounding boxes and  $C$  = no of classes the detector can detect, these  $N$  bounding boxes detect various objects. Fig. 6 graphs are the training loss and validation loss graphs auto-generated by Roboflow software. These graphs show the change in the loss function over training epochs or iterations. The training loss graph displays the loss on the training data, while the validation loss graph shows the loss on a separate validation dataset. These graphs help monitor the model's learning progress and identify potential overfitting or under fitting. Fig. 7 shows results obtained. Table I displays the accuracy percentages obtained for various class labels. It is evident that the swivel chair achieves the highest accuracy, while the class label exhibits the lowest accuracy when compared to the other class labels.

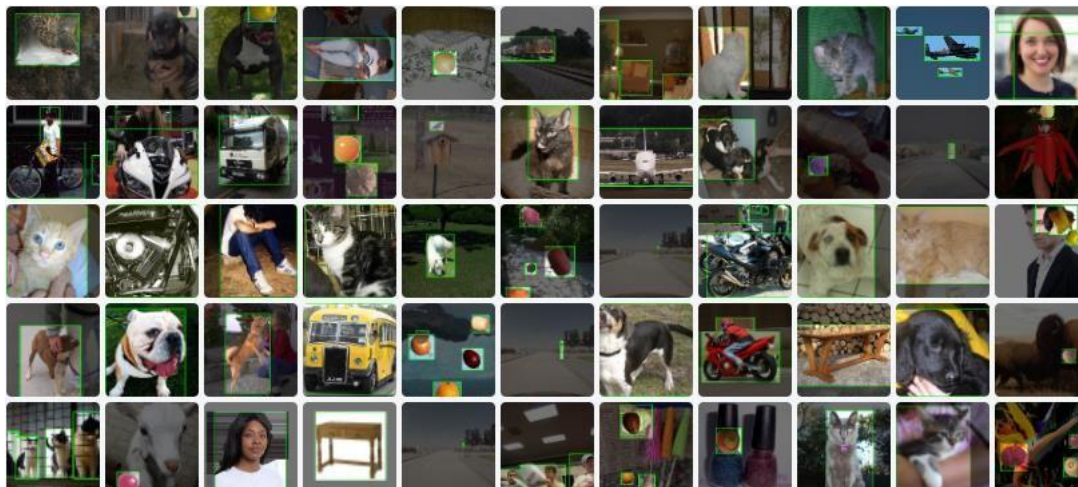


Fig. 4. Sample dataset of multi-object detection.

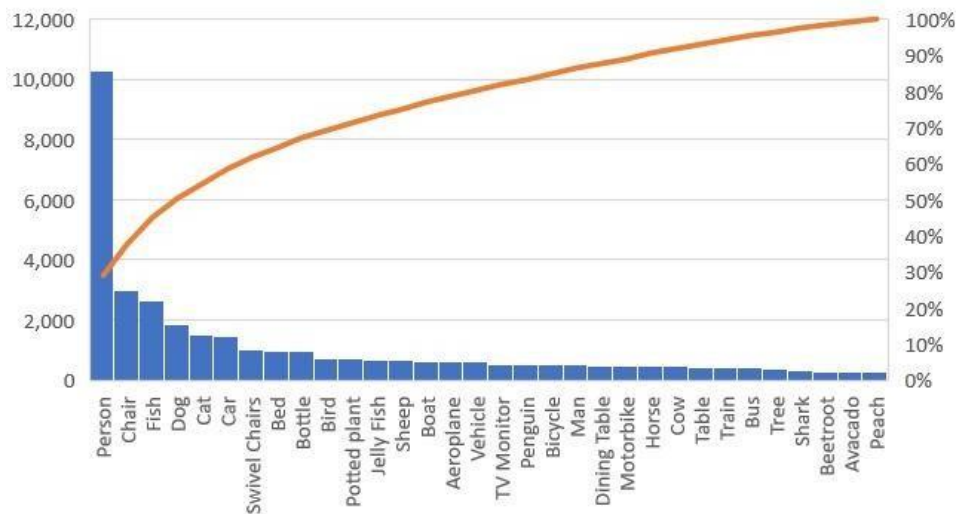


Fig. 5. Category-wise objects in the dataset.

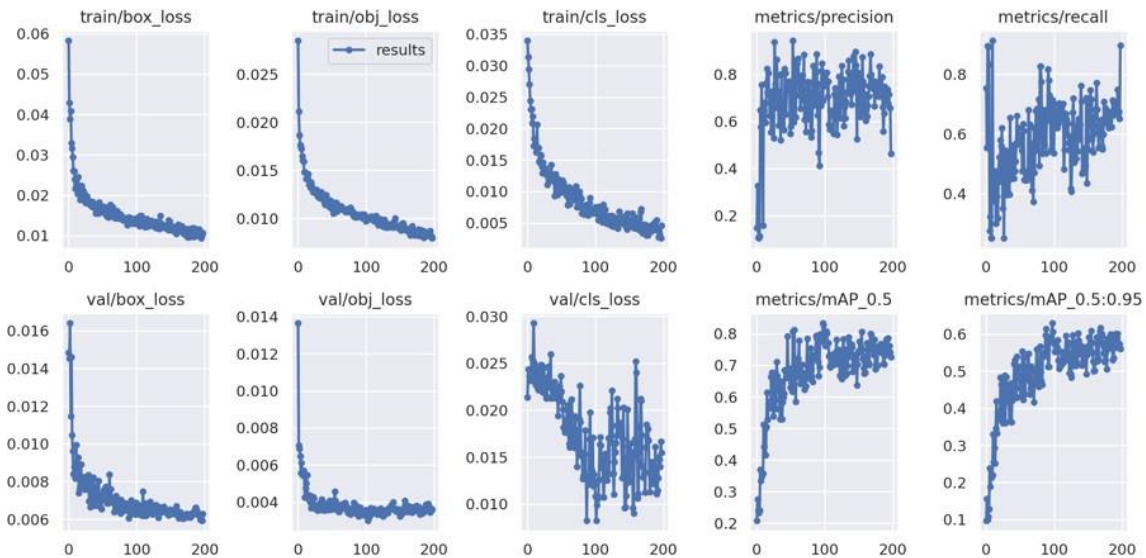


Fig. 6. Graph of performance parameter.

TABLE I. ACCURACIES OBTAINED FOR OUR DATASET CLASS LABELS

Class Labels	Accuracies
Swivel Chair	98%
Bed	95.3%
Cat	83.8%
Ambulance	79.2%
Man	76.5%
Dog	76.1%
Bus	74.2%

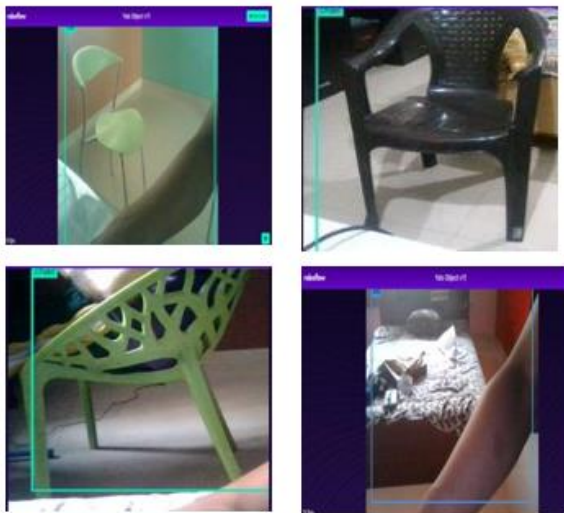


Fig. 7. Obtained results.

The existing research work on the comparisons of the object detection algorithm have been reviewed and presented. The comparison of various YOLO models and their accuracies is presented in Fig. 9. The test time is reduced by 15.6% compared to YOLOv3 due to YOLOv4's various improvements, which lead to the best detection results, as demonstrated above. Despite having fewer training

parameters than the YOLOv3-tiny model, the YOLOv4-tiny model's detection results are nonetheless accurate, are subpar. The detection effect is the worst of the models, only achieving 50.06%. The SPP module causes the YOLOv3-SPP3 model's performance to be slightly better than the YOLOv3 but noticeably worse than the YOLOv4. Fig. 8 depicts the YOLO classification loss, the loss compares the predicted class probabilities with the ground truth labels for each object in the image, the loss is being compared between YOLO and Faster R-CNN. Faster R-CNN is better than YOLOv5 in terms of accuracy with approximately 10 times higher inference rate [29]. This optimization occurs by utilizing backpropagation and gradient descent techniques to update the network parameters. To achieve optimal performance, the weights assigned to each loss component can be adjusted to balance their contributions within the overall loss function. Comparative analysis of various YOLO versions for rural road, urban road, and highways image dataset of sample size 120000, 124000, 150000 respectively [30] the Yolov3 has good precession with bad recall and F measure, and with low mAP, FPS. On the other hand, YOLOv4 and YOLOv5 have stable scores in terms of precision and MAP. YOLOv5 outperforms in terms of speed of the algorithm, and precision as compared to YOLOv3, and YOLOv4 [30]. The comparative analysis of YOLO versions for urban road dataset is provided in Fig. 9.

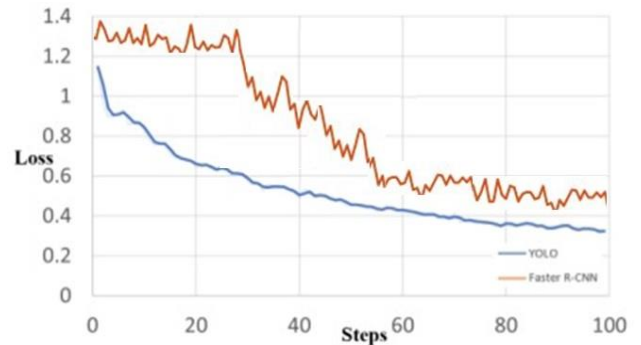


Fig. 8. YOLO classification loss.



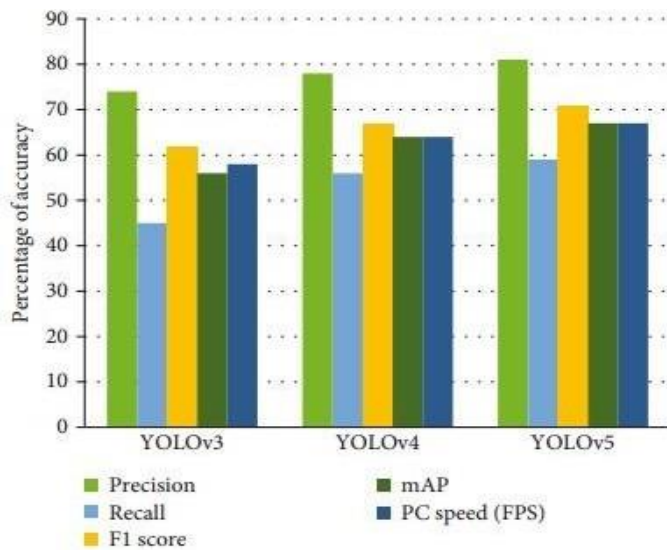


Fig. 9. Comparative analysis of YOLO versions.

In 2021 YOLO series was extended by introducing Yolox [32]. The series continues and the above of the mentioned models were created. Each model in the table above underwent 300 iterations of training. With the help of the ultralytics library's autobatch function, the micro groups' sizes were calculated. The YOLOv5s model's training took the least time. YOLOv5x training took the longest, lasting approximately nine hours, and was completed in under an hour. A comparative study of YOLOv5 is presented in Table II.

TABLE II. COMPARATIVE STUDY OF YOLOV5 VERSIONS DURING THE TESTING

Models	MAP	FPS	Parameters (M)	Test Time(s)
YOLOv3	76.55	35	61.5	122.23
YOLOv3-tiny	62.5	134	8.7	28.14
YOLOv3-SPP3	76.87	40	63.9	128.19
YOLOv4	87.48	72	27.6	103.86
YOLOv4-tiny	50.06	252	7.2	18.41

## V. CONCLUSION

In this study object detection algorithms and systems are analyzed based on their accuracy and the speed of detecting objects. It also observed that the accuracy and speed of object detection algorithms are improving daily. Fast R-CNN is an enhanced version of R-CNN that incorporates a selective search for generating Regions of Interest. In contrast, Faster R-CNN utilizes a Regional Proposal Network (RPN), contributing to its superior performance compared to Fast R-CNN. But the Faster R-CNN algorithm required many passes to extract all the objects from the single frame; this is where Single Shot Detector (SSD) came into the picture. Till the time when YOLO was not developed SSD was considered to be the best. YOLOv5 was designed in such a way that it can detect small objects also, especially in autonomous vehicles. Additionally, leveraging Roboflow for annotation and data management has streamlined the preprocessing stage, ensuring the availability of adequately

labeled training data for training object detection system. In a nutshell, YOLOv5 is a faster, more scalable, and lighter model compared to other competitors. In future work, it is very useful in IOT, or mobile-based detection, like objecting detecting sticks for blind people, sign language detectors, etc. YOLOv7 is a faster, but heavier model, hence can be used in robotics, satellite imaging, and other related things.

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# Enhancing IoT Security with Deep Stack Encoder using Various Optimizers for Botnet Attack Prediction

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**Abstract**—The Internet of Things (IoT) connects different sensors, devices, applications, databases, services, and people, bringing improvements to various aspects of our lives, such as cities, agriculture, finance, and healthcare. However, guaranteeing the safety and confidentiality of IoT data which has become rich in its quality requires careful preparation and awareness. Machine learning techniques are used to predict different types of cyber-attacks, including denial of service (DoS), botnet attacks, malicious operations, unauthorized control, data probing, surveillance, scanning, and incorrect setups. In this study, for improving security of IoT data, a method called Deep Stack Encoder Neural Network to predict botnet attacks by using N-BaIoT bench mark dataset is employed. In this study a new framework is introduced which will improve the performance of prediction rate to 94.5%. To evaluate the performance of this method assessment criteria are adopted like accuracy, precision, recall, and F1 score, comparing it with other models. From the optimizers of Adam, Adagrad and Adadelta, Adam optimizer gave the highest accuracy with relu activation function.

**Keywords**—Internet of things; botnet attacks; neural network methods; N-BaIoT; deep stack encoder; Adam optimizer; Adagrad optimizer; Adadelta optimizer; activation function

## I. INTRODUCTION

The Internet of Things is developed by wireless sensor networks. Through the Internet of Things, people can connect the physical world with the online world. With the rapid development of integrated circuit technology and wireless communication technology, engineers have been able to create IoT nodes that are very inexpensive and have both signal acquisition, data processing, and wireless communication capabilities [1].

The Internet of Things (IoT) is a network that connects assorted devices to the web through a definite protocol, facilitating data sharing, intelligent identification, tracking, placement, management, and monitoring. While the traditional perception of IoT revolves around a network of physical objects, the internet now encompasses a wide range of devices, including household appliances, smartphones, vehicles, toys, cameras, medical devices, advanced frameworks, individuals, animals, and buildings. These interconnected devices communicate and exchange data according to predetermined protocols.

The IoT's use in the industrial sector is supposed to increase output, efficiency, and security of industrial

processes, according to the industry 4.0 vision. In essence, the IoT refers primarily to the effective application of the IoT in industrial operations. The architecture of the IoT can be summed up in four layers. In the industrial sector, the Internet of Things (IoT) architecture comprises of multiple layers: physical, network, middleware, and application. The physical layer encompasses various physical equipment, sensors, mobile and computer devices, as well as other monitoring and automated devices. The network layer encompasses diverse communication networks such as machine-to-machine interfaces, cellular networks, and wireless sensor networks. The middleware layer includes cloud storage, application programming interfaces (APIs), and web services, which facilitate communication between the network layer and the application layer. Finally, at the topmost layer, the application layer enables a wide range of industrial processes and services, including robots, smart factories, smart buildings, smart healthcare, smart vehicles, and more.

IoT systems are made up of interconnected computing devices that can be mechanical, electronic, or any other type of object. For Internet of Things (IoT) systems, it is essential that each device has a unique identifier and the capability to transmit data above a network without relying on human-to-human or human-to-computer interaction. To connect with multiple devices or objects, IoT systems utilize distinctive network address schemes. Unfortunately, a significant number of IoT devices connected to the Internet lack sufficient security measures due to resource constraints, rendering them susceptible to cyberattacks. Yet, the majority of IoT systems run independently across unreliable network connections and the Internet, which exposes the network to cyberattacks. Security concerns need to be resolved as soon as possible given network attacks and cyber threats vs. the bright future of IoT systems.

An IoT network's, Network Intrusion Detection System (NIDS) keeps track of all internet traffic passing through the devices. It acts as a protective barrier that can identify threats and safeguard the network against unauthorized users and malicious attacks. The main defense against network intrusion and other threats in modern computer networks is NIDS. IoT devices are constrained by their physical counterparts' energy consumption, memory capacity, and computational power. Hence, it is nearly difficult to utilize conventional signature-based intrusion detection systems on these devices. Large datasets are frequently needed for signature-based NIDS in

order to build reliable detection systems for IoT. The resources of IoT devices must be taken into account when restructuring traditional signature-based NIDS.

In any communication network, the IoT is exposed to various kinds of vulnerabilities and security threats. In particular, security is a critical challenge for the IoT development, as it constitutes an extended version of the conventional unsecured Internet model and combines multiple technologies such as Wireless Sensor Networks (WSNs), optics networks, mobile broadband, and 2G/3G communication networks. Each of the aforementioned technologies is prone to various security risks.[2].

It is anticipated that IoT applications and technologies would advance beyond anything that is conceivable. Unfortunately, IoT technology development is still in its infancy and has not reached its full security protection maturity. IoT software developers' update management issues and non-uniform manufacturing standards are two security challenges faced by IoT systems. Critical challenges include the physical management of security concerns and users' ignorance as a result of their ignorance of security issues related to IoT devices. The network and surroundings of IoT systems must also be protected, in addition to using encryption techniques to secure data transmission.

However, the nature of the resource limitations prevents the use of conventional network security mechanisms in IoT systems. Due to the IoT system applications' quick development and widespread adoption, several network attacks have also surfaced. The number of assaults will increase as IoT use cases develop. Being aware of the substantial increase in cyber-threats within the IoT system significantly mitigates the probability of network security breaches and data compromises.

Some examples of the most prevalent attacks launched against IoT systems include:

#### A. Denial of Service (DoS)

Due to enormous cyberattacks IoT systems or network resources become unreachable to the intended authorized users. The purpose of these attacks is to temporarily or permanently interrupt the services provided by a host IoT system.

#### B. Distributed Denial-of-Service (DDoS)

A distributed DDoS attack is a malicious network attack that interrupts systematic traffic and network services. It involves overwhelming the target or neighboring infrastructure with a disproportionate volume of network traffic. DDoS attacks are effective when attackers exploit various compromised systems to produce a huge volume of traffic in the network. IoT systems or other devices which are the part of the network can also be targeted with these attacks.

#### C. Marai Botnet Attack

Cybercriminals employ the software known as Mirai to turn networked devices into remotely controlled robots in a catholic scale network as a part of botnet. It primarily targets internet consumer electronics, including IP cameras and

routers for the house. Mirai was frequently used as an initiator in attacks like DoS/DDoS.

#### D. Sybil Attack

Peer-to-peer networks are susceptible to Sybil attacks. A Sybil attack alters the identity of the IoT device to generate numerous anonymous identities and use an excessive amount of power. It was given that name in honor of Sybil, who wrote the book Sybil, in which a lady coping with dissociative identity disorder. An IoT device in a network that uses several identities frequently compromises reputation systems' allowed network access. Attacks using Sybil take use of this vulnerability in the IoT system network to launch initial attacks.

Since 2007 AI-based threats have been arisen as a significant trouble to the Internet of Things (IoT). These attacks, driven by artificial intelligence, present a greater danger compared to traditional human-focused attacks. Cybercriminals now leverage AI-powered tools that are faster, scalable, and more efficient, posing a serious challenge to the IoT ecosystem. The nature of AI-based assaults, with their increased volume, automation, and customization, makes them difficult to counter, despite sharing certain characteristics and strategies with traditional IoT hazards.

Further down, reader can see the literature survey which talks about the previous works and findings, followed by the proposed work and methodology, which covers about the information regarding the dataset, clean up and pre-processing techniques of the data, modules and tools used in the proposed work and libraries used for implementation of the proposed work, in succession there are algorithm which explains the detailed flow of the project from pre-processing to results and system architecture explaining the structure of the proposed work.

## II. LITERATURE REVIEW

The proliferation of the Internet of Things (IoT) has observed significant progress, making it vulnerable to cyberattacks targeting IoT devices. Safeguarding these devices to give security has become a crucial priority in order to mitigate potential risks. Among the various types of attacks, botnet attacks pose a severe and pervasive threat to IoT devices. One vulnerability lies in stationary IoT devices, as they often lack the necessary memory and computational capacity required for robust security measures. Moreover, several current systems are dedicated to enhancing security by identifying unfamiliar patterns within IoT networks [3].

The fundamental concept behind the Internet of Things (IoT) is to unite smart devices to the web, enabling seamless communication between physical objects and various entities like servers and mobile devices. The IoT has made its way into every sphere of life, spanning homes, industries, healthcare, automotive, and sensors. Consequently, the proliferation of vulnerabilities within IoT security poses severe risks to user safety and property [4].

The Internet of Things (IoT) industry flourishes; it has a significant rise in the diversity and abundance of IoT devices. These devices find widespread application in areas such as

smart homes, wearable technology, manufacturing, automotive, and healthcare, and other domains related to daily life. However, this rapid expansion also leads to a continuous emergence of security vulnerabilities in IoT devices. The escalating number of security vulnerabilities poses substantial risks to the privacy and property of users [5].

We have in-depth analysis of detection and prevention methodologies for various security attacks aimed at IoT systems. It is specifically aimed at software developers, researchers, and professionals working in the field of Internet of Things, who desire a comprehensive understanding of the strategies employed to detect and mitigate these attacks. Each item in the list is accompanied by a concise description and references that readers can refer for more detailed information [6].

The Industrial Internet of Things (IIoT) encompasses a wide range of elements, including sensors, machinery, industrial applications, databases, services, and workforce, which collectively contribute to various aspects of lives such as smarter cities, agriculture, and e-healthcare. While IIoT and consumer IoT share certain similarities, distinct cybersecurity measures are implemented for each network. Unlike consumer IoT, which is typically utilized by individual users for specific purposes, IIoT solutions are often integrated into larger operational systems. [7].

IoT-enabled devices have found applications in both industrial and commercial sectors, offering businesses a competitive edge over their rivals. However, the widespread use of interconnected smart devices has led to heightened concerns regarding privacy and data breaches. These concerns have disrupted workflow, activities, and network services within enterprises. To safeguard their organizational assets and ensure uninterrupted services, professionals must proactively address these risks by implementing comprehensive security protocols and policies [8].

One area that has received limited attention in previous literature is the vulnerability of routing protocol for low power and lossy networks to attacks. To address this issue, the author of this study proposed an artificial neural network (ANN) model for detecting decreasing rank attacks. The results showcased an impressive accuracy rate exceeding 97% and demonstrated strong performance across various tests conducted on the held-out testing dataset. These findings indicate the model's efficacy in terms of accuracy, precision, detection probabilities, false-positive rate, false-negative rate, and other relevant metrics [9].

The scientific community has shown considerable interest in the Internet of Things (IoT). The potential compromise of these devices by malicious individuals not only jeopardizes privacy but also poses significant risks to critical assets. Consequently, the detection and prevention of unique attacks within the IoT ecosystem are of utmost importance. In this study, the author introduces a novel threat detection system that integrates development and operations frameworks. In the initial phase, data from each application is processed by incorporating statistical and higher-order statistical features alongside the existing ones [10].

The integration of the Internet into corporate processes through IoT platforms becomes more prevalent, the need for stable and efficient connections becomes increasingly important. The authors of the article introduce a comprehensive automated intrusion detection system that focuses on enhancing Fog security and addressing cyber-attacks. The proposed model utilizes multi-layered recurrent neural networks that are specifically designed for deployment in Fog computing environments, which are situated in close proximity to end-users and IoT devices. Given that intrusion detection systems are among the key remedies employed for IoT security, it is common to adopt multiple strategies simultaneously. RNN and other neural networks can be effectively employed to analyze data and provide protection against cyber threats, offering layered defense mechanisms [11].

Employing machine learning within an IoT gateway helps protect the system in order to address the issues of securing IoT devices. They examine the use of Artificial Neural Networks in a gateway to detect anomalies in data transmitted from edge devices and are persuaded that this method can improve IoT system security. Security has been regarded as one of the weaker aspects in IoT during its growth. There are various hurdles to implementing security inside an IoT network, including system heterogeneity and the sheer number of devices that must be addressed [12].

All information processing systems now include a fundamental component for the detection of cyberattacks, and once an attack is identified, it might be possible to stop it or lessen its effects. In this study, the focus is on developing a straightforward detector to identify specific Botnet attacks on IoT systems. The proposed approach involves utilizing a learning recurrent random neural network (RNN), which offers advantages in terms of its compact 12-neuron recurrent architecture and low computational requirements, making it well-suited for edge devices. The RNN is trained offline using a simplified gradient descent technique, resulting in high detection rates of approximately 96% while maintaining minimal false alarm rates [13].

Security plays a critical role in nearly implemented or ongoing IoT applications. The widespread adoption of IoT is rapidly expanding and infiltrating various industries. While current networking technologies offer support for many IoT applications, certain applications demand more robust security measures from the underlying technologies they rely on. Looking ahead, IoT devices will not only be connected to the internet and local devices but will also have the capability to directly communicate with other devices across the internet [14].

The present era is characterized by an extensive deployment of IoT systems that generate vast amounts of data, and the detection of anomalies is a crucial aspect of every such system. These anomalies may indicate resource depletion in an industrial environment, unforeseen issues at an aerospace platform, or unusual performance of medical devices, among others. Hence, the ability to identify anomalies can have any monitoring system's overall performance is significantly impacted. The dataset in this

context includes several forms of threats, such as DoS/DDoS, Botnet, Brute Force, Web Attack, Infiltration, and Port Scan, that could potentially cause an IoT system to fail [15].

The number of Internet-connected devices, such as cameras, embedded machines, sensors, and many others that comprise the IoT, is rapidly increasing. By 2025, as projected by the International Data Corporation (IDC), the number of interconnected IoT devices is estimated to reach 41.6 billion. DL-based security mechanisms are heterogeneity tolerant since they can learn diverse features from unstructured data on their own. They can also be utilized to distinguish novel mutated threats from their older incarnations; thus, the security mechanism does not necessitate a patch on IoT devices on a regular basis [16].

The applications of IoT are expansive and continuously expanding, covering a wide range of areas such as public security, infrastructure development, connected healthcare, smart homes, cities, grids, and wearables. However, with such widespread use comes the risk of various attacks, including those aimed at denying service or taking control of the network. Among these, DDoS attacks pose a significant threat to IoT systems, as they involve many attackers from different locations overwhelming the network. To combat this, the author suggests using SDN and recurrent neural networks for DDoS detection and IoT security [17].

As the usage of IoT devices becomes increasingly widespread, network attacks have grown in frequency and severity. Denial of Service (DoS) and Distributed Denial of Service (DDoS) attacks have emerged as common types of threats targeting IoT networks. Traditional security measures like firewalls and intrusion detection systems are insufficient when it comes to detecting complex DoS and DDoS attacks. This is because they rely on static predefined rules to differentiate between normal and malicious network traffic [18].

The Internet has evolved from being a useful research tool for academic institutions to becoming an essential utility, comparable to gas, water, and electricity. However, as with any valuable resource, there is a risk of crime intended to exploit the technology illegally or to impede others from using it. The interconnectedness of the Internet makes it vulnerable to attacks from anywhere in the world, making cybersecurity a crucial concern. According to the latest survey conducted in 2015, security breaches are increasing [19].

This passage delves into an in-depth exploratory study that examines the obstacles associated with integrating these technologies into a cohesive system. The integration is affected by various challenges including security, scalability, accountability, and issues related to communication trust. The successful and effective integration of these technologies can accelerate the digital transformation of market, companies and the development of new business models [20].

The advent of the Internet of Things (IoT) has transformed the traditional way of living by introducing a sophisticated way of life. IoT has brought about numerous innovations such as smart homes, smart cities, pollution control, energy conservation, smart transportation, and smart industries.

Numerous important studies and research have been carried out to develop technology through IoT [21].

Copious IoT devices are presently available for use, many of which are extensively used in various services and are vulnerable to cyber-attacks. Cyber-attacks targeting IoT devices do not only affect the devices themselves. Since IoT devices are usually connected to other systems and appliances, they become entry points for hackers to gain access to anything connecting them [22].

The Internet of Things (IoT) has given rise to world of limitless opportunities for applications across many facets of society, but it also comes with several difficulties. Security and privacy are two such issues. To address this issue, incorporating security measures into the hardware of IoT devices beyond standard procedures is a potential solution [23]. A few examples of the devices are laptops, cell phones, tablets, washing machines, etc. IOT is a vast network of linked "things." The devices each have a microchip that connects them all. These microchips monitor their environment and report back to both humans and the network. The best feature of IOT is that every physical object may connect with one another and is reachable over the internet. Many devices are linked to the internet as a result of cheap internet access [24].

A method of identifying the neuron's structure and the optimal activation function of stacked autoencoders has been proposed for dimension reduction to minimize mean square error loss. A total of eight different neuronal structures of auto encoders and six activation functions are used to accomplish this. As a result, the optimal structure is 68-50-30-58-60 when viewed from the perspective of the mean squared loss function. As far as computational time and classification metric (97.4%) are concerned, the ELU is with negligible difference in the best activation function. It has been stated in [25] that this study will assist the defenders in selecting the activation method. In [26] it is recommended that activation and loss functions that may be useful to defenders. By using the CICIDS 2017 dataset, the effect of these functions is evaluated with an SVM-RBF classifier.

In [27] a model has been advocated by using semi-supervised Deep Learning, specifically Semi-supervised GAN (SGAN), for detecting botnet attacks on the N-BaIoT benchmark dataset is interesting. It appears that the approach has achieved high accuracy for binary classification (99.89%) and a decent accuracy for multiclass classification (59%). Semi-supervised learning techniques can be useful when labeled data is limited or unavailable. By leveraging both labeled and unlabeled data, semi-supervised models can learn from the available labeled data while utilizing the unlabeled data to improve the model's performance.

### III. PROPOSED WORK

In this work, the main concentration is on increasing the accuracy even for multi class classification by using autoencoders and also by considering confidentiality, availability, integrity, and privacy as they are more specific security needs, which are frequently referred to as security attributes. The technology tries to reduce latency and improve reliability while data is transmitted across the network. In

order to identify attacked data in the IoT context, this system makes use of the reputation model. In this proposed model Adam optimizer and Average subtraction-based optimizer are used which increases accuracy as compared to existing models. To make sure in terms of the security in the Internet of Things, it is crucial to accurately identify the interconnected devices. This involves employing a technology that can automate three key functions related to IoT security, specifically for device identification and discovery. IoT devices on the network are automatically and continuously detected, profiled, and categorized. Also it keeps a running list of the gadgets.

**A. Data-Set Collection**

For this study, the dataset which is used contains 10 lakhs of rows and 115 columns. This dataset was taken from [28]. It has many rows and columns and tried to include all the types of possible botnet attacks. The dataset which is used is N-BaIoT. The N-BaIoT dataset is a state-of-the-art and exceedingly refined assemblage of data that holds the capacity to revolutionize research within the realm of Internet of Things (IoT).

Table I gives brief information about IoT devices which have been used in two different botnet with their model names in the dataset considered. This dataset encompasses an extensive array of sensor readings and significant metrics, delivering a comprehensive and meticulous overview of the condition and conduct of IoT devices in authentic, real-life surroundings. The ongoing study undertakes an exhaustive exploration of the intricate and exceptionally advanced N-BaIoT dataset, encompassing an astonishing 7,062,606 records of network traffic, comprising both malevolent and benign activities.

The Table II depicts different IoT botnets which consists of various types of attacks and have been collected from a simulated organizational context. Last two columns of the specified dataset are the output columns which tells us whether the IOT devices are attacked or not and the category of the attack. The proposed model is checking whether the IOT devices undergone by botnet attacks or not and even specify the type of attack.

The graphs which are depicted for Marai and Bashlite bonnets (Fig. 1 and 2 respectively) consist of various types of attacks in individual botnets. These attacks are harmful as the complete network will be in the control of botmaster, the attacks which have been discussed, occur may be due to the sensitivity of IoT devices in the network [29]. The pursued dataset contains two types of Botnets and each one of it contains five different malwares and number of each has been depicted in the figures.

TABLE I. DEVICES IN N-BAIOT DATASET WITH MODEL NAMES

Types of devices with their model names
Danmini_Doorbell
Ecobee_Thermostat
Ennio_Doorbell
Philips_B120N10_Baby_Monitor
Provision_PT_737E_Security_Camera
Provision_PT_838_Security_Camera
Samsung_SNH_1011_N_Webcam
SimpleHome_XCS7_1002_WHT_Security_Camera
SimpleHome_XCS7_1003_WHT_Security_Camera

TABLE II. DIFFERENT BOTNETS AND TYPES OF ATTACKS IN N-BAIOT DATASET

IoT Botnets	Types of Attacks
Mirai	ACK
	Scan
	Syn
	UCP
	UDP Plain
Bashlite	Combo
	Junk
	Scan
	TCP
	UDP

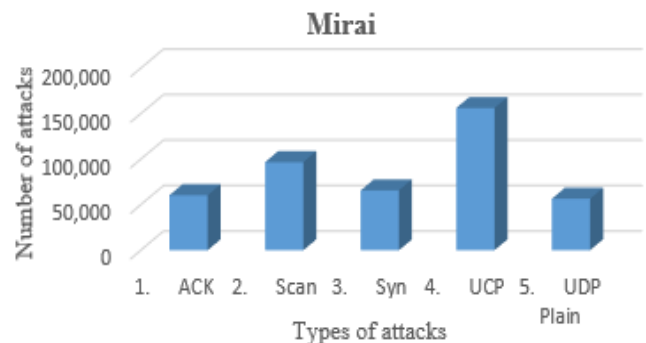


Fig. 1. Distribution of different attacks in Marai botnet.

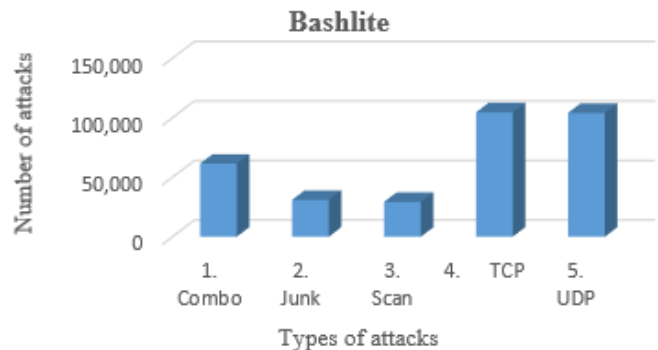


Fig. 2. Distribution of different attacks in Bashlite botnet.

### B. Normalization

Normalization is an adequate preprocessing technique which has various normalization methods as well. The study [30] uses min max normalization for intrusion detection in the network to identify malwares; however Z-score normalization is one good option. Z-score normalization, also known as standardization, is a method used to transform the values of a feature in a dataset to have a mean ( $\mu$ ) of 0 and a standard deviation ( $\sigma$ ) of 1. The transformation is performed while from each value is subtracted from the mean of the feature, and then dividing by the standard deviation. The transformed feature is then referred to as a standard score or a Z-score (eq 1). This normalization method is commonly used in machine learning and data preprocessing to ensure that all features are on a similar scale and to reduce the impact of outliers. Hence, the normalization technique is used to normalize the data given in the dataset and also by standardizing the features, it can also improve the numerical stability and convergence speed of some machine learning algorithms. Comparing to the other normalization techniques named min-max normalization, long scaling and clipping, and BCNF. Z-Score normalization gave highest accuracy.

$$Z - score(X) = \frac{(X-\mu)}{\sigma} \quad (1)$$

### C. Feature Selection using Information Gain

Information gain is a feature selection method used in machine learning to rank the importance of features based on the reduction of entropy in the data. In decision tree learning, information gain is used as a criterion for splitting the data based on the features. The entropy of a set of samples represents the amount of uncertainty or randomness in the data. By selecting features with high information gain, the entropy of the data is reduced, leading to a more predictable and accurate model. The idea is to select features that provide the most information about the target variable, by measuring the reduction in entropy after splitting the data based on each feature. Information gain for feature selection has been used which is a simple and effective feature selection method that can be used in various machine learning algorithms, especially decision trees and decision tree-based ensemble methods. Let  $F$  be the set of selected features then,

$$F = \operatorname{argmax}(\operatorname{InfoGain}(X_i, Y)): X_i \in X \quad (2)$$

### D. Data Processing

For data processing One Hot Encoder is used, which is a data transformation technique used in machine learning and data analysis. The process involves transforming categorical variables into a format that is compatible with machine learning algorithms. In one hot encoding, each unique categorical value in a column is converted into a binary vector of 0s and 1s. For example, if a categorical column has three possible values "A", "B", and "C", the one hot encoding process would convert this column into three binary columns: one for "A", one for "B", and one for "C". If a row had the value "B" in the original column, then the "B" column would have a 1 in that row and the other two columns would have 0s. So for converting strings into numerical values One Hot Encoder was used for machine learning algorithms.

## IV. METHODOLOGY

The architecture represented in the diagram (Fig. 3) is a deep stack encoder, consisting of numerous layers that are arranged on top of each other. This design allows the model to learn hierarchical representations by gradually extracting complex features from the input data. Before feeding the data into the encoder, a feature selection process is performed using information gain. Out of the original 115 features, 58 features are nominated based on their relevance and prominence to the task at hand. This choice helps to reduce the dimensionality of the input and emphasis on the most informative features. To optimize the model's parameters and improve the efficiency of training, different optimizers are employed. Precisely, the optimizers used in this work include Adam, Adagrad, and Adadelata. These optimizers regulate the weights and biases of the model throughout training, with the goal of lessening the loss function and taming the model's performance.

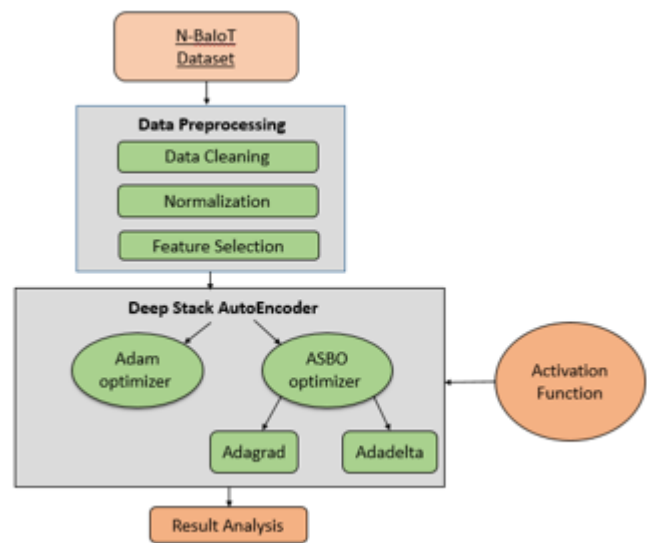


Fig. 3. Workflow diagram of proposed methodology.

The special choice of activation function is one more important factor in the model design. In this case, Rectified Linear Units (ReLU) are used as the activation function for both the input and hidden layers. ReLU activation is known for its ease and effectiveness in supporting the model to learn intricate nonlinear relationships in the data. For the output layer, the softmax activation function is employed which is commonly used in multi-class classification tasks as it converts the output values into a probability distribution over diverse classes, enabling the elucidation of the final predictions. By deploying these design choices, such as feature selection, diverse optimizers, and apposite activation functions, the model targets to attain superior performance and acquire better-quality outcomes for the specified task.

### A. Deep Stack Auto Encoder

Deep Stack Encoder is also known as stacked autoencoders, which are used in unsupervised learning. Stacked autoencoders consist of multiple layers of autoencoder neural networks. An autoencoder is a type of neural network that is trained to encode and then decode input



data, such that the output is as close as possible to the original input. By stacking multiple layers of autoencoders on top of each other, each layer learns to encode the input data in a more abstract and compressed way, with the final output being a low-dimensional representation of the input data. So Deep Stack Auto Encoder is used to encode and then decode the data. The model is having two types of optimizers, Adam Optimizer and Average Subtraction based Optimizer.

### B. Neural Network Using Adam Optimizer

Adam (Adaptive Moment Estimation) is an optimization algorithm widely used for training deep learning models, specifically neural networks. It combines the strengths of two popular optimization algorithms, namely RMSProp and Momentum. The algorithm computes a weighted average of previous gradients and squared gradients to adapt the learning rate on a per-parameter basis, as depicted in equation (2). This capability allows the algorithm to assign different learning rates to individual parameters, resulting in faster convergence and often superior performance compared to other optimization algorithms. The application of the Adam optimizer is done in present study, specifically focusing on two parameters,  $Y_1$  and  $Y_2$ . The present model comprises one input layer, three hidden layers, and one output layer. To utilize the Adam optimizer effectively, Tensor Flow and Keras libraries are imported. Finally, the network is compiled to prepare it for further processing.

$$\theta_t = \theta_{t-1} - \alpha * m_t / (\text{sqrt}(v_t) + \text{epsilon}) \quad (3)$$

where,  $\theta_t$  is the parameter vector,  $\alpha$  is the learning rate,  $m_t$  &  $v_t$  are the first and second momentum updates.

### C. Neural Network using Average Subtraction Based Optimizer

Average subtraction based optimizers are a class of optimization algorithms for training neural networks. They are called average subtraction based because they subtract the moving average of the gradient from the current gradient in order to update the weights. This helps to reduce the variance of the gradient and stabilize the training process.

One of the most well-known average subtraction based optimizers is the Adagrad optimizer. Adagrad updates the learning rate for each weight in the network based on the historical gradient, with a larger learning rate for weights (shown in Eq. 3) with a smaller historical gradient and a smaller learning at optimizer to adapt to the characteristics of each weight and reduces the risk of oscillations or stagnation during training. Another example of average subtraction based optimizers is the Adadelta optimizer, which extends the idea of Adagrad by using the average of the squared gradient instead of the gradient itself. Adadelta also includes a decay factor to reduce the impact of historical gradients over time shown in Eq. 4. Here average subtraction for two parameters  $Y_1$  and  $Y_2$  was done. In this model, there is a input layer, a hidden layers and a output layer. And for this adadelta optimizer TensorFlow, keras were imported.

$$\beta_t = \beta / \text{sqrt}(G_t + \text{epsilon}) \quad (4)$$

where  $\beta_t$  is the initial learning rate, epsilon is a small constant to prevent division by zero and  $G_t$  is the gradient.

$$E[\delta_w]_t = \rho * E[\delta_w]_{t-1} + (1 - \rho) * \delta_w^2 \quad (5)$$

where  $\rho$  is a decay rate that controls the contribution of past gradients to the moving average.

### D. Pandas

It is software package for the Python programming language that is used to manage and evaluate data. It is used in particular for huge calculations or bigger data; it has additionally Numpy in it. To perform operations on data files such as csv, pandas library is used. The `pd.read_csv()` feature is utilized to import and analyse the data stored in a csv file. Additionally, to make accessing data easier, names are given to each column and store them in an index list.

## V. ALGORITHM

Algorithm: Deep Stack Encoder with Feature Selection, Adam, Adagrad, and Adadelta Optimization.

1. Load the dataset (D) and store as matrix X with dimensions (n\_samples, n\_features) and vector Y with dimensions (n\_samples,).
2. Normalize the input features of X using Z-Score normalization.

$$Z - \text{score}(X) = \frac{(X - \mu)}{\sigma}$$

3. Perform feature (F) selection using Information Gain,

$$F = \text{argmax}(\text{InfoGain}(X_i, Y)): X_i \in X$$

4. Build three neural network models using Adam, AdaGrad, and Adadelta optimizers, and store them as  $M_1$ ,  $M_2$ , and  $M_3$  respectively.
5. for  $M_i$  in Models do
6. Train dataset  $D_{train}$  using the selected features F as input features and  $Y_{train}$  as output labels.
7. Predict the output labels for the test dataset  $D_{test}$  using the trained model and the selected features F as input features and store the predicted output labels as  $Y_{pred(i)}$ .
8. Calculate the performance metrics for each model  $M_i$  using the true output labels  $Y_{true}$  and predicted output labels  $Y_{pred}$ .
9. End
10. Output the performance metrics for all three models, METRICS ( $M_1$ ), METRICS ( $M_2$ ), and METRICS ( $M_3$ ).

Once the dataset have been loaded that consists of 115 columns where it is very huge and for which there is a need to decrease the number of columns. This can be achieved through feature selection by selecting top features by adapting information gain. Then normalize the data points by inheriting Z-score normalization and then construct three neural network models  $M_1$ ,  $M_2$  and  $M_3$  with three different optimizers Adam, Adagrad and Adadelta. Split the pre-processed dataset into two major division in ratio of 7:3 for training and testing

respectively and predict the output labels. Finally calculate the efficiencies by considering performance metrics.

### VI. SYSTEM ARCHITECTURE

System architecture is a pictorial depiction of all the components that come at a place to procedure the complete system. The architecture of the model is shown in Fig. 4, which also lists all the plans, tools, processes, and other components. Using the provided data set, leveraging the given dataset, two optimization techniques are employed, namely Adam and average subtraction-based optimizers, to enhance the dataset's performance and determine the accuracy of the model. By utilizing these optimizers, the aim is to fine-tune the dataset and achieve improved results. The proposed approach follows a sequential flow for attack prediction. It begins with the user loading the dataset, followed by data preprocessing to prepare the data for analysis. Feature selection techniques, such as information gain, are applied to identify 58 relevant features from the original set. When a user provides input, such as network logs or suspicious activity patterns, the deployed model processes the data and generates predictions regarding the likelihood or classification of an attack. This approach combines dataset loading, data preprocessing, feature selection, model training, deployment, and user input to expedite accurate attack predictions.

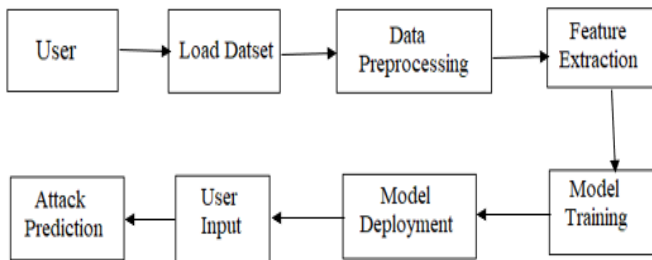


Fig. 4. System architecture.

### VII. EXPERIMENTAL RESULTS

Three different types of optimizers are used in the present neural network models, the results are as follows:

Accuracy, recall, precision, and F1-score metrics were considered to test the system for detection of botnet attacks. The equations are defined as follows:

Accuracy: It is the proportion of correct predictions made by the model out of all predictions. It is usually expressed as a percentage.

$$Accuracy = (TP + TN) / (TP + TN + FP + FN)$$

Where TP: True Positives, TN: True Negatives, FP: False Positives, FN: False Negatives.

Precision: It measures how many of the predicted positive instances are positive. It is a useful metric when the cost of false positives is high.

$$Precision = TP / (TP + FP)$$

Recall: It measures the ability of a model to identify all positive samples correctly. A high recall indicates that the model is good at identifying positive samples, while a low

recall suggests that the model is missing some of the positive samples.

$$Recall = TP / (TP + FN)$$

F1 Score: It is a metric used in binary classification problems, which is the harmonic mean of precision and recall. It takes both precision and recall into account to provide a balanced evaluation of the model's performance.

$$F1\ Score = 2 * (Precision * Recall) / (Precision + Recall)$$

TABLE III. COMPARISON TABLE FOR MODEL EVALUATION WITH MATRICS

	Existing Model	Feed Forward Adam	Adagrad	Adadelta
Accuracy	90.88	94.5	89.9	87.1
Precision	93	96.3	87	84.4
F1 Score	88	96.2	86.3	81.6
Recall	91	97.5	86.5	82.3

In the above table, Table III the performance of an existing model is assessed along with three optimization algorithms, to be precise Adam, Adagrad, and Adadelta, based on accuracy, precision, F1 score and recall metrics. The observation from the comparative study concluded that Adam outstripped the others in terms of accuracy, precision, F1 score and recall. It has been accomplished well with respect to overall performance and to facilitate the rightly classified instances. It is precisely vital to make a note that these results are definite to the considered dataset and may differ according to the type of the data and the job at hand.

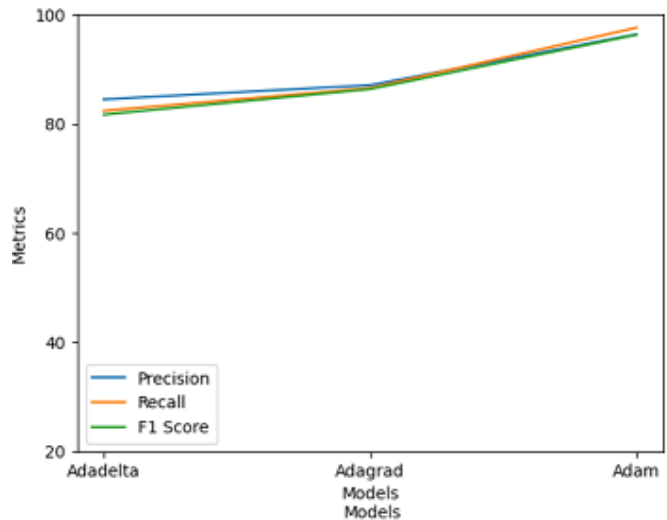


Fig. 5. Comparative graph for precision, recall, f1 score

In credit to adaptive learning rate of Adam optimizer projects higher results where it regulates the learning rate for each parameter during the training session. This adaptive nature guarantees that the model defined converges efficiently without overrunning or getting stuck in local optima. Fig. 5 is the comparative graph which depicts Adam optimizer grander performance in terms of precision, recall, and F1 score when compared to Adagrad and Adadelta.

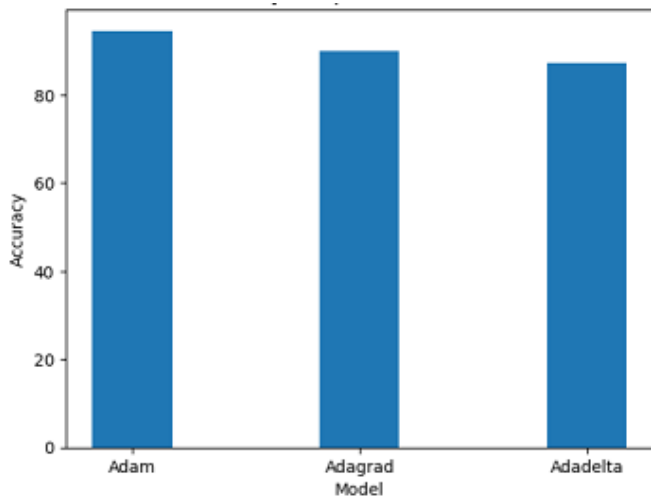


Fig. 6. Comparative graph for accuracy (%).

The major aim of this comparative graph which has been portrayed in Fig. 6 is used to appraise the performance of three optimizers-Adam, Adagrad and Adadelta. The fallouts of the analysis exhibits the Adam optimizer efficiency when compared with other two. The visual graph presented embodies x-axis with optimizer names and y-axis with accuracies with a bar graph. The bar for Adam optimizer stood above all the other optimizers signifying its efficiency.

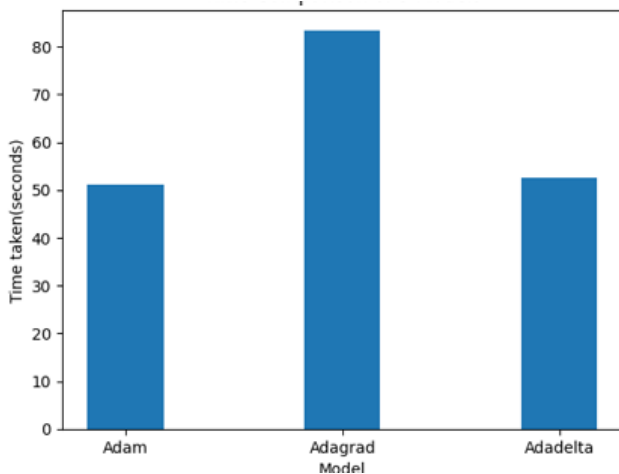


Fig. 7. Comparative graph for time complexity.

The time complexity of a neural network model is influenced by various factors, including the number of layers, the number of neurons in each layer, the type of activation function utilized, the number of training epochs, and the size of the input data. Typically, the time complexity of a neural network model can be expressed as  $O(N^3)$ , where  $N$  represents the number of neurons in the largest layer. The time taken to get the results for Adam, Adagrad, Adadelta are 53.63 sec, 68.52 sec and 65.32 sec (see Fig. 7). When there is a need for quick and superior results, commissioning the Adam optimizer is extremely recommended when it is related with other optimizers mentioned.

## VIII. CONCLUSION AND FUTURE ENHANCEMENT

In this work, the use of different kinds of optimizers named Adam optimizer, average subtraction based optimizer which contains Adagrad optimizer and Adadelta optimizer was done. These are the parts of deep stack encoder. Adam optimizer gave the accuracy of 94.56, Adagrad gave the accuracy of 89.95, and Adadelta gave the accuracy of 87.17. From the experimental results we conclude that Adam optimizer is the most accurate optimizer and less time taking. For future intensifications, we can change the number of hidden layers and number of neurons in input, output and hidden layers to increase accuracy further. As in here, there is only use of one input, one hidden and one output layers. The change in the number of layers can be multiple combinations which will bring significant difference in the results. The number of activation functions can change the future results.

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# Behavior Intention of Chronic Illness Patients in Malaysia to Use IoT-based Healthcare Services

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**Abstract**—The Internet of Things (IoT) has emerged as a trend in the healthcare industry to develop innovative solutions that enhance patient outcomes and operational efficiency. Healthcare has become more accessible, affordable, and efficient to sensors, wearables, and health monitors. The healthcare industry's adoption of the Internet of Things is lagging behind other sectors despite its many benefits. This study aims to investigate the extent to which chronic patients in Malaysia are using healthcare services made possible by the Internet of Things. To that end, this study proposes a unified framework to examine how these highlighted factors affect Behavioral Intention (BI) with regard to adopting IoT healthcare services. The innovation here is in bringing together three distinct theories: i) the Technology-Organization-Environment Framework (TOE), which is a framework for understanding how companies adopt new technologies; ii) the Unified Theory of Acceptance and Use of Technology (UTAUT); and iii) the Social Exchange Theory (SE). Patients in Malaysia who are coping with long-term health issues were surveyed online. This study also employs SPSS and Smart Partial Least Square (Smart PLS) for data analysis. Eleven hypothesized predictive components have been investigated. The results showed that chronic illness patients' BI towards adopting IoT solutions was considerably impacted by both individual and technological factors and related aspects. The impact of BI on Use Behaviour (UB) also showed similar outcomes. Moreover, trust somewhat mediates the impact of both individual and technological factors on BI. The findings of this investigation will be beneficial to policymakers and suppliers of healthcare in that country. Additionally, the patients and their family members would gain benefits from the study due to the fact that the delivery of comprehensive treatment, especially in the field of chronic disease management, will be improved through IoT-healthcare services. The Internet of Things will also let medical staff function remotely and professionally.

**Keywords**—Internet of things; IoT; chronic disease; adoption theories; adoption

## I. INTRODUCTION

Chronic diseases have become one of the most important problems of the twenty-first century. It is considered a very serious global, national, and individual health problem. Globally, in 2019, they were responsible for nearly 42 million deaths (Global Burden of Disease Collaborative Network 2020) [1]. This proportion has increased over time, from 67% of deaths worldwide in 2010 to 74% in 2019 (Global Burden of Disease Collaborative Network 2020). Although the COVID-

19 pandemic led to a considerable number of deaths due to communicable diseases in 2020 (WHO 2020) [1][2] Chronic diseases are generally defined as conditions that last for at least 1 year and require ongoing medical attention or limitation of daily living activities; approximately one in three adults is affected by multiple chronic conditions (MCCs), such as cardiovascular diseases, cancer, and diabetes.[2]. Their social and economic consequences can impact people's quality of life. Chronic conditions are becoming increasingly common and are a priority for action in the health sector [1].

In contrast, healthcare costs have been a significant global concern. The rising costs of healthcare can be attributed to various factors, including an aging population, an increase in chronic diseases, and costly administrative and technology expenses. These issues are being addressed by implementing more efficient healthcare models and investing in new technologies to improve patient outcomes and reduce costs.

In the previous decade, IoT has experienced exponential growth and revolutionized the application of technology in the healthcare industry [1]. It offers cutting-edge technology and services that enable communication between any two Internet-connected objects [2]. The Internet of Things (IoT) is being used by both nations and businesses to boost their competitiveness [2, 3].

No one has been able to agree on a single, comprehensive definition of the IoT. Researchers, however, use the term "Internet of Things" to refer to an online network of physical items [2-4]. The healthcare industry is slow to adopt IoT despite its many advantages [5]. In spite of the growing popularity of IoT healthcare services, there is a lack of data and research on how customers and patients are adapting to these technologies. The absence of information on users' opinions regarding the utilization and implementation of IoT in the healthcare system is notable. [6], Malaysia is no exception, especially for patients with chronic diseases.

The healthcare industry has indeed been slow in adopting IoT technologies, and a lack of a systemic approach could be a contributing factor. Despite ongoing efforts to promote the adoption of IoT in healthcare, other factors such as data privacy and security concerns, as well as the cost of implementing these technologies, remain challenges that need to be addressed [7]. Most current studies in Malaysia and elsewhere ignore the importance of human factors and social context in favor of studying the underlying technology,

components, and services. Regarding the matter at hand, it is important to clarify the definition of service. The term refers to any devices, applications, or services offered by a smart healthcare provider that is related to the diagnosis, monitoring, prevention, or treatment of human disease or the assessment or care of human health. [8]. To achieve successful adoption of IoT healthcare services, it is important to consider the user's perspective [9]. Hence, it is crucial to examine the factors that lead to the low adoption of smart healthcare services from the patients' perspective. Despite the various benefits of this approach, patients have concerns at both individual and technological levels, as outlined below:

1) At the individual level, users may find it challenging to comprehend IoT and may not be aware of its potential benefits for their daily lives [5, 10, 11].

2) At the technological level, patient data sensitivity involves concerns about security and privacy during the collection and transfer of data [12, 13].

Although the Internet of Things is still a relatively new technology, most research on the Internet of Things has been conducted in mature economies, with limited studies in developing and emerging markets. The healthcare sector is one of the many industries that have adopted IoT lately.

Prior studies have proposed several hypotheses to elucidate the reasons behind the low adoption of the Internet of Things (IoT). Understanding these predictors can help improve the explanatory power of IoT models and ultimately address the issue of low adoption [14-16]. Davis's concept, the technology acceptance model (TAM), is one of the most popular in use today. Venkatesh's research has shown that while the Technology Acceptance Model (TAM) can explain a significant portion of the variation in technology acceptance, it has limitations in predicting adoption rates. Venkatesh subsequently developed the Unified Theory of Acceptance and Use of Technology (UTAUT), which expands on TAM and other models to provide a more comprehensive understanding of technology adoption. UTAUT can explain up to 69% of the variance in technology adoption, making it a valuable tool for researchers and practitioners seeking to understand and promote technology adoption [17].

However, UTAUT and other models such as the Technology Acceptance Model (TAM) have been criticized for their emphasis on individual aspects and generalizations in predicting the adoption of new technologies. Nonetheless, these models provide a useful starting point for comprehending technology adoption and can be supplemented with other factors, such as organizational culture, social influence, and technical factors, to develop a more complete comprehension of technology adoption [17].

While individual variables are crucial, the properties of the technology itself, such as its security, privacy, and accessibility, can significantly influence its adoption rates. These factors can make or break the chances of a technology being adopted [17, 18]. Recent research has demonstrated that combining two or more theories can improve the ability to explain technology acceptance [19]. In light of this recommendation, the present investigation synthesizes the

UTAUT, an individual-based paradigm, with the TOE, a multi-perspective framework to identify the factors that encourage Malaysians with chronic diseases to use the Internet of Things (IoT) for their healthcare. The contributions of this study are:

1) Analysis of previous works to determine and investigate the behavior intention of chronic patients toward using IoT healthcare services.

2) Combining the UTAUT, TOE, and Social Exchange Theory to better understand IoT adoption in healthcare services.

3) Structural equation modeling (SEM) is deployed including the Smart Partial Least Square (Smart PLS) as part of the analysis process.

The paper is organized as follows: Section II shows the literature review including the related works. Section III presents the research framework and hypothesis. The methodology is shown in Section IV. All the results are presented and discussed in Section V; Section VI concludes the work, and finally, the limitation and future work are presented in Section VII.

## II. LITERATURE REVIEW

This section provides background on the use of IoT in healthcare and its relevant information. It also presents a theoretical background to show the main focus of previous studies related to IoT in the healthcare sector and discusses existing frameworks and models related to the study in detail. Additionally, a summary of related works is presented, addressing and contrasting them to highlight the gap in existing research that this work is addressing and to show the difference between previous works and this work.

### A. IoT in Healthcare

IoT in healthcare refers to the integration of internet-connected devices and sensors with healthcare systems to gather, monitor, and analyze patient data in real-time [20, 21]. The use of IoT modules in the healthcare sector has led to the emergence of "smart healthcare," which aims to improve patient outcomes and healthcare services through the use of technology. The adoption of IoT is expected to continue to grow in the coming years. Providing quality healthcare at an affordable cost is one of the most pressing societal and economic issues facing many nations today [22]. In some nations, healthcare expenditures are projected to reach 20-30% of GDP by 2050 [23]. Combining devices and technology reduces operating expenses and enhances the quality of healthcare services, making cost savings a key advantage of IoT healthcare innovation [24-26]. In light of the fact that increasing expenses will have a significant impact on patients' quality of life, this is particularly essential [22, 27].

At the moment, IoT is mostly used in healthcare for patient tracking through remote devices, data gathering, instantaneous transfer, and full network accessibility. It also paves the way for machine-to-machine data exchange, interoperability, and the analysis and exchange of crucial information. In the field of medical diagnostics, IoT has been essential as a result of moving the emphasis away from the hospital and onto the patient and their residence.



Consequently, IoT has reduced healthcare system costs and the incidence of risky errors, particularly for patients with disabilities and chronic diseases. [28-30]. According to the National Center for Chronic Disease Prevention and Health Promotion (NCCDPHP), chronic disease refers to a long-term health condition that persists over an extended period, typically lasting for three months or more. These diseases generally do not have a definitive cure and often require ongoing medical management to control symptoms and prevent further complications. They can impact various aspects of a person's life, including physical functioning, mental well-being, and overall quality of life [31].

In the United States, chronic diseases account for a disproportionate share of deaths and disabilities. Hypertension, cardiovascular disease, and diabetes mellitus are all examples of common chronic disorders. Despite the lack of a cure, most chronic diseases can be managed in various ways to lessen the severity of symptoms or slow their course [32]. Chronic illnesses are the leading worldwide cause of mortality and disability [33], so much so that they have been dubbed the "silent global epidemic". As reported by the WHO, diabetes has become one of the primary contributing factors to premature illness and death in many countries, including Malaysia. As shown in Fig. 1, Malaysia's Ministry of Health Malaysia (2019) depicts that Malaysia occupies the first spot in terms of mortality rates among the population aged between 20 and 79 globally.

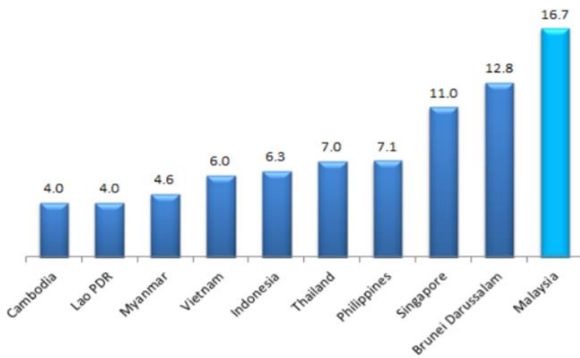


Fig. 1. Rate of death in Asian countries.

Several scholarly investigations have proposed that adopting Internet of Things (IoT) healthcare services could be the solution for improved monitoring and healthcare delivery to patients with chronic illnesses [6, 34, 35]. In this manner, the Internet of Things (IoT) could be used to improve patients' quality of life by reducing the stress placed on their loved ones and hospital visits. In light of this, prior research in Malaysia focused mainly on the development of smart homes, or specific information about Internet of Things deployment in sectors such as healthcare and industry [36-38]. However, it was hypothesized that individual and technological factors were responsible due to the poor rate of adoption of IoT, particularly among those suffering from chronic diseases in Malaysia [33].

### B. Technical Review

A variety of authors have reviewed this topic, with different perspectives on the role that various factors play in enabling IoT in healthcare. Three major categories of factors are

identified and discussed based on their significance to the success of the implementation of IoT in healthcare, such as factors related to the systems, factors related to individuals (end users), and other factors related to infrastructure and environments, as shown in Fig. 2.

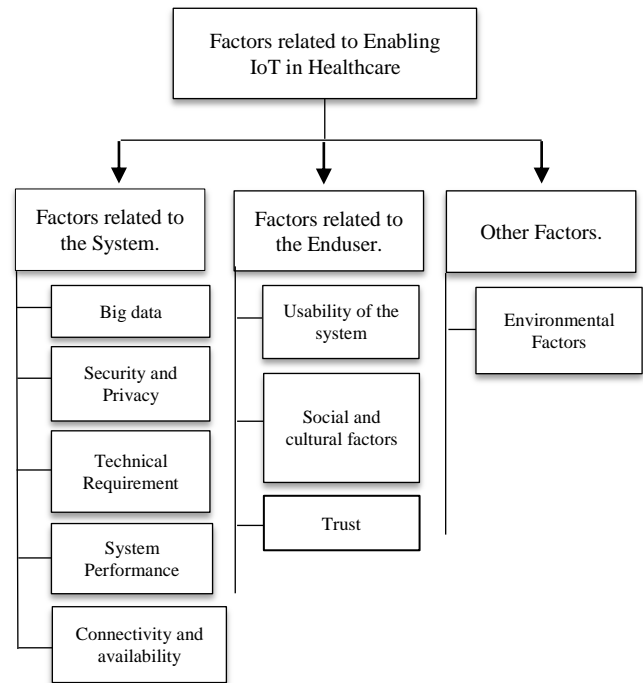


Fig. 2. Most related factor to enables IoT in healthcare.

1) *Factors related to the system:* It refers to the factors that impact a system's capacity to accomplish its intended purpose. These aspects are considered critical to the success or smooth functioning of Internet of Things services, such as big data, security and privacy, technological requirements, connectivity, and availability, and they represent the system factors required for a connected IoT in a healthcare context. Each of these elements is described briefly in the sections that follow.

a) *Big data:* The phrase "big data" is used to refer to a huge amount of data that exceeds the capacity of traditional storage and processing methods [39]. This deluge of information may be assembled or fragmented. How to reliably and securely acquire and retain data in systems has been a major topic of study in recent years [28, 40], as well as the means through which to preserve a strong level of integrity [25, 28]. How the system would handle a large amount of healthcare data collected from a variety of sensors was the topic of several studies [33]. Several studies voiced concerns about the speed and analysis of massive volumes of data [21, 40, 41] following data collection and processing [42, 43], data management [2, 44], and data monitoring. These potential difficulties must be addressed in order to assure the availability, dependability, and correctness of big data [28, 45] and to aid decision-makers in making sound decisions [43, 46].

*b) Security and privacy:* Both "security" and "privacy," which concentrate on data security, are related concepts. Security is mainly concerned with preventing unauthorized access to the system's data or information, whereas privacy relates to the protection of personally identifiable information. These words work better with modern healthcare software to protect patients' personal information [9, 24, 47]. Security risks, data breaches, insecure devices, and wearability are just some of the potential security and privacy issues that have been the subject of several studies [2, 4, 27, 48-50]. Data security and patient privacy must be prioritized for the longevity of any smart healthcare system [21, 51, 52].

*c) Technical requirements:* Besides the necessary basics, we should consider technical requirements [53, 54] leaks from energy storage systems and batteries [20, 55], low power consumption in operation [22, 56], leveraging IoT endpoints for use in intelligent decision-making, and power usage [50, 57-62] to improve communications and store information quickly [63]. Smart hospitals rely on connections to upload patient data, link medical equipment, and react fast (via sensors) [64]. Researchers focus on network connections and data transmission reliability [60, 65, 66] and handle problems like traffic [67]. Other studies improve service quality and performance [9, 60, 68].

*d) Enhance system performance:* Numerous aspects of the healthcare system are of interest to the authors in order to improve service quality in a timely and accurate manner. [40, 69], such as raising people's consciousness about the need to use medical equipment regularly, dealing with delays in responses or problems in latency [60, 70], and keeping up a high rate of data transfer quality [63, 71], also decreasing packet loss, determining the relationship between ICT and healthcare, and how ICT can help an individual [67]. Patients also get the best healthcare applications [20, 58, 65]. Some research has recommended early detection using improved monitoring systems [45, 72, 73] such as hypertension and blood pressure, and a deep learning-based vocal pathology detector to identify false main users [41, 74]. Rural healthcare should be egalitarian [40, 75]. Maintaining current technology and creating a smart healthcare engineering course to interest students [76, 77].

*2) Factors related to the individual:* Providers of healthcare must guarantee that user requirements and perspectives are prioritized. Several of the reviewed studies highlighted user problems and concerns, such as system performance, ease of use, accessibility to healthcare services, reliability of IoT devices, high cost, and trust [64, 78]. Thus, IoT aims to lower patients' expense burden by reducing hospital and clinic visits while providing precise and effective healthcare [22]. Most research has focused on these issues [73, 74]. Some have attempted to make smart gadgets and communication technology for remote monitoring systems more affordable [50, 56]. Thus, the notion of a "smart stone" has been embraced by some academics as a means of reducing elderly citizens' issues using mobile devices and tablets by limiting the system's involvement with the user [27]. This

approach was also utilized to determine the primary elements impacting senior people's adoption of smart gadgets for health care [5]. IoT healthcare's major problem is user uptake. To determine the most important elements affecting technology adoption, researchers must dig deep [29].

*3) Other factors:* Some researchers have reported additional issues, particularly in terms of external influences [3], traditions, laws, and ordinance platforms [45, 75], healthcare information systems that use social media, and how they can improve patient care [50, 79], and the benefit of working in the healthcare industry for a long time [80]. An increase in the senior population is a direct result of the correlation between healthcare system improvements and a longer lifetime duration. Physical incapacity, long-term illness, and technological headaches are just a few of the difficulties that the elderly face [29].

### C. Theoretical Review

In the study of how people embrace new technologies, there are eight prominent models, theories, and frameworks. UTAUT is the newest model available. TAM, however, is the standard. However, these two paradigms have been panned by healthcare experts for being overly simplistic and narrow in their concentration on the individual. Yet, the technological side, which is more concerned with technology's potential and public opinion of it, is rarely incorporated.

The TOE is an integrative paradigm that seeks to address this shortcoming from a variety of angles. It involves elements of technology, management, and ecology. Once again, the TOE is inadequate for the separate facets of technological diffusion.

Researchers have suggested that combined theories are able to explain the variation in adoption [81]. Few studies combined more than one theory to better explain the rise of the IoT [82]. Therefore, this study merges the TOE and UTAUT. The social exchange theory can be used to account for contextual factors like customer trust in service providers, which will boost the proposed model's ability to explain observed phenomena (SE).

*1) Existing frameworks and models of IoT:* The theory of reasoned action is a foundational concept in the history of technology adoption (TRA). Fishman and Ajzen created TRA [83]. According to the theory's central tenet, people's actions are driven by their attitudes and internalized values. Ajzen recognized the theory's flaws and developed the Theory of Planned Behavior (TPB) [84] by combining attitude, subjective norms, and perceived behavioral control. Davis combined TRA and TPB to create the TAM model [85].

According to research, UTAUT and TAM are commonly used models for measuring people's willingness to adopt new technologies, but they have been criticized for being too simplistic and narrow in focus. Meanwhile, the TOE framework, which includes elements from technology, organization, and natural phenomena, is considered more holistic but still lacks key components for effective technological integration. Therefore, combining the TOE and UTAUT models is necessary to gather data on both individual and technological aspects. By including the contextual variable

of trust, the proposed model's explanatory power can also be enhanced.

TABLE I. SUMMARIZES THE DIFFERENCES AND SIMILARITIES BETWEEN SEVERAL THEORIES AND MODELS OF TECHNOLOGICAL ACCEPTANCE

Theory/ Model	Explained variance
1- Theory of Reasoned Action (TRA)	0.36
2- TAM	0.54
3- Motivation Model (MM)	0.38
4- Theory of Planned Behavior (TPB)	0.47
5- Combined Technology Acceptance Model and Theory of Planned Behavior (C-TAM-TPB)	0.39
6- Model of PC Utilization (MPCU)	0.47
7- Innovation Diffusion Theory (IDT)	0.40
8- Social Cognitive Theory (SCT)	0.36
9- Unified Theory of Acceptance and Use of Technology (UTAUT)	0.69

According to the social exchange theory, people are more likely to adopt an innovation when they trust specific individuals or groups promoting it and when they believe that the benefits outweigh the risks and costs associated with its use are less [86, 87]. As a result, establishing and maintaining trust in the adoption of new technology is essential for promoting positive attitudes and behaviours toward innovation [64].

In previous studies, a combination of more than one theory was also investigated such as a study, that combined TAM and IDT to predict the adoption of IoT by users [32]. Before combining TAM, TRA, and TPB to foretell IoT adoption, Rahimi studied each one separately, and the results demonstrated that IoT adoption can be largely explained by three theories, or previously unconsidered constructs could be added to existing theories [82].

2) *Discussion of related work:* This section discusses and summarizes all the related works to IoT adoption studies; Table II shows the research gap and limitations found in the literature.

TABLE II. A SUMMARY OF RELATED WORKS

Ref.	Type of study	IV	DV	Theory	Respondent	Sample size	Findings
[4]	Empirical study (Mixed methods)	<ul style="list-style-type: none"> <li>Human detachment concerns,</li> <li>Privacy concerns,</li> <li>Life quality expectancy</li> <li>Cost concerns</li> <li>Enhance patient safety.</li> <li>Lack of communicating and transferring data between doctors and patients.</li> </ul>	Intention to use WSN-SHHS	<ul style="list-style-type: none"> <li>UTAUT</li> <li>PAD</li> </ul>	IoT users 18- and above	1- interview (the data collected from 15 home healthcare patients)  2-survey the data collected from 140 respondents	Patients are more likely to embrace WSN-SHHS if they are concerned about human alienation than if they have high-performance expectations
[5]	Empirical study (Online survey)	<ul style="list-style-type: none"> <li>Performance Expectancy</li> <li>Effort Expectancy</li> <li>Social Influence</li> <li>Facilitating Conditions</li> <li>Technology Anxiety</li> <li>Perceived Trust</li> <li>Perceived Cost</li> <li>Expert Advice</li> </ul>	Behavioural intention	<ul style="list-style-type: none"> <li>UTAUT</li> </ul>	IoT users 55 and above	254	The R2 value of 81.4% indicates that the established framework has satisfactory explanatory power. This suggests that a theoretical framework explaining the use intention of smart homes among the elderly in a health setting may be developed by combining UTAUT with other constructs.
[88]	Empirical study	<ul style="list-style-type: none"> <li>Data sharing</li> <li>Expert support</li> <li>Device</li> <li>Task scope (monitoring, diagnosis, treatment)</li> <li>Provider profession (Technology + medicine)</li> </ul>	Behavioural intention to use IoT disease management service	<ul style="list-style-type: none"> <li>Nil</li> </ul>	IoT users 20- above 50	493	Potential consumers' acceptance of an IoT healthcare service is predicted to be affected by the key factors mentioned in this research.
[20]	Empirical	<ul style="list-style-type: none"> <li>Attitude towards Adoption</li> <li>Perceived usefulness</li> <li>Perceived ease of use</li> <li>Intrusiveness</li> <li>Comfort</li> </ul>	Behavioural intention to use IoT	<ul style="list-style-type: none"> <li>TAM</li> </ul>	IoT users	273	The findings highlight the connection between IoT applications and the healthcare sector by focusing on four important user key-drivers that investigate intrusiveness (INTR).

Ref.	Type of study	IV	DV	Theory	Respondent	Sample size	Findings
[32]	Empirical	<ul style="list-style-type: none"> <li>• Convenience</li> <li>• Safety</li> <li>• Interaction</li> <li>• Low-cost</li> <li>• Usefulness</li> <li>• Ease of use</li> <li>• Quality of technological service</li> <li>• Compatibility</li> <li>• Trust</li> <li>• Perceived value</li> <li>• Social factors</li> <li>• Product image</li> </ul>	Behavioural intention to adopt mobile healthcare	<ul style="list-style-type: none"> <li>• TAM</li> <li>• IDT</li> </ul>	IoT users	Nil	The results highlight the significance of cultural norms, product perception, and customer confidence in pushing product adoption.
[70]	Empirical	<ul style="list-style-type: none"> <li>• Health concern</li> <li>• Health information concerns</li> <li>• Privacy concern</li> <li>• Challenge appraisal.</li> <li>• Threat appraisal</li> <li>• Problem-focused coping.</li> <li>• Emotion-focused coping.</li> </ul>	<ul style="list-style-type: none"> <li>• Challenge appraisal.</li> <li>• Threat appraisal</li> <li>• Problem-focused coping.</li> <li>• Emotion focused coping.</li> <li>• Extended use</li> </ul>	<ul style="list-style-type: none"> <li>• coping model of user adaptation</li> <li>• (CMUA)</li> </ul>	Users of IoT 20-above 50	260	This research helps us better understand how customers' restrictive habits affect the widespread adoption of wearable healthcare equipment.
[89]	Empirical	<ul style="list-style-type: none"> <li>• Security</li> <li>• Privacy</li> <li>• Compatibility</li> <li>• Complexity</li> <li>• Behavioural control</li> <li>• Confirmation</li> <li>• Utilization</li> </ul>	Cloud health information system utilization	<ul style="list-style-type: none"> <li>• TRA</li> </ul>	The user of IoT 25-30	259	There was a statistically significant impact from doctors' confirmation and behavioural control systems' compatibility, complexity, security, and privacy. The use of technology by doctors was improved by both confirmation and behavioural control.
[45]	Empirical	<ul style="list-style-type: none"> <li>• Privacy and Security associated with medical records.</li> <li>• Data reliability, and Data authentication</li> <li>• Real-time monitoring</li> <li>• Real-time detection</li> <li>• Real-time diagnosis</li> </ul>	Smart health monitoring system	<ul style="list-style-type: none"> <li>• Nil</li> </ul>	User of IoT	183	Present a framework that will transform the concept of automated health monitoring systems.
[75]	Empirical	<ul style="list-style-type: none"> <li>• Relative advantage</li> <li>• Quality</li> <li>• Security</li> <li>• Inter-operability</li> <li>• Perceived usefulness</li> <li>• Perceived ease of use</li> <li>• Implementation intention</li> </ul>	Use behavior	<ul style="list-style-type: none"> <li>• TAM</li> </ul>	User of IoT	Nil	The significant impact of intention is influenced by factors such as perceived ease of use and usefulness, relative advantage, interoperability, perceived quality, and perceived security. The perceived usefulness is influenced by the relative advantage, whereas the apparent simplicity of operation is impacted by interoperability. The objective had a significant influence on the utilization of IoT.
[82]	Empirical	<ul style="list-style-type: none"> <li>• Perceived usefulness</li> <li>• Perceived ease of use</li> <li>• Attitude</li> <li>• Subjective norms</li> <li>• Perceived behavioural control</li> </ul>	Behavioural intention	<ul style="list-style-type: none"> <li>• TAM</li> <li>• TRA</li> <li>• TPB</li> </ul>	User of IoT	Nil	The adoption of IoT is significantly impacted by the perceived user-friendliness and utility of the devices. Furthermore, the factors of attitude and subjective norms are significant predictors in the adoption of technology. The adoption of IoT is not significantly influenced by perceived behavioural control. Each of the three models has the

Ref.	Type of study	IV	DV	Theory	Respondent	Sample size	Findings
							capacity to account for the proportion of the variability observed in the Internet of Things (IoT).
[90]	Empirical	<ul style="list-style-type: none"> <li>• Perceived Advantage</li> <li>• Technological Innovativeness</li> <li>• Compatibility</li> <li>• Trialability</li> <li>• Image</li> <li>• Perceived Vulnerability</li> <li>• Perceived Severity</li> <li>• Perceived privacy risk</li> <li>• Cost</li> <li>• Perceived Ease of Use</li> <li>• Attitude</li> <li>• Perceived Usefulness</li> </ul>	Behavioural Intent to Adoption	<ul style="list-style-type: none"> <li>• Technology acceptance model (TAM)</li> <li>• Innovation diffusion theory (IDT)</li> <li>• Technological innovativeness (TI)</li> <li>• protection motivation theory</li> <li>• privacy calculus theory</li> </ul>	Users of IoT	426	<p>The results of the entire model indicate that perceived advantage (PA), image, and perceived ease of use (PEOU) have a substantial impact on the intention to adopt IoT healthcare technology solutions. PA is a more significant factor in determining PEOU among males than females, according to the findings. Men are more affected by issues of appearance, privacy concerns, and feeling insecure than women.</p>

From the literature, it is obvious that the number of experimental studies is greater than the number of theoretical studies, which seems logical given that a good service must be provided to patients by developing an efficient healthcare system to deliver the best customer service. After ensuring that the service is worthwhile enough, we turn to theoretical studies to examine the intention of people to adopt these services in their daily lives, as well as highlight the users' concerns about these services to give a clear indication to the providers to put more effort into providing a better experience with IoT healthcare services.

It can be seen from Table II that the number of studies pertaining to the adoption of IoT in the healthcare sector is limited. Most previous studies adopted an experimental rather than empirical approach. As can be seen in the summary table (Table I), the empirical, quantitative, and adoption studies are focused on the factors or predictors of IoT adoption among users. Most of the studies employed TAM to explain the behaviour toward adopting IoT.

Among these studies, perceived ease of use (PEOU) and perceived usefulness (PU) were found to be critical for the adoption of IoT [20]. Similar findings were derived in the study of Liu who indicated that social norms, trust, as well as PEOU and PU were the predictors of IoT adoption [32]. Rahimi deployed TAM and also reported that PEOU and PU were critical for the adoption of IoT, along with TAM the researcher also examined the validity of TRA and TPB [82]. Studies using TAM were also conducted by many researchers [90, 91]. The empirical studies also deployed other theories of technology adoption, such as UTAUT. In a study by Pal, the UTAUT model was applied along with variables such as anxiety, trust, and cost to understand the adoption of IoT by the elderly in four Asian countries [5]. The findings showed that the variables of UTAUT along with trust and cost were important predictors of IoT adoption among the elderly population. Meanwhile, Meri used the theory of reasoned action (TRA) to predict the adoption of IoT [89]. Previous research has shown that several different theories often work together. In Liu's research, for instance, TAM and IDT were coupled to anticipate user adoption of the internet of things

[32]. Rahimi tested TAM, TRA, and TPB individually and then combined them to predict IoT adoption [82].

In conclusion, theoretical studies in the area of IoT adoption in healthcare are still limited, and there is a need to go in-depth due to its importance in providing distinguished healthcare services for patients. This can contribute to reducing the number of deaths and improving overall healthcare outcomes. Furthermore, findings revealed that a combination of more than two theories is needed to develop a comprehensive model that captures the complex nature of IoT healthcare service adoption.

### III. RESEARCH FRAMEWORK AND HYPOTHESIS

IoT adoption among patients with chronic diseases is a topic of increasing interest in the healthcare industry. In Malaysia, where chronic diseases are prevalent, understanding the factors that predict IoT adoption is crucial. This research aims to explore these factors using the Unified Theory of Acceptance and Use of Technology (UTAUT), the Technology-Organization-Environment (TOE) framework, and the social exchange theory. According to UTAUT, individual factors such as performance expectancy, effort expectancy, and social influence play a significant role in predicting IoT adoption.

IoT adoption is also affected by technological factors such as security, privacy, and availability. Due to the sensitive nature of health data, security concerns arise, while privacy concerns refer to the preservation of users' personal information for the availability of Internet of Things devices and their associated services.

Facilitating conditions, which are a component of UTAUT, are also crucial IoT adoption predictors. These conditions pertain to the infrastructure and resources necessary for the effective use of IoT devices. For instance, the availability of dependable internet connectivity and technical support can have a significant impact on the adoption decisions of end consumers.

According to social exchange theory, trust is a crucial mediator for predicting IoT adoption. Patients with chronic

diseases may be hesitant to implement IoT devices out of concern for the technology's dependability and precision.

Having confidence in the technology and its purveyors can help mitigate these concerns and boost adoption rates.

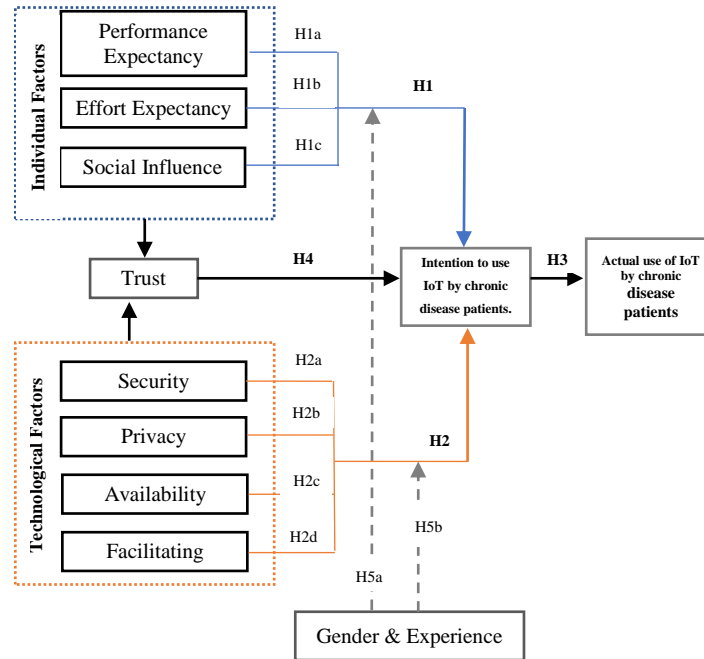


Fig. 3. The research framework.

According to UTAUT, there are moderating factors, such as gender and experience. We will use gender and chronic disease patient experience as moderating factors in this investigation. Fig. 3 illustrates the research framework used in this study.

#### A. Individual Factors

Performance expectancy (PE), effort expectancy (EE), and social influence (SI) are considered individual factors in the context of IoT adoption. Previous studies have shown that these factors have a significant positive effect on the intention to adopt IoT [92]. Based on this, it is expected that individual factors will also have a positive and significant impact on IoT healthcare service adoption in this study. Thus, it is hypothesized that:

H1: Individual variables influence positively the BI to adopt IoT-healthcare services by patients with chronic diseases.

1) *Performance Expectancy (PE)*: The term "performance expectancy" refers to the degree to which a person feels that using a certain piece of technology will assist them in doing their duties in a manner that is both more effective and efficient [93]. In the context of the Internet of Things (IoT), this term refers to the extent to which an individual believes that making use of IoT devices will improve their overall performance when carrying out a given set of responsibilities. According to Venkatesh's findings, PE has been identified as the most influential factor in determining an individual's behavioural intention (BI) toward technology adoption. This was reported in reference [93]. According to Pai and Huang PE impairs the ability of BI to utilize health information systems [43].

Carlsson revealed that performance expectations have a direct positive effect on an individual's intention to use mobile devices. This means that if an individual believes that using a mobile device will help them perform their tasks more efficiently and effectively, they are more likely to have the intention to use it [94]. The greater the PE, the more likely it is that mobile health services will be embraced, according to experimental studies [95]. Therefore, the following hypothesis was put up for this investigation:

H1a: PE has a positive effect on the BI for chronic disease patients to adopt IoT-healthcare services.

2) *Effort Expectancy (EE)*: The ease of use (or EE) of a system is defined as "the degree of simplicity" [96]. Researchers have found that EE has a substantial effect on users' propensity to embrace a health information system. Clinical support for decision systems, mobile health monitoring systems, and e-health solutions accessible via smartphones are all examples, and portable well-being has all been shown to be positively influenced by EE [17, 95]. Pal found that effort expectancy has a major impact on the adoption Internet of Things in healthcare [5]. Hence it entails that:

H1b: EE has a positive effect on the BI for chronic disease patients to utilize IoT-healthcare services.

3) *Social Influence (SI)*: "How important it is to other people that you accept the new technology" [93] is how social influence is defined as it relates to technology adoption. Liu concludes that SI is a crucial factor and has a significant effect



on the spread of mobile medical services. Pal also looked into how peer pressure affects the uptake of smart homes to improve the health of the elderly [5]. Literature reviews have found a similar pattern: people are more inclined to adopt new technology when they see other people using it, too [97]. It is hypothesized in this investigation that individuals with chronic diseases will be influenced to accept and use IoT-healthcare services:

H1c: SI has a positive effect on the BI for chronic disease patients to adopt IoT-healthcare services.

### B. Technological Factors

The TOE relies heavily on technological aspects. Their impact on the spread of various technologies has been the subject of several studies. According to Lian's research, technological factors have a significant effect on cloud computing's uptake in Taiwan [101]. Cloud computing adoption in the public sector has been the subject of several studies, including one by Polyviou and Pouloudi [107], who showed that technological characteristics were significant predictors of cloud adoption among public sector personnel. In India, cloud computing has been slow to catch on, according to research by Gangwar [90]. Thus, it is hypothesized in this study that technical factors will have a beneficial impact proceeding the behavioural intention of Malaysians with persistent illness to implement IoT healthcare. Accordingly, it is assumed:

H2: Technological factors have a positive effect on the BI for chronic disease patients to adopt IoT-healthcare services.

1) *Security*: The healthcare industry is facing serious security challenges. Without adequate safeguards, billions of sensitive medical files are kept on unprotected servers. Concerns regarding the safety of patient data and infrastructure have grown in tandem with the prevalence of ransomware attacks. In the present study, we define security as the confidence that patients with chronic diseases have in IoT healthcare services as safe places to save and share their personal information [98]. Security was introduced as a technological aspect by Lian, Senyo, and Alkhatir [92, 99, 100]. So, this research takes into account security as a factor of the technological factors. Numerous studies have looked into how people's perceptions of risk influence their decisions about whether or not to adopt new technology. According to Junqi's research, [75] security concerns significantly affect whether or not a healthcare system is adopted. It is hypothesized as:

H2a: Security has a positive effect on the BI for chronic disease patients to adopt IoT-healthcare services.

2) *Privacy*: When it comes to the use of IoT devices in healthcare, privacy is a key problem. Medical devices such as (but not limited to) pacemakers, insulin engines, and individual monitors are frequently used in hospitals to keep tabs on patients' vital signs. In order to exchange data, these gadgets join a wireless network. Multiple hackers have broken through these systems as of late, taking the information for their end. If patients find out later that their doctors are using Internet of

Things devices on them, they may feel violated. The term "privacy" refers to "the extent to which individuals with chronic diseases perceive that their personal information is secure" [98]. Researchers have taken privacy into account as a technological aspect in the spread of cutting-edge tools in a variety of contexts. For the Internet of Things to be widely used in healthcare, researchers have shown that protecting patients' personal information is crucial [2, 52, 101]. Hence, it is assumed that:

H2b: Privacy has a positive effect on the BI for chronic disease patients to adopt IoT-healthcare services.

3) *Availability*: Availability, which is one of the sub-constructs of technological factors, is the perception of how much personalized and uninterrupted connection and communication an individual has with other individuals and networks through ubiquitous technology [94]. Lack of internet connectivity is one of the main barriers to utilizing telehealth/telemedicine, as 68% of health care professionals reported this as their top concern in adopting these new technologies [17]. When formulating the TOE model, Tornatzky and Fleischer took into account accessibility to technology as a technological component [102]. Pathinarupothi, who noted that availability is vital for remote monitoring, and impacts the amount to which users are ready to embrace IoT, is one of the researchers that looked at how accessibility affected IoT uptake [69]. The willingness of users to employ the Internet of Things is affected by factors such as availability. According to research in the field of technology adoption, such as the Phaphoom study, availability is crucial for the spread of cloud computing [103]. Positive findings on the impact of availability on BI to use IoT by Malaysians with chronic diseases are anticipated in this research. So, the following is postulated:

H2c: Availability has a positive effect on the BI for chronic disease patients to adopt IoT-healthcare services.

4) *Facilitating Condition (FC)*: The variable "FC" is one of the constructs of the Unified Theory of Acceptance and Use of Technology (UTAUT). "FC" stands for "facilitating conditions," which refers to "the extent to which a user believes that an organizational and technical infrastructure exists to support the system's use" [104]. The FC was directly related to the employment of cutting-edge technology by the researchers that deployed UTAUT [93, 105, 106]. The extent to which a user is pleased with and finds value in an IT application has been shown in other research to be a major predictor of that user's intention to involve with new technologies [107]. Consequently, if the FC for a new system is high, it's likely that its users will be pleased with it and want to keep using it. Academic technology adoption was found to be significantly influenced by FC [106]. As a result, it stands to reason that FC has a significant impact on patients' propensity to engage in IoT-based healthcare services. Then, it is theorized as:

H2d: FC has a positive effect on the BI for chronic disease patients to adopt IoT-healthcare services.

### C. Behavioural Intention (BI) and Use Behaviour

Is a catch-all phrase covering research into how people engage with and make use of technological systems. From marketing to the law, BI has found a home in many industries. Yet, the field is most commonly associated with the study of human-machine interactions in the social sciences. A definition of BI is the extent to which a person has deliberated over whether or not to engage in a particular course of action in the future [106]. Individual's subjective evaluation of whether or not they should engage in the desired behavior (UB) [93]. Individuals' subjective evaluation of whether or not they should engage in the desired behavior (UB) [93]. Most earlier models of technology acquisition such as TAM and UTAUT have connected the BI to the UB [85, 93]. Gao observed a substantial correlation between BI and UB in their research [106]. Many investigations [108-110] have found the same thing. Therefore, in this study, it is hypothesized as:

H3: BI has a significant effect on the actual use of adopt IoT healthcare services by chronic disease patients.

### D. Mediating Role of Trust

Patients with chronic conditions who have faith in the integrity of IoT-healthcare services are said to have "high levels of trust" [98]. Users were more likely to adopt new technologies when they had a positive impression of the companies providing those services [111]. Lansing and Sunyaev concluded, using a classification system based on how trust plays out in trying out new gear, that trust was underappreciated in this context and that the variable trust mediated the relationship between the factors of success of acquisition and utilization goals [112]. Ghazizadeh, Lee, and Boyle used trust as an intermediary among PEOU, helpfulness, and BI [113]. The conclusions revealed that trust completely mediated the consequence of PEOU on BI.

According to Social Exchange Theory, trust is a critical aspect that might impact an individual's desire to employ technology in healthcare. As stated in previous studies, patients who have trust in IoT healthcare technology are more likely to use, learn from, and realize its advantages. Furthermore, a trust may influence how individual and technological factors influence an individual's behavioural intention to adopt new technology. The research hypothesis is that trust will play a mediating role in the relationship between individual and technological factors and patients' behavioral intention (BI) to adopt Internet of Things (IoT) healthcare services. In other words, the study proposes that trust will act as a link between these factors and patients' willingness to use technology in healthcare. It is theorized as follows:

H4a: Trust mediates the effect of individual factors on BI to adopt IoT-healthcare service by chronic disease patients. H4b: Trust mediates the effect of technological factors on BI to adopt IoT-healthcare service by chronic disease patients.

### E. Moderating Effect of Gender and Experience

Recent research has examined the impact of gender and experience on the relationship between UTAUT constructs and

people's intentions to use technology. The results suggest that gender and experience can have a significant influence on people's attitudes towards technology, and should be taken into account when introducing new technological solutions [93]. Another point should be highlighted that the user's background and familiarity with the internet, computers, and other forms of information technology is another important factor to consider when introducing new technology solutions. The Unified Theory of Acceptance and Use of Technology (UTAUT) has also recognized that people are more likely to use technology when they have a high level of familiarity with it. This suggests that prior experience with technology can influence people's attitudes toward new technology and may impact their willingness to adopt it.

Rezvani used gender and professional experience to moderators the relationships between TAM and privacy and connectedness. [38]. The findings showed that these two characteristics affected the perceived utility (PU), perceived ease of use (PEOU), privacy, and desire to use IoT. Based on the UTAUT paradigm, this study hypothesizes that gender and experience affect the connection between individual and technological factors and patients' adoption of IoT. Accordingly, the following is hypothesized:

H5a: Gender moderates the effect of individual factors and technological factors on the BI to adopt IoT-healthcare service by chronic disease patients.

H5b: Experience moderates the effect of individual factors and technological factors on the BI to adopt IoT-healthcare service by chronic disease patients.

## IV. METHODOLOGY

### A. Population and Sample Size

This section describes the characteristics of the participants included in this research, how they were selected as well as the study's sample size.

1) *Population*: The population is described as "the entire group of people, events, or things that can be observed or measured." [114]. This definition is quite wide and might include anything from individual people to entire societies. Other researchers defined population as "the intended group that shares similar characteristics with the group in which the researcher wishes to generalize the research findings" [64]. When collecting data, it is important to choose the population carefully to ensure collecting relevant and reliable data. In the current research, the population of this study is patients suffering from chronic diseases in Malaysia. Presently, there are no specific statistics that reflect the number of patients with chronic diseases in Malaysia. However, the prevalence of chronic illnesses such as diabetes, hypertension, and heart disease is increasing among patients in Malaysia.

This study focuses on the Klang Valley area given that it is an urban area with the highest population in Malaysia amounting to 8.4 million people according to the World population review. Approximately 1.2 million of these patients are estimated to have one or more chronic conditions according to the Ministry of Health, Malaysia.

2) *Sampling*: The sample size is defined as “a process of selecting a number of individuals from a population to be tested or studied” [115]. The selection of a target population is critical to ensure that the sample is representative of the larger population of interest [114]. According to the Ministry of Health, about 1,000,000 Malaysians with chronic conditions live in the Klang Valley. SEM data analysis requires a sample size of 100–200 [116]. Kline said that SEM samples are typically 200 [117]. According to Krejcie and Morgan [118] and Sekaran [114], 384 respondents are a substantial and acceptable sample for this study's population.

### B. Questionnaire Design

A standardized, closed-ended questionnaire was used to compile information for this investigation. The variables are measured in accordance with standards established by earlier research into the spread of IoT healthcare services. There are three sections in this questionnaire as it is shown in Fig. 4:

- 1) The first section explains the purpose of the questions.
- 2) The second section collects demographic data from respondents, such as age, gender, usage of IoT services, familiarity with IoT, expertise with IoT, and whether they have any chronic diseases.
- 3) The third section contains items designed to measure technological and individual characteristics, as well as research variables like behavioral intention, trust, and actual usage behavior.

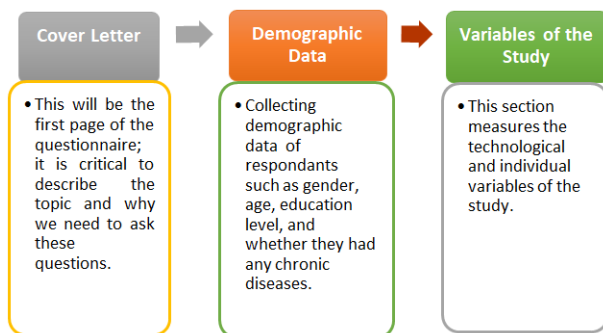


Fig. 4. The questionnaire sections.

Items are graded on a 5-point Likert scale, with 1 representing strongly disagreeing and 5 representing strongly agreeing. Compared to seven- and ten-point Likert scales [119–121], Likert scales are utilized because they have been found to be more accurate in gauging respondents' thoughts and feelings. The "closed-ended" nature of these questions makes them easier to answer than open-ended questions that ask respondents to describe how they feel about an issue or topic. These types of questions also increase the reliability of the data and make it easier to analyze the data and interpret the results [122].

### C. Preliminary Test

After the questionnaire was designed, and before collecting actual data, it was crucial to conduct a preliminary test to ensure that the questions were appropriate, to obtain accurate results [123]. Particularly if the questions of the questionnaire

were adopted from earlier studies, there is a need to modify the questions in a way to fit the new purpose of the research. As it has been done in this investigation were the questionnaire adopted from previous studies [124–126].

Pre-test and pilot studies were conducted in this study. The purpose of this test is to determine errors and ambiguity, make sure that questions are clear enough and understood by respondents, as well as identify any technical problems that may prevent the results from being reliable and accurate [64, 114].

### D. Data Collection Procedures

Several approaches can be used for collecting data via surveys in research studies, including online and mail surveys, telephone interviews, face-to-face interviews, and drop-off surveys [114]. The present study aligns with previous research that investigated the adoption of IoT in healthcare and deployed a survey approach to collect the data due to the cost-effectiveness, convenience, and time of the studies [15, 38, 90]. Surveys also enable researchers to collect a large number of responses in a relatively short period [114]. Given that the data collection process occurred during the lockdown of COVID-19, an online survey may be the best option, as it allows patients to complete the survey at a time that is convenient for them and reduces the amount of contact between the patient and the researcher during that period. respondents who met the inclusion criteria were selected to complete the questionnaire. An online questionnaire was deployed for the data collection.

Among the initial 384, we received 252 valid responses. As Kline stated that SEM responses more than 200 are satisfactory [117], such results are regarded adequate. SPSS 24.0 and Smart PLS 3.3 are used to analyze the data. Missing values, outliers, normality, and multicollinearity checks are all part of SPSS's preliminary analysis. The measurement type and the structural version are both a part of the main analysis conducted using Smart PLS.

## V. RESULTS

### A. Descriptive Information

The respondent descriptions and variables for the study are included here. The former was reported in terms of frequencies and percentages, while the latter was represented statistically by means of each variable. The level of education, gender, age, chronic illness, frequency of use, and method of accessing IoT healthcare of the respondents are shown in Table III.

Factors and their associated descriptions are shown in Table IV. The average score for performance expectation (PE) was 3.29, indicating that most respondents agreed with the items used to calculate PE. The majority of respondents moderately agreed with the items evaluating effort expectancy (EE), as seen by its mean score of 3.39. Similar results for social impact could be shown (SI). The degree of individual-related elements had an overall mean score of 3.31. All of the factors taken into account under individual-related aspects in this study were moderately supported by respondents, it may be concluded.

TABLE III. DESCRIPTIVE INFORMATION OF RESPONDENTS

	Label	Frequency	Percent
Education	Less than high school	4	1.6
	High School or Less	21	8.3
	Diploma	93	36.9
	Bachelor	120	47.6
	Master	10	4.0
	PhD	4	1.6
Gender	Male	157	62.3
	Female	95	37.7
Age	18-30 years	10	4.0
	31-40 years	41	16.3
	41-50 years	88	34.9
	51-60 years	113	44.8
Chronic disease	Yes	252	100.0
Usage of IoT healthcare services	Yes	79	31.4
	No	173	68.6
Tool to access IoT healthcare services	Smartphone	39	15.5
	Devices in the house	19	7.5
	Wearable devices	21	8.4
	Not using	173	68.6

Table V lists the four dimensions of the level of technologically related factors: security, privacy, availability, and facilitating conditions. Security, privacy, availability, and facilitation conditions have comparable mean scores of 3.20, 3.18, 3.38, and 2.96. A substantial level of agreement with the

associated items or measures was determined in this study to be a mean score greater than 2.5. In light of this, the majority of respondents showed moderate agreement with all of the technologically linked criteria examined in this study. This is mirrored in Table IV's total mean score, which is 3.18.

TABLE IV. DESCRIPTIVE STATISTICS OF INDIVIDUAL FACTORS

Code	Mean	Std. Deviation	Level
PE1	3.34	.983	Moderate
PE2	3.25	.935	Moderate
PE3	3.29	.898	Moderate
PE4	3.28	.920	Moderate
Performance expectancy	3.29	-	Moderate
EE1	3.26	1.038	Moderate
EE2	3.49	.998	Moderate
EE3	3.42	1.036	Moderate
EE4	3.39	.999	Moderate
Effort expectancy	3.39	-	Moderate
SI1	3.41	.931	Moderate
SI2	3.15	.996	Moderate
SI3	3.17	1.193	Moderate
Social influence	3.24	-	Moderate
Overall mean score	3.31	-	Moderate

TABLE V. TECHNOLOGY-RELATED FACTOR DESCRIPTIONS

Code	Mean	Std. Deviation	Level
SC1	3.21	.986	Moderate
SC2	3.22	1.000	Moderate
SC3	3.18	.985	Moderate
Security	3.20	-	Moderate
PC1	3.08	1.019	Moderate
PC2	3.09	1.018	Moderate
PC3	3.04	1.021	Moderate
PC4	3.51	1.004	Moderate
Privacy	3.18	-	Moderate
AV1	3.45	1.057	Moderate
AV2	3.32	1.069	Moderate
AV3	3.38	1.048	Moderate
AV4	3.36	1.025	Moderate
Availability	3.38	-	Moderate
FC1	3.04	.950	Moderate
FC2	2.90	.973	Moderate
FC3	2.96	1.011	Moderate
FC4	2.95	1.066	Moderate
Facilitating conditions	2.96	-	Moderate
Overall mean score	3.18	-	Moderate

The trust-related descriptive data are shown in Table VI. As a result, the overall average is 3.33, suggesting a moderate degree of agreement with the trust-measuring statements.

According to Table VII, the overall average grade for that behavioral intention (BI) is 3.30. All items used to gauge BI

severity have received moderate agreement from participants, as indicated by the mean score being larger than 2.50.

Table VIII displays the outcomes for the frequency of use. The majority of respondents only somewhat agreed with the assertions pertaining to real behavior, as indicated by the mean score of 3.41 for actual behavior (AB).

TABLE VI. DESCRIPTIVE STATISTICS OF TRUST

Code	Mean	Std. Deviation	Level
TRT1	3.27	.952	Moderate
TRT2	3.44	1.030	Moderate
TRT3	3.29	.952	Moderate
TRT4	3.32	1.172	Moderate
The overall mean of trust	3.33	-	Moderate

TABLE VII. DESCRIPTIVE STATISTICS OF BEHAVIOURAL INTENTION

Code	Mean	Std. Deviation	Level
BI1	3.29	1.009	Moderate
BI2	3.29	.931	Moderate
BI3	3.36	1.297	Moderate
BI4	3.27	1.016	Moderate
The mean of behavioural intention	3.30	-	Moderate

TABLE VIII. ACTUAL BEHAVIOUR DATA WITH DESCRIPTIVE STATISTICS

Code	Mean	Std. Deviation	Level
AB1	3.52	1.261	Moderate
AB2	3.37	1.185	Moderate
AB3	3.08	.979	Moderate
AB4	3.67	1.156	Moderate
Overall Mean	3.41	-	Moderate

B. Structural Equation Modeling

Structural Equation Modeling (SEM) is a statistical method for analyzing the relationships between multiple variables [127]. SEM can be used for a variety of purposes, including testing theoretical models, investigating complex relationships between variables, and examining causal relationships [128]. Some of the advantages of SEM include its ability to handle multiple variables, account for measurement errors, and test complex models. Additionally, SEM allows researchers to test both direct and indirect effects between variables, making it a powerful tool for hypothesis testing and theory development [129]. The structural equation model assessment is divided into two models. The first model is the first-order variables while the second model is the second-order variables. The steps of assessing the SEM-PLS are shown in Fig. 5. By using SEM, researchers can gain valuable insights into the factors influencing the behavioral intention of chronic disease patients to adopt IoT-healthcare services in Malaysia.

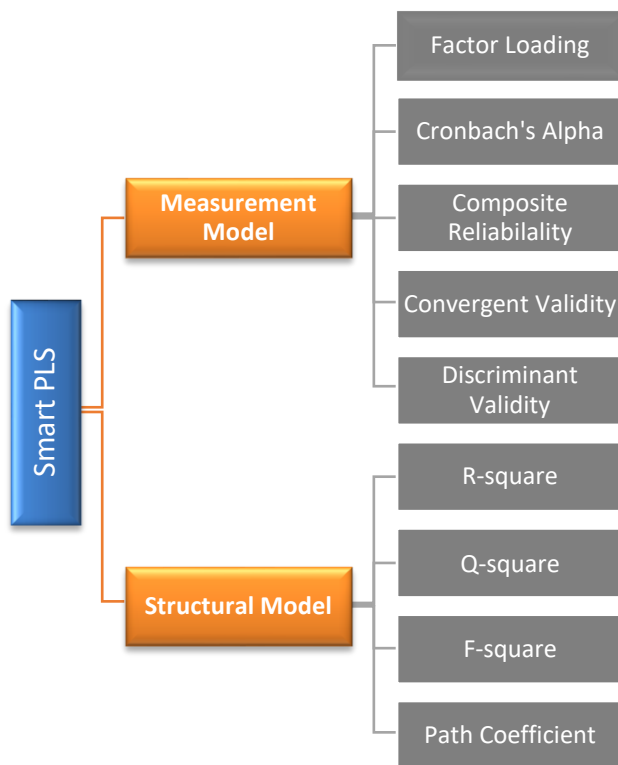


Fig. 5. Steps of assessing SEM-PLS.

1) *Measurement model assessment:* First-Order Measurement Model Assessment of SEM evaluates a structural equation model where all variables are measured by a single indicator, while Second-Order Measurement Model Assessment evaluates a structural equation model where one or more latent variables are themselves measured by other latent variables. Both assessments involve examining the reliability and validity of the measures used to operationalize the latent variables in the model to ensure that the measurement model provides a good fit to the data and accurately reflects the underlying constructs of interest [129, 130].

The finalized measurement model of this study is presented in Fig. 6, comprising the main constructs (1) individual-related factors (second order) and their dimension, performance expectancy, effort expectancy, and social influence (first order), and (2) technological-related factors (second order) and its dimension, which consist of the first-order variables; availability, security, privacy, and facilitating conditions. The factor loadings of the items on their respective variables and the loading of the first order on the second order are also presented.

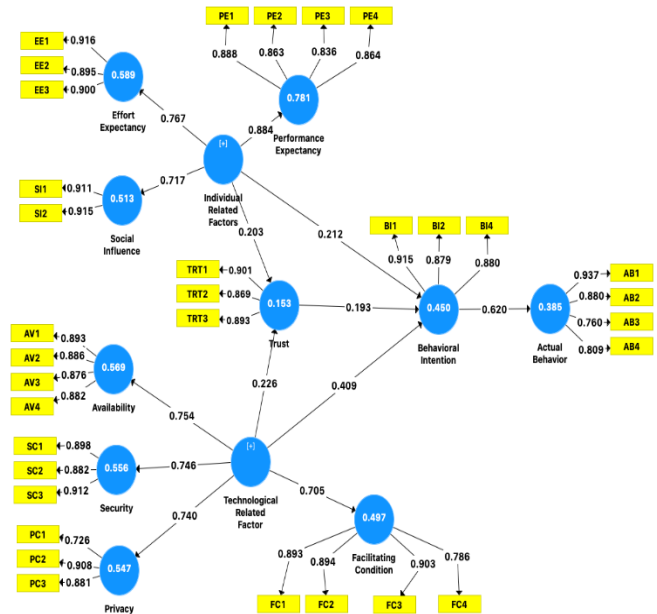


Fig. 6. Measurement mode.

2) *Structural model:* The structural model is used to test hypotheses about the relationships among the variables and to estimate the strength and direction of those relationships [131]. The assessment of the structural model involved four criteria: R-square, Q-square, F-square, and the path coefficient. By integrating both the structural and measurement models, structural equation modeling provides a comprehensive analysis of the relationships among latent variables and their corresponding indicators.

C. Result of Hypotheses Testing

All three types of hypotheses—direct effect, mediating effect, and moderating effect—were examined here. Following Hair [74], all hypotheses were tested using a p-value of less than 0.05 and a bootstrapping sample size of at least 5,000. The direct effect hypotheses are summarized in Table IX.

The first hypothesis (H1) and its three components (H1a), (H1b), and (H1c) predicted the impact of personally relevant factors on behavioural intent. With p-values smaller than .05, the results showed that both performance expectation and social influence had a substantial direct impact on BI.



TABLE IX. THE OUTCOME OF THE TESTS OF THE HYPOTHESES

H	Factors	B	Std.	T-value	P Values	Significant
H1	Individual Related factors -> BI	0.238	0.082	3.032	0.002	Yes
H1a	Performance Expectancy -> BI	0.158	0.072	2.180	0.016	Yes
H1b	Effort Expectancy -> BI	0.043	0.057	0.752	0.230	No
H1c	Social Influence -> BI	0.153	0.072	2.121	0.019	Yes
H2	Technological related factors -> BI	0.454	0.072	6.288	0.000	Yes
H2a	Security -> BI	0.199	0.064	3.119	0.001	Yes
H2b	Privacy -> BI	0.042	0.063	0.665	0.253	No
H2c	Availability -> BI	0.107	0.055	1.971	0.045	Yes
H2d	Facilitating Condition -BI	0.238	0.054	4.400	0.000	Yes
H3	Behavioural Intention ->AB	0.620	0.047	13.217	0.000	Yes

H1, H1a, and H1c are all supported by this level of evidence ( $p < 0.05$ ). Since the expected effect of effort on BI was not statistically significant, H1b cannot be true. The second hypothesis claimed that technological factors, including security (H2a), privacy (H2b), availability (H2c), and facilitating conditions (H2d), had a major impact on behavioral intention. The p-values for security, availability, and enabling conditions were less than 0.05, implying that hypotheses H2, H2a, H2c, and H2d are accepted. Yet, the impact of privacy on BI proved insignificant, leading to the rejection of H2b. The impact of BI on user habits is substantial for H3 with a p-value of just under 0.05. As a result, H4 is supported.

Trust can mediate the relationship between different factors and people's behavioral intention (BI) to use technology. Specifically, the direct effect of trust as a mediator is significant, meaning that trust plays an important role in shaping people's attitudes toward technology. The indirect effect of technological-related factors via trust on BI is also significant, indicating that people are more likely to use technology when they trust it and perceive it as reliable. Similarly, the effect of individual-related factors on BI through trust as a mediator is also significant, suggesting- that people's personal characteristics and beliefs can impact their trust in technology, which in turn influences their intention to use it.

The results indicate that education plays a moderating role in this relationship, meaning that it can influence the strength of the association between individual/ technological - related factors and BI.

#### D. Discussion of Hypotheses Testing

The study found that individual factors, specifically performance expectancy (PE) and social influence (SI), significantly affected the patients' behavior intention (BI) towards adopting these services. The results are consistent with previous studies, suggesting that these factors are crucial in determining patients' willingness to adopt IoT healthcare services. While EE has an insignificant effect on BI, The explanation for this finding is that patients may only anticipate the benefits of these services without fully understanding the effort required to participate in them, in addition, since many individuals have grown accustomed to using contemporary gadgets in their daily lives, it has become easier for them to adapt to new technologies.

The second main hypothesis proposed that technological-related factors have a significant impact on BI, and the results indicated that these factors do have a significant effect on patients' BI. The findings suggest that technological factors are crucial in determining patients' willingness to use IoT healthcare services. This indicated that an increase in the level of technological-related factors will cause an increase in BI toward using IoT healthcare services among these patients. The results of the hypotheses testing revealed that security, availability, and facilitating conditions have a positive and significant impact on the BI, except for the privacy factor. The insignificant effect of privacy on chronic disease patients' behavioral intention (BI) towards adopting IoT healthcare services, may be due to patients' understanding of the difficulties in sharing their information with a third-party. This understanding may be attributed to Malaysia's local laws that protect patients' privacy, which could have influenced patients' willingness to use IoT healthcare services.

According to the third hypothesis, BI has a significant impact on the UB of IoT healthcare services among chronic disease patients. The findings indicated that BI is an important driver of UB.

The fourth hypothesis was related to the mediating effect of trust between individual and technological-related factors and chronic disease patients' BI towards using IoT healthcare services. The findings of the mediating analysis reflected that trust partially mediated the effect of individual-related factors on BI toward IoT adoption. Likewise, trust mediated the effect of technological-related factors on BI in facilitating IoT usage among chronic disease patients. This indicates that trust in the service providers can explain part of the relationship between individual and technological-related factors and BI.

The last hypothesis of this study predicted that gender and experience moderate the effect of individual and technological factors on BI towards using IoT by chronic disease patients. The findings indicated that the prediction was untrue. Gender did not moderate the effect of individual factors on BI nor the effect of technological factors on BI towards the use of IoT by chronic disease patients.

A possible explanation of the insignificant moderating effect of gender is the fact that the IT knowledge level among the patients was similar among male and female patients. In addition, the IoT is easy to use by both genders. In terms of experience or education, this study proposed that education

will moderate the effects of individual and technological-related factors on BI towards using IoT by chronic disease patients. The findings showed that this assumption is true.

## VI. CONCLUSION

The ultimate goal of this research is to examine the factors that influence patients' behavioral intention toward IoT adoption when dealing with chronic illnesses. The study found that patients who were provided with more information about their illness and believed that IoT devices could improve their quality of life were more likely to adopt IoT healthcare services in the form of wearable devices.

To enhance the model's explanatory capacity and originality, the investigation combined the UTAUT and TOE models with SET. The researchers used structured equation modeling (SEM) methods to test the integrated model on a group of Malaysians with chronic illnesses.

The study's findings indicate that individual factors and their dimensions, such as performance expectancy (PE) and social influence (SI), had a significant impact on chronic disease patients' behavior intention (BI) towards IoT healthcare services adoption in Malaysia. These results align with previous studies. The study also observed similar outcomes for technological-related factors and their dimensions, including security, availability, and facilitating conditions. Additionally, the effect of BI on UB was significant. Trust partially mediated the effect of individual and technological-related factors on BI, while education played a moderating role in the latter relationship.

This research is unique in the current literature on the Internet of Things (IoT) because it was undertaken in Malaysia. This study explored a number of hypotheses to shed light on what influences IoT adoption among Malaysians with chronic illnesses, as opposed to the narrower focus of TAM in other studies. Understanding the possibility of implementing IoT healthcare services in Malaysia Legislators and suppliers in the healthcare system are going to find the study results quite helpful. Patients and their loved ones would benefit from this research since the widespread implementation of IoT healthcare services will improve the quality and efficiency with which chronic disease management is handled. Meanwhile, healthcare workers will benefit from this study as well, since the IoT will facilitate the remote performance of their duties.

## VII. LIMITATIONS AND FUTURE WORK

Several limitations should be highlighted in this investigation. Patients with long-term illnesses were the focus of this research. This means that the results only apply to people who have a chronic illness. In light of this, it has been proposed that scientists increase the size of the sample numbers, such as those with mild diseases and frequent hospital visitors. This research looked into the use of Internet of Things healthcare services by people living with chronic diseases in Klang Valley, Malaysia. Researchers may therefore suggest conducting a global study with patients from diverse nations would allow for an additional thorough international comparison of results, as the current study's findings are specific to this demographic.

In this research, we looked at how gender and level of experience/education can act as moderators. There is a lack of information about how these factors influence users' decisions to use IoT, so more research will be needed to better understand the underlying relationships. Some of the observed associations between the studied variables and trust can be attributed to the role of trust as a mediator. To better operationalize trust in online interactions, in service delivery, and in healthcare settings, it is advised that future research investigate the possible role of this characteristic.

In this work, UTAUT, TOE, and SET were integrated to form a model for examining the research aspects. In subsequent works, a similar method could be utilized to more adequately illustrate the aforementioned IoT adoption variation. For instance, the combination of TAM and DOI or TAM and TPB or TAM, TOE, and DOI can be deployed to examine their power in explaining the adoption of IoT or other technologies.

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# Dynamic Difficulty Adjustment of Serious-Game Based on Synthetic Fog using Activity Theory Model

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**Abstract**—This study used the activity theory model to determine the dynamic difficulty adjustment of serious-game based on synthetic fog. The difference in difficulty levels was generated in a 3-dimensional game environment with changes determined by applying varying fog thickness. The activity theory model in serious-games aims to facilitate development analysis in terms of learning content, the equipment used, and the resulting in-game action. The difficulty levels vary according to the player's ability because the game is expected to reduce boredom and frustration. Furthermore, this study simulated scenarios of various conditions, scores, time remaining, and the lives of synthetic players. The experimental results showed that the system can change the game environment with different fog thicknesses according to synthetic player parameters.

**Keywords**—Dynamic difficulty adjustment; serious-game; activity theory model; synthetic fog; synthetic player

## I. INTRODUCTION

One of the most significant challenges in successful teaching is preparing a suitable learning environment [1]. Several studies have shown that appropriate teaching methods are usually active, engaging, goal-oriented, [2] generate spontaneous random feedback, and provide solutions to challenges [2], [3]. The last two characteristics are also possessed through instructional content when playing games embedded in a computer [4]. Scientifically, this category of game is called a serious game [5], and it aids in making the learning process more interesting, fun, comfortable, effective, improves learning performance, student's skills, and behavior [5], [6].

This research aims to change the habits, ways of thinking, views, increase knowledge, and train the soft skills of serious-game players. It also increases engagement, extrinsic and intrinsic motivation, creates awareness, and analyzes games developed to focus on a particular lesson, which can be played in the classroom or at home.

Carvalho et al. [7], [8] proposed a scheme to analyze and evaluate various student experiences with learning material for later aggregation and study. According to Callaghan et al. [9], the serious-game view is complex and covers three principal activities, namely gaming, learning, and instructional, comprising the student and the teacher. The game consists of basic supplementary attempts or resources obtained from the teacher.

The Activity Theory Model Serious-Game [10] (ATMSG) method [8] comprises four analytical phases. In the first stage, the teacher explains the critical tasks relevant to the system action and defines the course and theme. The second stage establishes a sequence as a map to help define the game's core elements and provide an initial point for determining the interlinked aspects of the system framework. In the third stage, the trainer describes elements relevant to each node of the game [11] order. While in the last phase, the teacher collects suitable acts, resources, and targets that equally belong to the game order. After completing the phase, the trainer has a summary of the play structure, knowledge, and didactic components, as well as their application.

However, some weaknesses are associated with the serious game, such as difficulty in playing, which sometimes frustrates the players. To overcome these weaknesses, the player must achieve a state of "flow" [12][13], which is usually characterized by sustained concentration and increased achievement. Several studies proposed Dynamic Difficulty Adjustment (DDA) [14]–[19], a mechanism to dynamically maintain a game's difficulty level [20]–[22] to ensure an increase in user's interest.

The mechanism of dynamic difficulty adjustment starts with processing data from players and enemies in the game and changing the difficulty level [23]–[26] based on the player's skill. The attributes of both parties are usually changed to dynamic, and the more skilled the player, the greater the possibility of the system limiting resources and the harder it will be to beat the enemies. However, when the player suffers defeat, the game will provide weaker enemies and abundant resources [27].

Several studies have examined DDA in games, such as computer-controlled players [27], and inferred difficulty curves from real-time data [28]. These studies developed automatic difficulty selection [29], applied appropriate difficulty based on player information [30], determined the effect of difficulty setting on trust players [31], and produced dynamic game content based on evidence-centred design [32]. However, this study will adopt simpler and faster techniques [32] by using a dynamic value to adjust the game's difficulty level.

This study proposes the automatic DDA based on synthetic fog setting to reduce players' visibility. Artificial fog



technique is widely used to measure fog removal techniques from natural images [33]–[36]. Nevertheless, artificial fog is more used to produce difficulty when playing games, adding a mysterious experience and increasing tension. This technique has not been previously used in preliminary studies to determine difficulty level because artificial fog is an art without any standards. Moreover, the in-game synthetic fog only serves as a compliment.

A synthetic agent [37][38]–[41] was used to determine the serious-game [42] dynamic difficulty levels that should be achieved based on the final target scenarios, which is modified at each level.

## II. RELATED WORKS

A study conducted in 2015 [43] proposed setting the difficulty of the enemy character, which can change their nature and behaviour, based on the game player's ability. It only focused on changes in the conduct of the enemy's character with the difficulty setting method completed [44] using an evolutionary algorithm. Lach [45] used an adaptive evolutionary algorithm to regulate non-player characters' behaviour. These approaches do not provide details of the framework used for the serious-game foundation.

Callaghan proposed using a serious-game framework based on activity models [8] to integrate analytical techniques in engineering lessons in 2018 [9]. However, the approach taken does not consider adaptive difficulty management.

Another research article [30] proposed using a fuzzy coordinator for dynamic difficulty setting in commercial games applied to bots. Although the study described the behaviour of smart bots, which have a variety of capabilities, it was not applied in serious games.

A dynamic process was used by [29] to determine the difficulty setting in video games without stating the use of methods and parameters set dynamically at each level. The report by [28] also proposed a dynamic difficulty setting, for puzzle games, using a rating system. Preliminary studies [28], [29] have not implemented the serious-game strategy because they do not use machine learning methods.

A previous study by [32] proposed a dynamic difficulty setting in game-based learning using the ECD framework to design and assign each student's competency. A dynamic difficulty setting was designed by changing the non-player character's attributes that can balance the abilities of students who are playing dynamically. The study focused on educational content questions without considering the game environment setting. It also introduced the ECD framework for dynamic difficulty management [32], focusing on mathematics using standard Indonesian student exams. These studies focused on the evidence used as a reference to process dynamics more accurately and effectively.

The study by [27] proposes creating an enemy using the dynamic difficulty setting and applying it to the business content. The dynamic difficulty setting handles two strategies, namely enemies who can decide strategies and provide threats

to players, who are expected to be more involved in the game.

An architecture was proposed in [46] to produce enemy formations in a procedurally two-dimensional game. This was carried out to determine the variable difficulty curve and enemy variation used to design an appropriate difficulty setting based on the fitness function calculation [47]. The study by [46] presented the dynamic difficulty adjustment with a skill chain and ranking system used to balance the game's difficulty. Their discussion suggested that the skill chain can be useful for getting players to complete a higher number of tasks with a greater difficulty level.

Studies on the dynamic difficulty setting of the serious game are challenging to explore. To date, no system has been proposed, using the concept of the activity theory model [9], irrespective of its numerous advantages and convenience in developing and analyzing the learning strategies of the games.

Meanwhile, the serious-game dynamic difficulty setting system with the activity theory model has a more detailed division and is more suitable for an educational game. Several studies have discussed the dynamic difficulty settings [27][48][47] aimed at enemy characters capable of deciding strategic behaviour and producing appropriate attack formations. It also uses skill chains to produce balance by providing several missions with a higher level of difficulty. However, this present study aims to design a dynamic difficulty management system which uses the activity theory model to determine environmental changes and the difficulty level of the serious game. This process is carried out by applying synthetic agents as substitutes for players to facilitate analysis. The contributions of this research are described in the following paragraphs.

First, a dynamic difficulty adjustment is proposed in the activity theory model of the serious-game. The system reads the player's parameters' initial value and then re-reads it after the player receives an award. Based on reading this second parameter, the system can dynamically adjust the difficulty level. Furthermore, it changes player and game parameters, saved in the settings log, to produce a new level of play. In this study, the virtual environment system can interact with players.

Second, the change in difficulty is designed using the artificial fog model, where the thickness can be calculated according to a heterogeneous distribution. This artificial haze can prevent players from recognizing objects that must be collected as part of the learning mission that must be achieved. Third, synthetic agents can be used to test the system for difficulty level changes, making it easier to analyze and more comfortable to fix.

Several sections of this research describe the development, testing, and analysis of file systems. Section III discusses the introduction to the dynamic difficulty adjustment, the activity theory serious-game model, the dynamic difficulty adjustment model, the artificial fog model and the application of synthetic agents. Furthermore, the experimental results and the discussion are shown in Section IV, while Section V concludes the research.

### III. DYNAMIC DIFFICULTY ADJUSTMENT

The dynamic difficulty adjustment process was carried out using parameters at an entry-level. When players increase or decrease a specific parameter, they have new values, which add to the old one to create a new parameter. Therefore, from new parameters, the game starts a new level, which splits its parameters into HVHL and LVHL. HVHL represents higher value parameters used to determine health and score. A player with high health and score is tagged better; hence the difficulty level should be adjusted. LVHL reflects a parameter that indicates a better player for a higher value [32]. This parameter is increased when the player solves a game problem quickly. Table I shows the game's parameters. Curriculum and the Education Unit Level Curriculum[49], as shown in Table II.

Compute each parameter's value by determining the skill value ( $efF_i$ ), which is determined using equation (1). It calculates the player's performance, which is dependent on the current achievement parameter ( $F_{val_i}$ ), the maximum ( $F_{max_i}$ ), and the minimum ( $F_{min_i}$ ) values.

Measure the overall player value and enemy's skill to specify the total amount ( $ef$ ), the player or opponents abilities using equation (2). Equation (2) includes the weight of each parameter. The value serves as the significance of a parameter used to define the players' performance, as shown in Table III. For a detailed explanation, please refer to [14]–[19].

$$efF_i = \begin{cases} \frac{F_{val_i} - F_{min_i}}{F_{max_i} - F_{min_i}} & \text{for HVHL} \\ \frac{F_{max_i} - F_{val_i}}{F_{max_i} - F_{min_i}} & \text{for LVHL} \end{cases} \quad (1)$$

$$ef = \frac{\sum_{i=1}^n (efF_i * weight_i)}{\sum_{i=1}^n weight_i} \quad (2)$$

Analyze the skill values of the player and the opponent ( $diff\ ef$ ) to determine whether the change is necessary using equation (3). The  $efp$  and denotes the player's and the enemy's skill value, which is measured using equation (2).

$$diff\ ef = > p_{lim} * efp \quad (3)$$

Compute the arrangement value and replace the opponent parameters. The game parameters are modified using equations (4) and (5).

$$adj\ Fi = \begin{cases} diff\ ef * (F_{max_i} - F_{min_i}) & \text{for HVHL} \\ -diff\ ef * (F_{max_i} - F_{min_i}) & \text{for LVHL} \end{cases} \quad (4)$$

$$F_{val_{0,i}} = \begin{cases} F_{val_{old_{0,i}}} + adjF_i & \text{for } efp > efo \\ F_{val_{old_{0,i}}} - adjF_i & \text{for } efp < efo \end{cases} \quad (5)$$

$adj\ Fi$  and  $F_{val_{0,i}}$  denote the appropriate value and current modification values of the players. This indicates that the device lowers the skills of players' previous opponent and attributes  $F_{val_{0,i}}$  for them to beat the enemy more efficiently. The method is continuously used until the players have solved all problems or their health points equal zero.

#### A. Activity Theory Model Serious-Game

The gameplay consists of 6 steps, as shown in Fig. 1. In phase 1, the player is asked to take action by customizing the avatar or choosing the model after entering the game through its configuration section. Furthermore, in phase, players learn how to play and assess the game based on the activity model. In phase 3, they face the choice to choose a new mission or continue with the old one. When players select a new task, they play a puzzle, and when they decide not to select a new mission, the game system provides suggestions. The puzzle played in phase 4 consists of the tool in the form of tiles. The game's goal is to visualize the changes in the value achieved. Students perform tasks to fulfil missions, overcome challenges to remember knowledge, and focus on work.

Furthermore, in phase 5, the game awards added values to determine additional player abilities and other bonuses. After receiving the award, players face another challenge, which is an opportunity to increase the rewards they have received until the maximum value is achieved. There are three sides of players on the activity theory model, namely the play, learning, and intrinsic instruction. The player seeks help to learn the game interface using a pre-installed tutorial. From a learning point of view, the player analyzes the device provided by the game in the form of suggestions. The intrinsic instruction process enables the player to demonstrate and provide the player with learning instructions. Game systems assess, measure performance, and give feedback to players. Phase 6 evaluates, appreciates and improves the performance [5], [9], [46], [50]–[52].

TABLE I. GAME'S PARAMETERS

Subject	Group's Parameter	Process	Game's Parameter
Player	HVHL	Number of correct answers	Score
	LVHL	The time to fix the task	Action Time
Enemy	HVHL	Enemy knack to break the problem with distinct form of query	Strength
	LVHL	knack to resolve matter in restricted time	Velocity

TABLE II. HIGHEST AND LOWEST VALUE OF EACH PARAMETER

No.	Attribute in-game	Value	
		Highest Value/Fmax	Lowest Value/Fmin
1.	Score	100	45
2.	Action Time	210	0
3.	Strength	100	45
4.	Velocity	250	0

TABLE III. PARAMETER'S WEIGHT

Parameter	Weight
Score/Strength	0.8765
Action Time/Velocity	0.1235

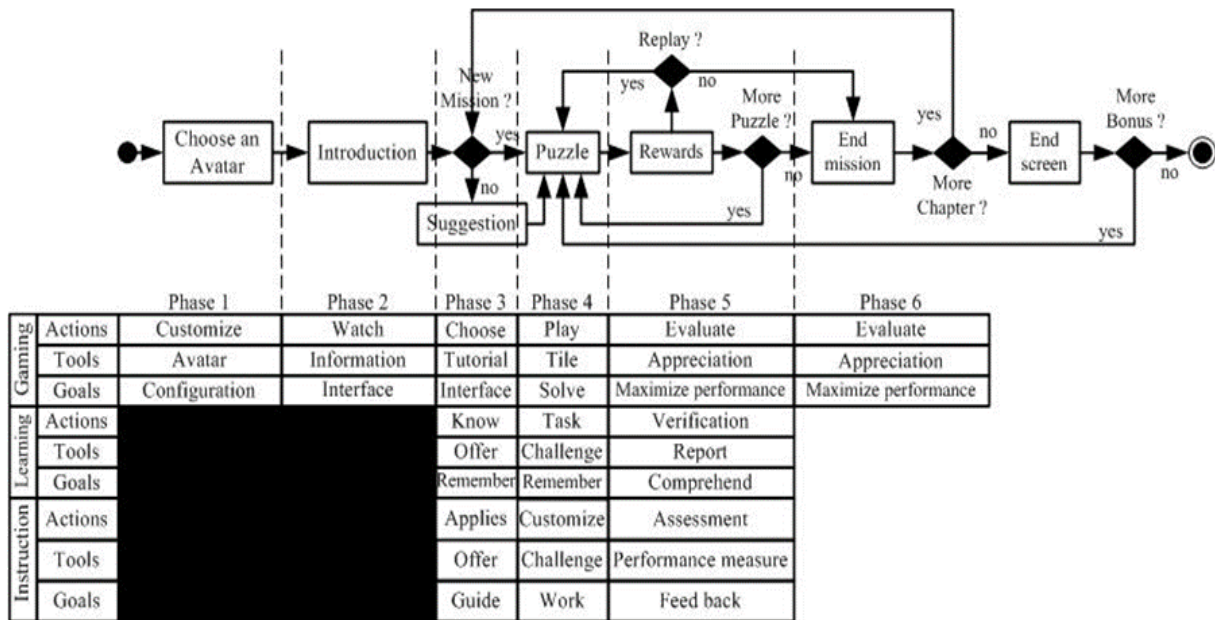


Fig. 1. Phases of Gameplay.

**B. Dynamic Difficulty Adjustment Model**

The process applied when the player successfully answers the question is analyzed in the dynamic difficulty adjustment model. There are four main processes in the application of FDDACP method in the game, these include 1) Collect Enemy's and Player's Attributes, 2) Adjust Level of Difficulty, 3) Change Enemy's and Player Attributes and 4) Save changes in Log. This process is shown in Fig. 2 [32].

**C. Dynamic Difficulty Adjustment Model in Activity Theory Model Serious Game**

Fig. 3 shows the mechanism of implementing the dynamic difficulty system in a serious game. This process is applied when the player fulfils the associated task. The proposed method in this research comprises the following six stages.

- 1) Read the initial parameter value of the player. This mechanism collects the entire parameter value before the player starts the game.
- 2) Player puzzle. After several times, the player receives the rewards, and the system reads the parameter value. This step processed the parameter value provided by the reward step and used it as input for the system adjustment method.

3) Adjust level using dynamic difficulty adjustment processes the parameter value provided by the 2<sup>nd</sup> step and calculates it to determine the mechanism.

4) The change of the player's parameter is carried out based on the adjustment value. For instance, if players are about to lose, the game gives them more time to answer the next question in peace.

5) Save Log Settings. This method saves the process of change in the game to see where the student needs change.

6) Create a new level. The change value is stored in the Log function to generate a new level.

When the player asks questions in the game, all processes above are completed. The next question will change the parameter as long as the player is safe.

**D. Synthetic Fog Model**

The use of synthetic foggy imagery aims to facilitate the creation of three-dimensional fog in a game. Therefore, changes can be made more measurable to reduce manufacturing time. The standard size of the PSNR and SSIM index is used to facilitate evaluation and comparison and a more detailed explanation can be seen in the reference [36][34]. Fig. 4 shows a different fog environment.

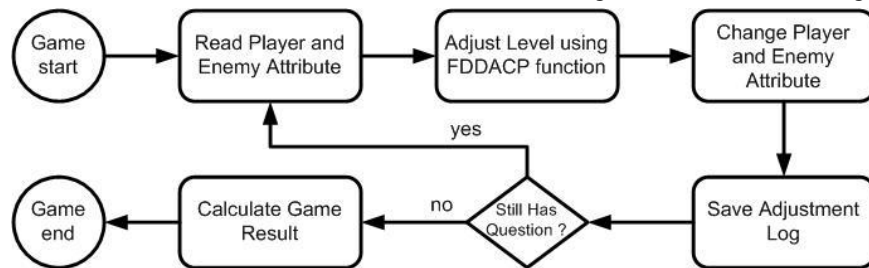


Fig. 2. Dynamic difficulty adjustment model.

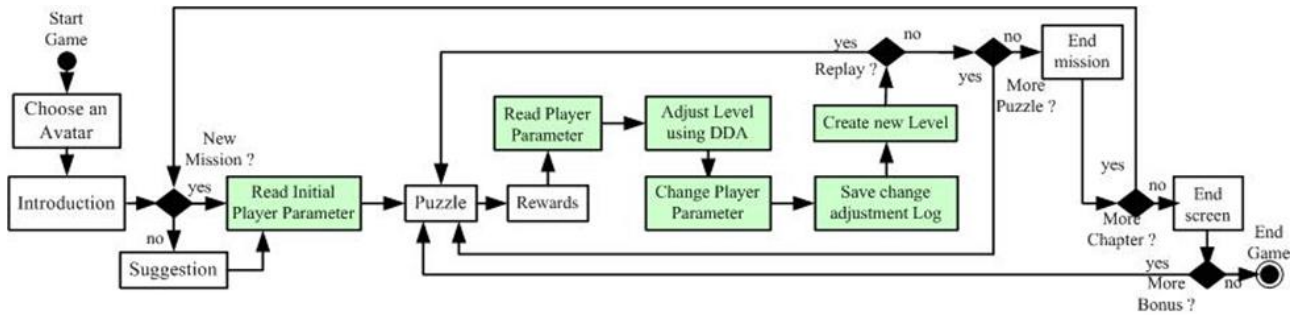


Fig. 3. Proposed dynamic difficulty adjustment in activity theory model serious-game.

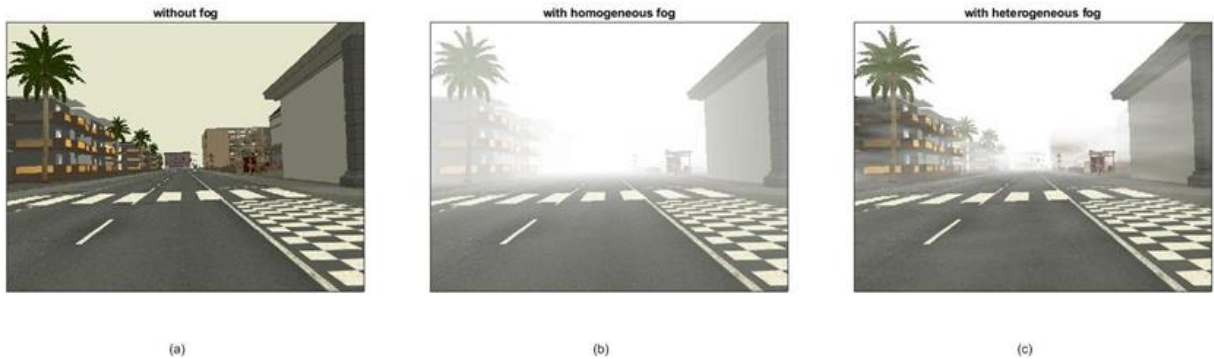


Fig. 4. The different fog environments. (a) No-Fog environment, (b) Homogeneous fog, (c) Heterogenous fog.

#### IV. RESULT AND DISCUSSION

##### A. Dynamic Difficulty Calculation

The results obtained from equations (1) to (6) are shown in Table IV. It comprises two scenarios, namely the enemy is lower and higher than the player. Therefore, for the first case, the parameter power was 1 (HVHL), and the speed was 100 (LVHL). This means that when the player reaches a score and time-act of 10 and 43, the game system will change, and in the next stage, the enemy's parameters increase hence the power and speed become 8.88 and 96.65. When the player's achievement is almost the same, the score becomes ten, and the time-act 40, hence the power parameter increases to 9.32, while the speed drops to 93.31.

Furthermore, in 2<sup>nd</sup> scenario, the enemy was higher with power and speed value of 15 and 30, while the player's achievement remained the same as in the previous scenario, at a score and time-act of ten and 43. When the power decreased to 13.62 and speed increased to 30.76, with the player's score, time-act, power and speed parameters of 10, 40, 10.08, and

32.11.

##### B. Synthetic Fog

This research used the score, time remaining, and player life parameters to determine the opponent's function in the game system. At the beginning of the game, players were not allowed to fight their opponents, but against time, score, and life, known as HVHL. The time remaining and the player's health are denoted with LVHL. The DDA changes the fog's thickness to hinder players from fulfilling the mission given. The fog used in this study is synthetic [36][34], as shown in Table V. Therefore, the thinner the fog, the lower the difficulty level generated, and the thicker the fog, the harder it becomes.

The haze is divided into ten parts, as shown in Table V. It starts from level 0 to 9, which denotes dense to extremely clear. In the game, fog level 0 (thick) means it is the most challenging, and 9 (extremely clear) denotes easy, as shown in Table VI.

TABLE IV. EXAMPLE OF THE GAME SCENARIO

Scenario 1 <sup>st</sup>				Scenario 2 <sup>nd</sup>			
Enemy = Low				Enemy = High			
HVHL	LVHL	HVHL	LVHL	HVHL	LVHL	HVHL	LVHL
Score	Time-act	Power (enemy)	Speed (enemy)	Score	Time-act	Power (enemy)	Speed (enemy)
10	43	1	100	10	43	15	30
10	40	8.88	96.65	10	40	13.62	30.76
		9.32	93.31			10.08	32.11

TABLE V. DIVISION OF FOG IN INTERNATIONAL VISIBILITY [36][34]

Haze level	Haze	Visibility
0	Dense fog	<50 m
1	Thick fog	50 - 200 m
2	Moderate fog	200 – 500 m
3	Light fog	500 m – 1 km
4	Thin fog	1 km – 2 km
5	Haze	2 km – 4 km
6	Light haze	4 km – 10 km
7	Clear	10 km – 20 km
8	Very clear	20 km – 20 km
9	Extremely clear	>50 km

TABLE VI. FOG/HAZE TYPE FOR EACH LEVEL IN THE GAME

Game level	Fog/Haze type
Level 1	Extremely clear
Level 2	Very clear
Level 3	Clear
Level 4	Light haze
Level 5	Haze
Level 6	Thin fog
Level 7	Light fog
Level 8	Moderate fog
Level 9	Thick fog
Level 10	Dense fog

### C. Game Screenshot

The proposed game is shown in Fig. 5, where Fig. 5(a) is a screen belonging to the synthetic player, which comprises the time remaining, the achieved and target scores, the game difficulty level, and the synthetic player's life. Fig. 5(b) is the mission the synthetic player needs to complete, while Fig. 5(c) is the object to avoid. If the task can be accomplished, points will be added, while a decrease in the synthetic player's life is obtained when the object is held.

Fig. 6(a) and 6(b) represent the game's 3<sup>rd</sup> and 4<sup>th</sup> levels. The mission and object positions that must be avoided are visible in both figures. Fig. 7(a) and 7(b) show the 3<sup>rd</sup> and 5<sup>th</sup> levels of the game and its conditions. A thicker haze surrounds the game environment compared to Fig. 6(b). In Fig. 7(b), the mission positions to be reached and the objects to be avoided are increasingly invisible due to the thick fog.

Fig. 8(a) shows the 3<sup>rd</sup> level of the game, as illustrated in Fig. 6(a) and 7(a) It also shows the mission positions and objects to avoid. Meanwhile, Fig. 8(b) shows the condition when the game reaches the 9<sup>th</sup> level. Apart from the mission and invisibility of the objects to be avoided, the trees in front of the synthetic player also start to disappear.

### D. Dynamic Difficulty Level Selection

The selection of dynamic difficulty levels is shown in

Table VII. It indicates several different parameters owned by a synthetic player, such as score, student time, life, and health of the synthetic player. The following column shows changes in the level of difficulty with and without using DDA. The scoring parameter, remaining time and life of 12, 63 and 27 are shown in the third row. According to the settings based on DDA, with and without the game, levels are 3 and 2. The challenge increases with greater excitement when the player is at level 3.

Furthermore, when the score level drops on the scenario 4<sup>th</sup> to 10, the DDA will set the game level back to level 2. In contrast, in the settings without using the game level is increased to level 3 because it will undoubtedly cause players to feel frustrated and easily bored with the game.

Another example is seen in scenarios 7 to 10 in yellow highlight, where the setting with and without DDA determines the difficulty level to be 7 and 5 in green highlight, respectively. When the synthetic player score increases to 49 in red highlight, the setting uses DDA of the difficulty level rises to 8 in magenta highlight. Furthermore, the synthetic player score increases to 52 and 54 with the rise in the difficulty level to 10.

This is different from the difficulty level settings without DDA because when the synthetic player score is 35, the game system without DDA determines the difficulty level at 5 in green highlight. When synthetic player's score increase to 49, 52, and 54, the game difficulty level is suddenly raised to level 10 shown in grey highlight, which will lead to a sudden rise, frustrating the player and making them more reluctant to continue the game.

The phenomena in Table VII are graphically visualized, as shown in Fig. 9. The graph shows that the increase in the difficulty level using DDA is progressing, as indicated by the purple line.

A synthetic player is used to provide the advantage of testing many times without worrying about boredom. Fig. 10 is an experimental visualization of 10 repetitions, where each experiment is carried out 1,000 times to determine the difficulty/gameplay change.

TABLE VII. THE GAME LEVEL SELECTION COMPARISON

Scenario	Input Parameter			Game Level	
	Score	Time Remain	Player Life	DDA	without DDA
1	2	70	10	1	1
2	4	66	28	1	1
3	12	63	27	3	2
4	10	47	35	2	3
5	14	42	38	3	3
6	26	36	31	4	4
7	35	28	38	7	5
8	49	25	40	8	10
9	52	11	50	9	10
10	54	9	65	10	10



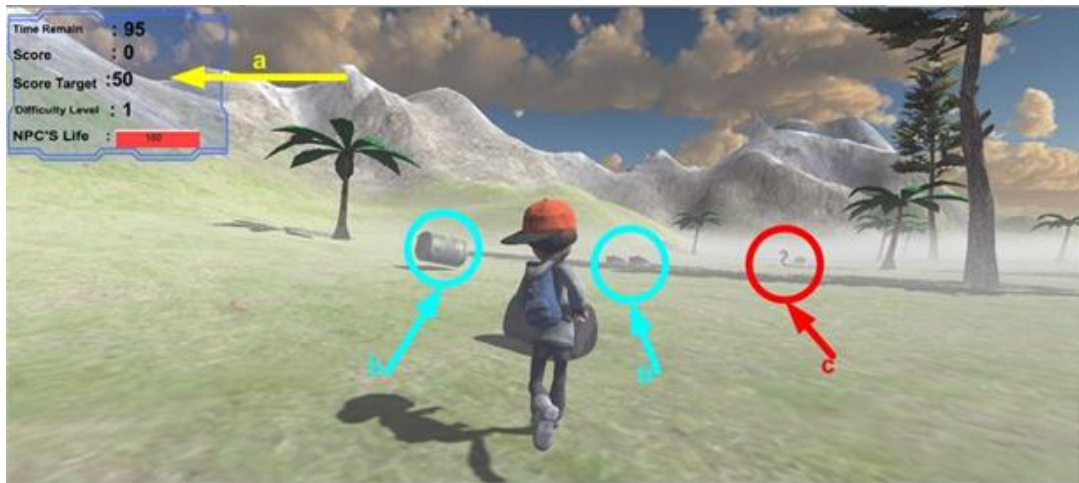


Fig. 5. (a) Panel belongs to synthetic players, (b) The mission to complete, (c) The object to avoid.



Fig. 6. The game screenshot: (a) The mission and the object in the 3<sup>rd</sup> level are still visible, (b) The mission and the objects are still visible in the 4<sup>th</sup> level.



Fig. 7. The game screenshot: (a) The mission and the objects in the 3<sup>rd</sup> level are still visible, the synthetic haze covers (b) The mission and the objects in the 5<sup>th</sup> level.



Fig. 8. The game screenshot: (a) The mission and the objects in the 3<sup>rd</sup> level are still visible, the synthetic haze covers (b) The mission and the objects in the 9<sup>th</sup> level.



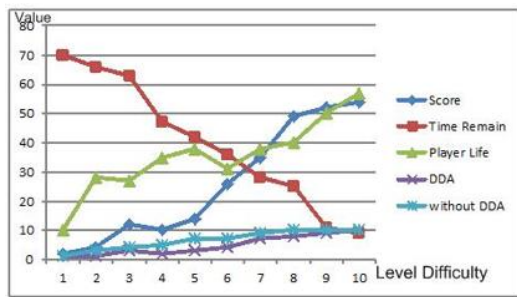


Fig. 9. The graph shows a gradual change in difficulty level.

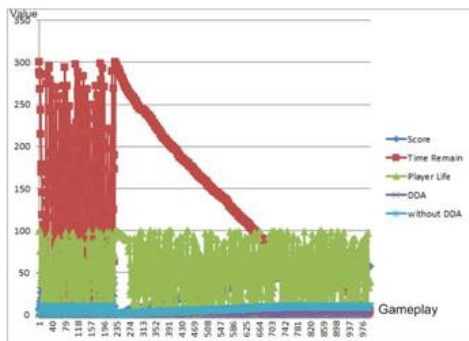


Fig. 10. The visualization of 1,000 times the difficulty level/gameplay change.

E. Comparison

This study produces a dynamic difficulty adjustment system applied to a serious game based on the activity theory model for educational material in 3D format. It differs in characteristics compared to the application of DDA in other studies. Table VIII shows these differences in detail with reference [32] to students and determining what has changed in enemy behaviour without implementing the serious-game model of activity theory. This is in accordance with the study by [27] on applying DDA in business and in-game. The study [48] is a study that focuses on setting up enemy formations in the 2-dimensional role play game genre. Adjustments are made based on variable difficulty curves and enemy variations of the fitness function. Preliminary study by [47] implements DDA using a ranking system to balance gameplay. When compared with the four studies, this research has similar characteristics [32]. However, the advantage of environmental changes resulting from DDA is applied in a serious-game-based activity theory model and tested using a synthetic player.

TABLE VIII. DIFFERENCE IN CHARACTERISTICS COMPARED TO THE APPLICATION OF DDA IN OTHER STUDIES.

References	3 D	Synthetic player	Environment change	DDA -ML	Education	Activity Theory Model Serious-Game
[32]	-	-	-	√	√	-
[27]	-	-	-	-	√	-
[48]	-	-	-	√	-	-
[47]	-	-	-	√	-	-
proposed	√	√	√	√	√	√

V. CONCLUSION

In conclusion, this study proposed a dynamic difficulty setting system to overcome boredom and frustration when playing educational games. The game format selected is serious-game with an activity theory model, which details each goal into instruction, learning, and games. The serious-game comprises the same scope, namely action, equipment, and targets, making it easier to design a serious-game for specific and precise educational needs.

At the experimental stage, the serious-game system building was combined with a dynamic difficulty setting to obtain the players' abilities and skills. Furthermore, the limited visibility at different levels of difficulty led to the proposal of a 3D serious-game, which does not need the process of determining the characters in the early stages of the game. Designing a serious game for education determines the dynamic difficulty setting and educational content. The experimental results showed that the game system created can adjust the game environment smoothly.

Compared to previous studies, the system in this study has the advantage of using a serious-game model that focuses on improving student knowledge, involving smooth environmental changes, and avoiding competition with enemy characters. Besides, the proposed system is also able to follow the abilities of players who are not always the same.

Our next study is to add educational material settings for different player achievements. So not only setting the fog thickness but also considering the setting of educational materials. And we added artificial intelligence to make the changes more subtle.

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# Detection of Breast Cancer using Convolutional Neural Networks with Learning Transfer Mechanisms

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**Abstract**—Breast cancer is the leading cause of mortality in women worldwide. One of the biggest challenges for physicians and technological support systems is early detection, because it is easier to treat and establish curative treatments. Currently, assistive technology systems use images to detect patterns of behavior with respect to patients who have been found to have some type of cancer. This work aims to identify and classify breast cancer using deep learning models and convolutional neural networks (CNN) with transfer learning. For the breast cancer detection process, 7803 real images with benign and malignant labels were used, which were provided by BreakHis on the Kaggle platform. The convolutional basis (parameters) of pre-trained models VGG16, VGG19, Resnet-50 and Inception-V3 were used. The TensorFlow framework, keras and Python libraries were also used to retrain the parameters of the models proposed for this study. Metrics such as accuracy, error ratio, precision, recall and f1-score were used to evaluate the models. The results show that the models based on VGG16, VGG19 ResNet-50 and Inception-V3 obtain an accuracy of 88%, 86%, 97% and 96% respectively, recall of 84%, 82%, 96% and 96% respectively, in addition to f1-score of 86%, 83%, 96% and 95% respectively. It is concluded that the model that shows the best results is Resnet-50, obtaining high results in all the metrics considered, although it should be noted that the Inception-V3 model achieves very similar results in relation to Resnet-50, in all the metrics. In addition, these two models exceed the 95% threshold of correct results.

**Keywords**—Convolutional neural networks; transfer learning; deep learning; classification; breast cancer

## I. INTRODUCTION

Breast cancer is the second most common cancer in women globally with more than 2.2 million cases in 2020. Breast cancer is the leading cause of mortality in women worldwide, as it is estimated that, in 2020, this carcinoma killed about 685 000 women [1]. This can be classified according to its histological basis into in situ and invasive carcinoma. Regarding the diagnosis of this disease, the evidence recommends that women over 40 years of age should undergo a screening mammogram every two years at the latest [2]. Mammography is the most used technique for the diagnosis of breast cancer; however, this test usually requires other ancillary tests to accurately determine the status of the tumor, among which are ultrasound [3] and tissue sampling [4]. Therapeutic treatment consists of debulking surgery, radiotherapy, endocrine targeted therapy and chemotherapy [5]. Among the surgical interventions, segmental mastectomy has proven to be effective in the treatment of tumors detected at early ages,

especially when combined with the use of radiotherapy [6]. From these interventions, a sufficiently representative tissue sample is also obtained to perform the histopathological studies necessary for the determination of the benign or malignant nature of the tumor, which is why these images are used for the work. The main problem is how to identify and classify breast cancer using deep learning models. Also, as specific problems we have What kind of models can be applied? How to evaluate each of the models for the proposed case?

This paper presents four CNN models that can discover the features in the images, such as edges and corners to detect the type of breast cancer from biopsies, which can be used by medical centers to detect carcinoma in their patients. The four deep CNN models were programmed to classify the images into two types: benign and malignant. The CNN-based transfer learning models used for this research work are: VGG16, VGG19, ResNet50, and Inceptionv3, these models were programmed with the database hosted in Kaggle. The four CNN models seek to diagnose the type of breast carcinoma from histological breast images. It should be noted that the models used do not have the same number of depth layers, nor programming architecture, so the results are different in terms of accuracy. The objective of this work is to identify and classify breast cancer using Transfer Learning.

This paper is organized in the following order: In Section II a review of related works was performed, in Section III the methodology used for training the models is synthesized, in Section IV the results after experimentation are presented in addition to the discussion and in Section V the paper is concluded.

## II. RELATED WORK

In recent years, the concept of CNN has started to be used in fields such as medicine. This is because since their introduction they have presented very good results in image processing, as stated by LeCun in [7], [8].

The capacity of CNNs in image processing has led researchers to start using them in the classification of histological images, as is the case of [9], where they carried out a work for the classification between benignity and malignancy of images obtained from breast tumors in a Brazilian laboratory, a model with AlexNet architecture was trained using four different strategies to deal with the high resolution of the images presented; obtaining results close to 85% in all strategies. Among the results of the work, an accuracy of 89.6

+/- 6.5% stands out. In a different work it can be observed that the applications expand to other medical fields, as is the case of [10] where a model based on the Inception V3 architecture is trained to detect the stress of a person based on thermal images of points of interest of the head. The results obtained were good, reaching an accuracy of 88% when 5 stress classes were used, but 97% when these 5 classes were divided into 2 with the labels "No stress" (classes 1 and 2) and "Stress" (classes 3, 4 and 5). The authors, in [11] developed a CNN model to segment the various types of breast abnormalities, based on the pretrained ResNet 50 model, achieving a recognition rate of 88%. Similarly, in [12] used 3 CNN models, Inception V3, Inception-ResNet V2 and ResNet-101, to predict whether patients with primary breast cancer will metastasize, based on their ultrasound images, the results were compared with the performance of 5 radiologists, having positive results in the two tests performed, in A and B with an area under the receiver operating characteristic curve (AUC) of 0.9 and 0.89, a sensitivity of 82% and 85% and a specificity of 0.79% and 72%, respectively. Another study by in [13] implemented a method to classify breast cancer into benign and malignant based on a CNN, AlexNet. The results obtained show that AlexNet obtained an accuracy greater than 99%, superior to existing algorithms.

The following Table I summarizes the results obtained by the authors described in the previous points.

In [14] used a new advanced methodology that develops machine learning algorithms, such as deep learning algorithms, to accurately classify breast cancer. Deep learning algorithms are fully automatic in learning, feature extraction and classification and are suitable for all images, from natural images to medical images. The authors used a deep convolutional neural network, AlexNet, to classify breast cancer in mammography images. The performance of the proposed convolutional network structure they evaluated and compared with existing algorithms. In [15], four convolutional neural network (CNN) models were proposed for pneumonia detection in chest radio-graphs. They were trained to classify radiographs into two types: normal and pneumonia, using multiple convolutional layers. The models used in this work are pre-trained: VGG16, VGG19, ResNet50 and InceptionV3. The metrics used to evaluate the results are accuracy, recall and F1 score. The results showed that the Inceptionv3 model performed the best with 72.9% accuracy, 93.7% recall and 72.9% F1 score. 72.9% accuracy, 93.7% recall and 82% F1 score. This shows that CNN models are suitable for detecting pneumonia with high accuracy.

TABLE I. SUMMARY OF MODEL PERFORMANCE METRICS ACCORDING TO AUTHORS

Authors	Accuracy	Error rate	Other indicators
Fabiol, O. Luiz, P. Caroline and H. Laurent [10]	85% 88.9%	--6.5	-
S. T. Ahmed and S. M. Kadhem [11]	88% - 97%	-	-
Maleika, B. Nazmeen, D. Wasiimah, N. Shaista, G. Xiaohong, Sinha GR [12]	88%	-	-
Z. Li, W. Xing, H. Shu, W. Ge-Ge, Y. Hua, W. Qi [13]	82%- 85%	-	AUC: 0.8- 0.9 sensitivity 82% specificity 79%

### III. METHODOLOGY

This section details the procedure or methodology used for training and fitting CNN-based models from data acquisition to validation (evaluation) of results. Fig. 1 summarizes the 8-step process for model fitting, and subsequently the evaluation of the fit or generalization using data that the model has not seen (data test). This process starts with the data source, is ingested into the work environment for division into training and test data, followed by a normalization phase, then images are generated from the existing ones with the data augmentation technique, then transfer learning and fine tuning are applied to create models adapted to the case, then goes the training and adjustment, then metrics are used for model evaluation and model validation, if the model exceeds the threshold the final model is obtained otherwise it returns to the phase of pre-trained models for application of fine tuning until the model is valid.

#### A. Data Source

The breast cancer histopathology images acquired from patients have been obtained from the Kaggle platform, whose main source and original publication was provided by "Laboratory of Vision, Robotics and Imaging (VRI)" at the following link <https://web.inf.ufpr.br/vri/databases/breast-cancer-histopathological-database-breakhis/>, where there are two folders, one for each class, the first one for benign type images and the other one for malignant type images. The data source provides 7803 histopathology images obtained from the platform mentioned in the previous point, such images are provided in two types, 2479 images correspond to benign type and 5324 are of malignant type, in Fig. 2 a sample can be observed.



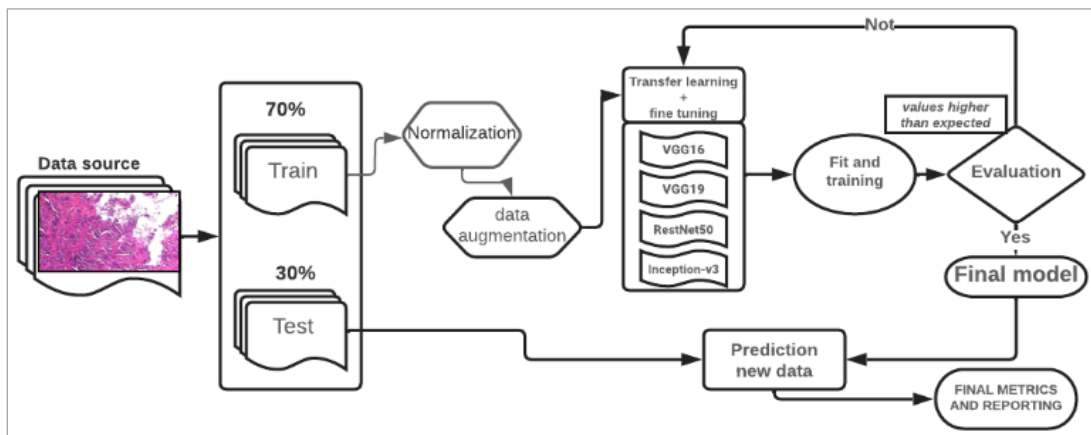


Fig. 1. Flow diagram corresponding to the phases of the silver-plated system.

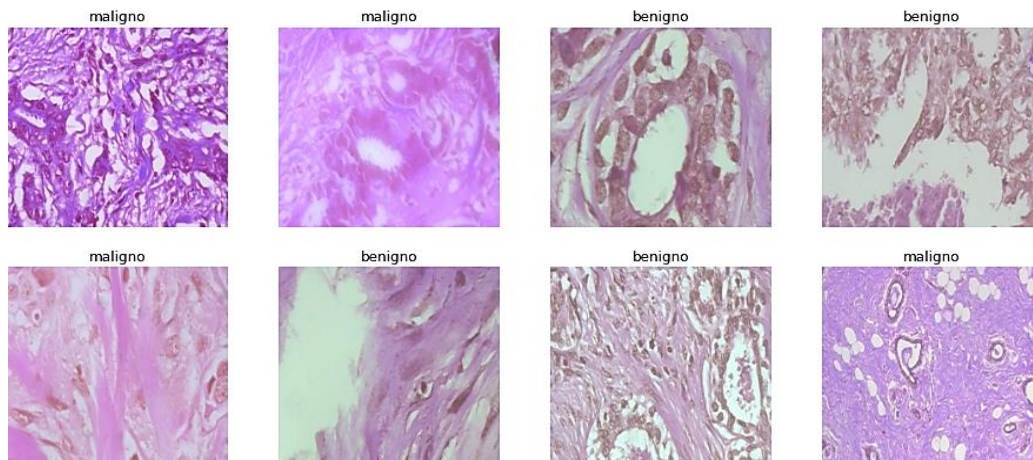


Fig. 2. Sample histopathology images obtained from the source.

### B. Data Train and Test

Once the images have been ingested, they have been divided into training and test data, the criterion is 70% to train the models and 30% to evaluate results, this will allow determining the generalization of the models.

### C. Normalization

The original images go through a normalization process, to avoid problems at the time of training [16][17], the criterion used is the division 1 between the maximum value of the pixels, for the case 1/255, which gives values between the range of 0 and 1.

### D. Data Augmentation

The objective of data augmentation is to generate more images from the existing ones [18][19], the criteria used are: random rotations of 25 degrees, increase and decrease of width and height corresponding to 0.15 of the original size, random zoom of 20%, points outside the input limits by the "reflect" method and randomly flip the inputs horizontally, in Fig. 3 an example of a particular image and the result of five transformations can be observed.

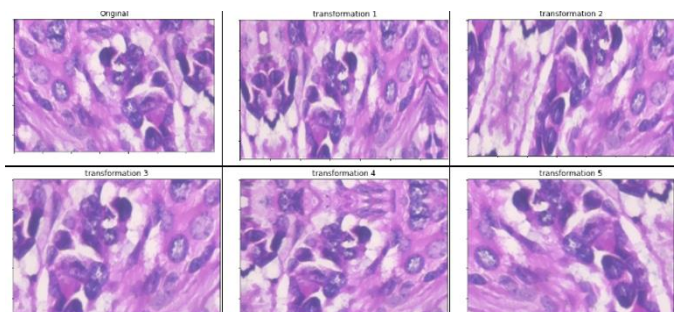


Fig. 3. Results of data augmentation transformation for the images under study.

### E. Transfer Learning and Fine Tuning

Transfer learning is a method where previously trained models are used and applied to a particular case, for this study we have used models trained with a set of data provided by the "ImageNet" contests and that have been shared by the keras library [20][21], the models correspond to VGG16, VGG19, Resnet 50 and Inception V3. Such models were trained with 1.4 million photographs as input and 1000 image classes as output, among which vehicles, plants, animals, etc. stand out. The description of the models is detailed in the following points:



1) *VGG16*: The architecture of this neural network model stands out for using 3x3 convolution kernels, smaller than the previous models, in addition to max-pooling layers of a size of 2x2 [22]. The input size of the network is 224x224. At the output of the convolution layers, we have 3 layers of neurons formed by 4096 the first 2 and 1000 the last one, which presents a SoftMax activation function to determine the image class. Fig. 4 represents the architecture for this study.

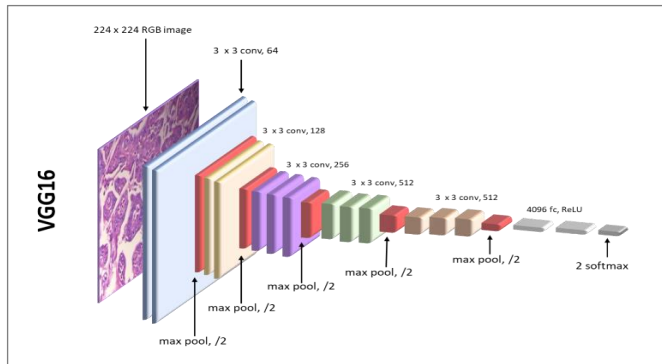


Fig. 4. VGG16-based model for breast cancer staging.

2) *VGG19*: The architecture of this neural network is like that of VGG16, where the difference in number represents the number of convolutional and dense layers in each model, which, in this case, would be 19 [23], Fig. 5 shows the architecture for this research.

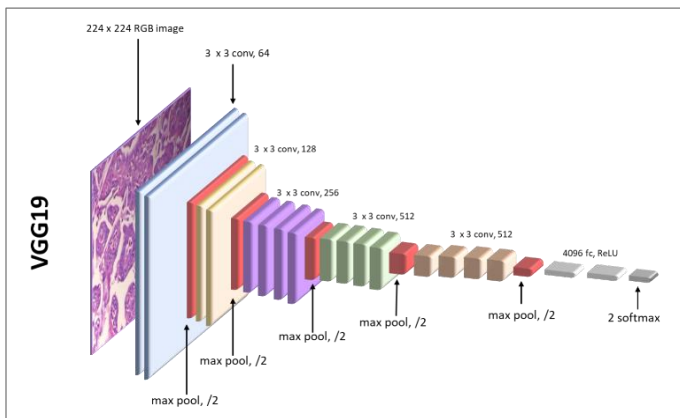


Fig. 5. VGG19-based model for breast cancer staging.

3) *ResNet50*: Convolutional neural network with 50 layers deep. These layers are ordered starting with one of a 7x7 convolution kernel, a 2x2 max-pooling [24], 9 layers repeating 3 times a sequence of 3x3. 64, 1x1,64 and 1x1,256, 12 layers repeating 4 times a sequence of 1x1,128, 3x3,128, and 1x1,512, 18 layers repeating 6 times a sequence consisting of 1x1,256, 3x3,256 and 1x1,1024 and completes the 50 layers with 3 repetitions of a sequence of 1x1,512, 3x3,512 and 1x1,2048. From this the average-pooling layers are used, in Fig. 6 the model used for the case is represented.

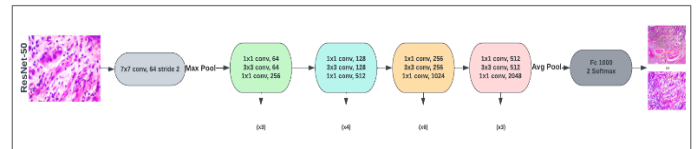


Fig. 6. ResNet 50-based model for breast cancer classification.

4) *Inceptionv3*: This is the third version of a neural network with 48 layers deep, unlike the VGG architectures, it requires considerably less computational power, but still provides reliable results. The size of the network image input is 299 x 299. Fig. 7 shows the synthesized process for the case.

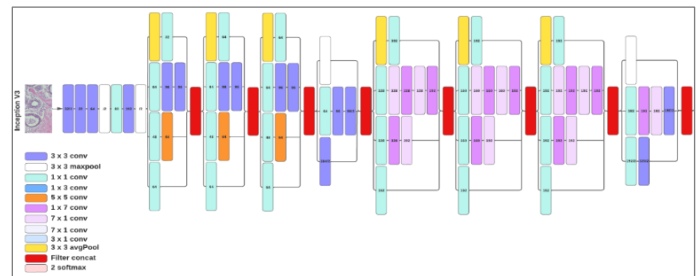


Fig. 7. Inception V3 model for breast cancer staging.

Fine tuning is the method that allows to adapt the results when using a pre-trained model, since such models had a different or similar task to the one being studied. For this case of this study whose output is of two classes, in which you want to evaluate whether an image corresponds to benign or malignant type, it is used import the original models without considering the fully connected layer, then the convolutional layer is retained, the fully connected layer is added and the output of two classes.

A convolutional neural network model has the first layer corresponding to the convolutional layer, it is a block where most of the computations occur, given by a set of convolutional filters each of which allows to detect certain characteristics of the images. For example, 1) Pooling operation: it allows to simplify the output of the results of the convolution operation by decreasing the subsampling rate, thus reducing the number of parameters that the network needs to learn. There are several types of subsampling, for this study Max-Pooling is used; 2) Flatten layer: allows to add a flat layer where the spatial dimensions of the input collapse in the dimension of the channel, this procedure is used in this pooling and prior to the fully connected layer; 3) Fully connected: in this stage all the input neurons (flattened) are connected to each neuron of the output layer. The main objective of this fully connected layer is to carry out a kind of clustering of the information that has been obtained so far, which will be used in subsequent calculations for the final classification; 4) Evaluation: for the evaluation of the different models, multiple evaluation measures are used to assess the performance of a Deep learning model. Its objective is to verify the accuracy of the generalization of a model on new data. Different metrics such

as confusion matrix, accuracy, precision, recall, F1-Score, etc. are used to evaluate the models.

#### F. Evaluation Model

Multiple evaluation measures are used to assess the performance of a deep learning model for the evaluation of different models. Their objective is to verify the accuracy of the generalization of a model on new data.

#### G. Matriz De Confusión

The confusion matrix is a matrix representation that allows to compare the results of the predictions and the actual data of the target class. Each predicted value gives as correct or incorrect result, this depends on the coincidence with the correct value:

True Positive (TP): The predicted value when compared to the stored value is correct.

True Negative (TN): The predicted value when compared to the stored value is not correct.

False Positive (FP): Predicted value is positive when compared to the stored value is negative.

False Negative (FN): The predicted value is negative and when compared to the stored value is positive.

#### H. Accuracy

This is the total percentage of items correctly classified [25].

$$Accuracy = \frac{TP + TN}{TP + FP + FN + TN}$$

##### a) Error Rate

This is the total percentage of incorrectly classified items.

$$Error\ rate = \frac{FP + FN}{TP + FP + FN + TN}$$

##### b) Precision

The number of items that have been properly recognized as positive out of a total number of items recognized as positive [25].

$$Precision = \frac{TP}{TP + FP}$$

##### c) Recall

The metric allows reporting on the rate of true positives [25].

$$Recall = \frac{TP}{TP + FN}$$

##### d) F1-Score

This metric combines precision and recall obtaining a much more objective value.

$$F1 = 1 * \frac{(Recall * precision)}{Recall + precision}$$

## IV. RESULTS AND DISCUSSION

The results obtained following the proposed methodology are synthesized in this section, from the division between training data (70%) and test data (30%) of the 7803 original images. The number of epochs for each of the models was a maximum of 20 and the parameters for the activation function "relu" for the hidden layers and for the output "Sigmoid" were used, to reduce the overfitting restricted to the deactivation of 30% of neurons in each layer (dropoud=0.30), the learning rate of 0.001 and the stochastic downward gradient optimizer with momentum, for the training of the models with the adaptation detailed in the previous point, GPU was used for the processing and adjustment of the model. Fig. 8 shows the results and the evolution of the Loss and accuracy for the VGG16 model, clearly there is a significant change in the first epochs of the training process, in relation to the Loss, this decreases drastically in the first two epochs, from then on there is a slow decrease, with respect to the accuracy, until epoch 10 there was a good increase and from then on there is no significant improvement and even has to fall into a problem of overfitting.

From the model fit, the test data was used to predict using the model and make a comparison between the expected output results and the given prediction, a summary through the confusion matrix is shown in Fig. 9.

The results show that of the correct or positive true predictions, 1487 correspond to 63.52% of the total and 569 true negative predictions, representing 24.31% of the total; the incorrect predictions, with respect to false positives, were 201 images and false negatives correspond to 84 images.

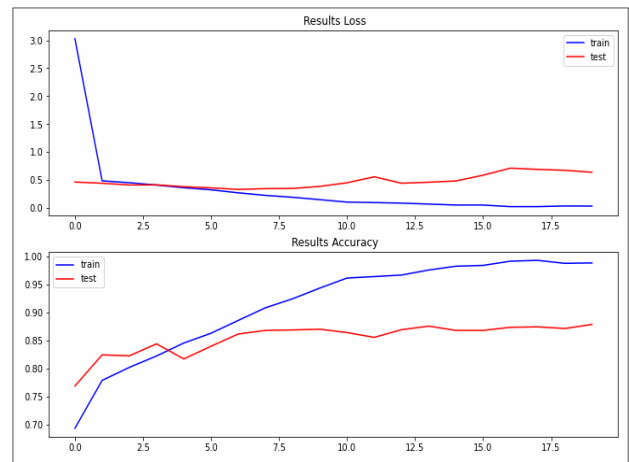


Fig. 8. Evolution of results loss and accuracy of the training process - Model VGG16.

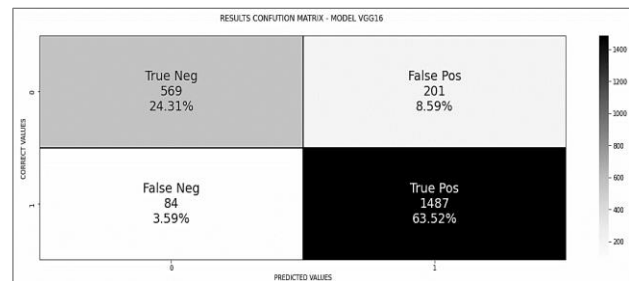


Fig. 9. Confusion matrix of the VGG16 model.

With respect to the training results of the VGG19 model, they show that as the number of epochs increases the error decreases and the accuracy increases, this change can be seen with greater force until the second epoch, in advance the change is slow and even approaching epoch 20 the values begin to differ between the training and test data. Once the model has been fitted with the training data, the test data is used to predict and evaluate how well it generalizes to new cases.

Regarding the third model ResNet50, it shows the evolution of the error function during the training process, the model starts with high variability between the training versus test data, from the eighth epoch the process stabilizes; regarding the accuracy it increases significantly until the eighth epoch, thereafter no significant change is observed.

Finally, the Inception V3 model shows the improvement in the two metrics clearly distinguished, regarding Loss in the first epochs decreases drastically and even in the fifth epoch the results are more stable or homogeneous, as you increase the epochs these results improve the accuracy between training and test data is very close, the model fit metrics finally corroborate this perspective (further shown below).

After fitting the models and using the prediction test data to evaluate the accuracy of each model, Table II summarizes the performance measures for each model, with the metrics accuracy, error-rate, precision, recall and f1-score.

TABLE II. SUMMARY PERFORMANCE METRICS OF THE MODELS PROPOSED FOR BREAST CANCER PREDICTION

Modelo	Accuracy	Error rate	Presicion	Recall	f1-score
VGG16	0.88	0.12	0.88	0.84	0.86
VGG19	0.86	0.14	0.86	0.82	0.83
ResNet 50	0.97	0.03	0.96	0.96	0.96
Inception V3	0.96	0.04	0.96	0.95	0.95

The results indicate that there is a significant correlation with related work, the findings of this paper are discussed below with relevant research highlighting similarities and differences. For example, the ResNet-50 model achieved an accuracy of 97%, this result is consistent with that achieved in papers [9] and [12], in which CNN was used to classify breast cancer abnormalities, achieving a performance of 75% and 83%, respectively. Also, the Inception-v3 model achieved a very significant performance of 96%, higher than that achieved in the work [13], where they used this model to predict lymph node metastasis from images, achieving an accuracy of 85%, 73% specificity and 73% sensitivity. The VGG16 model also achieved satisfactory results in terms of 88% accuracy. However, this model, achieved a better performance in [14], reaching 95.70% accuracy in tumor detection in monograph images and the VGG19 model in this work achieved a

performance of 86% accuracy, higher than that achieved in [15], where it reached 72% pressure in pneumonia detection through transfer learning with CNN. Artificial intelligence, specifically neural networks, have contributed significantly to the clinical field, models such as ResNet50 and Inception-v3, are great and efficient predictors in this field of health, and in this work have been classified as the best models in performance and accuracy, to identify and classify breast cancer using transfer learning page.

## V. CONCLUSIONS

This work by using deep learning models allowed retraining and adaptation for the correct classification of benign or malignant cancer from real histopathology images, four models based on VGG16, VGG19, ResNet 50 and Inception V3 were considered, and a retraining process was carried out using GPU for faster convergence, once the models were adjusted, the result evaluation process was carried out with test data. The model that achieves the best performance is ResNet 50, with 97% of correctly classified cases, although the model based on Inception V3 has a value of 96%, statistically there would be no significant difference (at 95% confidence), the model that has the lowest performance is based on VGG19 with 86%. Individually for the prediction of the positive classes that are positive, the models based on ResNet 50 and Inception v3 obtain equal scores with 96% of the cases. Regarding the positive values that have been correctly classified the model based on ResNet 50 obtains the highest value corresponding to 96 % equal to the f1-score. It is followed by the Inception v3 model with 1% below these results; statistically there would be no significant difference. The work shows a suitable methodology for the retraining of Deep learning models, the results are encouraging, the model based on ResNet 50 and Inception v3 exceeds the threshold of 90% for the classification of breast cancer of the case raised.

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# Zero-Watermarking for Medical Images Based on Regions of Interest Detection using K-Means Clustering and Discrete Fourier Transform

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**Abstract**—Watermarking schemes ensure digital image security and copyright protection to prevent unauthorized distribution. Zero-watermarking methods do not modify the image. This characteristic is a requirement in some tasks that need image integrity, such as medical images. Zero-watermarking methods obtain specific features for the master share construction to protect the digital image. This paper proposed a zero-watermarking scheme based on K-means clustering for ROI detection to obtain specific features. The K-means algorithm classifies the data according to the proximity of the generated clusters. K-means clustering is applied for image segmentation to identify ROI and detect areas that contain important information from the image. Therefore, the Discrete Fourier Transform (DFT) is applied to the ROI features, using the high frequencies to increase its robustness against geometric attacks. In addition, an edge detection based on the Sobel operator is applied for the QR code creation. This type of watermark avoids errors in watermark detection and increases the robustness of the watermark system. The master share creation is based on an XOR logic operation between extracted features from the selected ROI and the watermark. This method focuses on the protection of the image despite it being tampered with. Many proposed schemes focus on protection against advanced image processing attacks. The experiments demonstrate that the presented algorithm is robust against geometric and advanced signal-processing attacks. The DFT coefficients from the extracted ROI features increase the efficiency and robustness.

**Keywords**—Zero-watermark; ROI detection; machine learning; k-means; image security; copyright protection

## I. INTRODUCTION

In recent years, the advances in communication technologies and multimedia file sharing through different digital systems have increased related to the conditions generated by the COVID-19 pandemic. In addition, the images transmitted through different communication channels may contain sensitive information [1]. For this reason, technology for digital image protection, authentication and copyright protection is a requirement. One technology that has attracted the attention of researchers is the watermarking systems, which provide security, copyright protection, or certify digital images [2].

The protection of medical images has become a relevant task in recent years since there has been an increase in remote medical consultations. Therefore, medical images carried out

the patient's data which is an essential requirement. For this reason, watermarking systems are a solution to this problem.

Traditional embedding algorithms imperceptibly embed ownership information into the host image to ensure the copyright, consequently, the signal is recovered from the watermarked image [3], [4], [5]. Traditional watermarking methods embed a signal with ownership information into a host image [4], [5]. This process distorted the image and modified its information. However, this process can generate some distortion generating a wrong image analysis. An example is the one proposed by Juarez-Sandoval et al. [3]. They present a method of imperceptible-visible watermarking. A homogeneous region is detected by the variance of the values in the pixels, followed by the just noticeable difference (JND), which represents the maximum luminance variation. The JND identifies the most appropriate area in the image to embed the binary watermark. Guanghai and Hao [6] used the Arnold transform to encrypt the watermark. On the other hand, they applied the Wavelet Transform based on the Mallat decomposition, representing the coefficients of the low-pass and high-pass filters, thus adjusting the intensity of the watermark to the pixel variations. To avoid distortions in the images, Zero-watermarking techniques are developed, these schemes do not embed information into the digital data. Instead, zero-watermarking used specific features from the image, and the watermark to create a master share (a feature matrix) without losing the host image quality. The master share is unique for each image.

Region of interest (ROI) detection on images identifies specific areas with relevant information for its analysis and features extraction that belongs to the selected region [7], [8]. On the other hand, regions of non-interest (RONI) generally used related features to the background [9], [10]. ROI methods are used in watermarking algorithms to make the embedding and detection process of the watermark signal more efficient since it takes advantage of the detected features that are unique for each ROI. Zhang et al. [11] developed a watermarking system by inserting the signal into the RONI of medical images. They applied the Discrete Wavelet Transform (DWT) and added two bits in each frequency sub-band obtained (low, medium, high). Next, the Otsu algorithm identifies the RONI, and then the detected ROI is encrypted with a hashing algorithm to combine it with the patient's information. In [12] Qi et al. proposed two factors to select the ROI by detecting variations, especially in the case of medium frequencies. Subsequently, the visual effect factor (VEF) determines the



region of watermark embedding. Lampezhev et al. [13], proposed a K-means segmentation for ROI detection on medical diagnosis. Therefore, a fuzzy clustering evaluation criterion was applied to select specific features from the image to determine the statistical data required for making decisions in applied medicine.

Medical image watermarking schemes divide the image into ROI and RONI for signal embedding. In addition, the ROI and RONI segmentation can be modified easily by the software. As a solution, zero-watermarking systems generate lossless protection in the image quality being more efficient. In zero-watermarking algorithms, the signal is not embedded into the base image [14], [15]. Extracted features from the image are fuzzed with the watermark related to the owner's information for the creation of the master share. These associations are stored and provide continuous protection [16]. In addition, the main advantage of this algorithm is the generated robustness.

Khafaga *et al.* presented in [17] a descriptor based on multi-channel Gaussian-Hermite moments of fractional order for feature extraction to create a vector with the most robust features and used the 1D Chebyshev chaotic map to scramble the watermark and increase its security. Finally, it is performed an XOR operation for the master share creation. Xing, Li, and Liang created a zero-watermarking scheme [18]. The Discrete Cosine Transform (DCT) is applied to high-frequency coefficients obtained from the Discrete Fourier Transform (DFT). The coefficient matrix is extracted from the left corner and has the same size as the watermark. The Arnold Transform scrambles the watermark to increase the security of the system. Thus, the coefficient matrix and the scrambled watermark are fuzzed for the master share generation.

ROI detection-based algorithms have a relevant role in zero-watermarking systems, as it identifies unique features from each image [15]. The extracted features create the master share serving for identification, protection, authentication, and certification of the digital image against misuse [19], [20]. Fang et al. in [21] present a watermarking scheme that detects specific areas in medical images by extracting the SIFT descriptors. Therefore, they apply the Bandelet Transform for pixel change detection. Thus, the Discrete Cosine Transform (DCT) is applied to generate more robustness against geometric attacks. The Arnold Transform increases watermark security. Finally, the watermark and the ROI features are combined. Gong et al. [22] applied a Residual-DenseNet to obtain a feature vector of the image, then the logistic map creates a Chaotic matrix and generates the feature matrix through a logical XOR operation, which is stored to verify the image. In [23] Hosny and Darwish applied Multi-channel Fractional-order Gegenbauer moments of color images to obtain the ROI-related features of the image and form the feature vector, which is combined with the watermark to generate image protection.

This paper proposes a zero-watermarking scheme-based detection of regions of interest using K-means clustering. Therefore, the DFT is used to obtain high frequencies to create a feature matrix. The features remain without distortions if the image has been tampered with. Thus, the process of the

watermark construction used the Sobel filter to obtain the image edges. Finally, the master share is created by fuzzing the watermark and the feature matrix.

The k-means algorithm provides robustness to the presented method, generating an image segmentation based on features clustering for the ROI detection. The main advantage of this technique is the ROI detection which remains without modifying the pixel values used for the master share generation and detection even if the image has been tampered with. On the other hand, the DFT makes the system more efficient, even though some geometric or advanced image processing attacks are applied to the image by an unauthorized user. High frequencies do not change despite image manipulation. The master share provides continuous copyright protection and image certification.

The main contributions of this paper are:

- K-means ROI detection and DFT-based feature extraction increase the robustness of the watermark system.
- ROI detection creates a feature matrix related to the image. These features are not modified when advanced signal processing is applied to the image.
- K-means clustering is applied for image segmentation to identify ROI and image patterns for the identification of areas with important infrastructures from the image.
- The DFT coefficients generate unique invariant features against geometric attacks.
- The extracted features for the master share construction are unique and generate a lossless watermarking system, which does not distort or modify the image, allowing its analysis for a correct diagnosis.
- This method focuses on the protection of the image despite it being tampered with. Many proposed schemes focus on protection against advanced image processing attacks.

The rest of the paper is organized as follows. Section II provides the background of study. Section III presents the proposed method. Section IV provides the experimental results, and Section V concludes this paper.

## II. BACKGROUND

This paper proposed a zero-watermarking scheme based on K-means clustering for ROI detection. ROI detection increases the efficiency of feature detection and extraction. Furthermore, high-frequency coefficients of the DFT provide robustness against geometric attacks, where the selected features do not change.

### A. K-Means Clustering for Image Segmentation

Image segmentation analyzes the image and identifies ROI with useful detected features [24]. ROI detection may determine the areas which must be tampered avoiding their use for feature extraction to create the master share [25]. ROIs have areas with relevant information. In the case of medical images, this information is vital for analysis for a correct and



efficient diagnosis, so they should not be modified or distorted and thus not affect the patient's diagnosis.

Unsupervised learning refers to a kind of machine learning where there are no labels or the output is not known, like the clustering algorithms [26], this technique is like classification methods since it divides the data into groups called clusters.

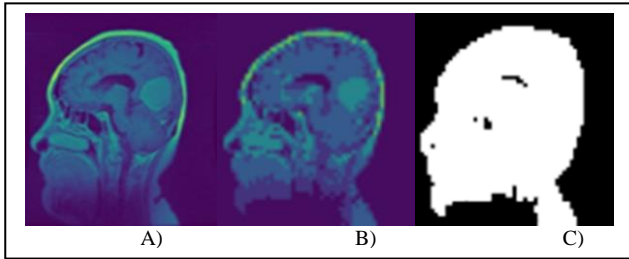


Fig. 1. Example of K-means image segmentation: A) Original image B) K-means segmented image, C) ROI detection.

Clustering techniques separate the data by associating points into different classes. K-means is one of the most used clustering algorithms, due to its implementations which consist of an iterative algorithm that assigns the data to a specific cluster based on the Euclidean distance (1) from an arbitrary centroid ( $\eta$ ).

$$\min(E(\eta) = \sqrt{\sum_{i=1}^n (p_i - \eta_i)^2}) \quad (1)$$

where  $p$  is the data point, and subsequently the centroids are realigned to the mean of the assigned clusters ( $S$ ) on each iteration (2) [27], [28].

$$\frac{\delta E}{\delta \eta} = \mathbf{0} \rightarrow \eta_{i+1} = \frac{1}{S} \sum p \quad (2)$$

K-means is a popular algorithm because is easy to understand and implement and it can be used in many tasks. One of the disadvantages is that the number of centroids must be set before the initialization. K-means algorithm clusters the pixels for image segmentation and pattern recognition for ROI detection [29], [30]. The clustering technique detects interest points on the image for pattern recognition using different centroids [31]. K-means segmentation detects ROI to determine the most important features from the image to obtain better results for pattern recognition and feature extraction in zero-watermarking algorithms [32] (Fig. 1). Segmentation methods recognize ROI if an attack is applied to the image the feature points may change. Furthermore, DFT coefficients improve feature detection due to their properties which make the frequency coefficients from the selected area invariant to geometric attacks.

### B. 2D Discrete Fourier Transform

The Discrete Fourier Transform (DFT) (3) makes a representation of the space domain image into the frequency domain, providing robustness against geometric attacks (scaling, cropping, translation, rotation) [33].

$$F(u, v) = \frac{1}{\sqrt{M}\sqrt{N}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} I(x, y) e^{-j2\pi(\frac{xu}{M} + \frac{yv}{N})} \quad (3)$$

The Fourier Spectrum (4) (Fig. 2) describes frequency coefficients. The DFT has a real value (Re) and an imaginary value (Im).

$$|F(u, v)| = \sqrt{(\text{Re}\{F(u, v)\})^2 + (\text{Im}\{F(u, v)\})^2} \quad (4)$$

Phase (5) describes the symmetry of the signal.

$$\theta = \tan^{-1}\left(\frac{-\text{Im}\{F(u, v)\}}{\text{Re}\{F(u, v)\}}\right) \quad (5)$$

The magnitudes in (4) and (5) make a polar representation of the DFT (6).

$$F(u, v) = |F(u, v)| e^{-j\theta uv} \quad (6)$$

The DFT has the properties of linearity, scale, translation, symmetry, rotation, and cropping (sampling). Consequently, the DFT improves the performance and efficiency of the presented method.

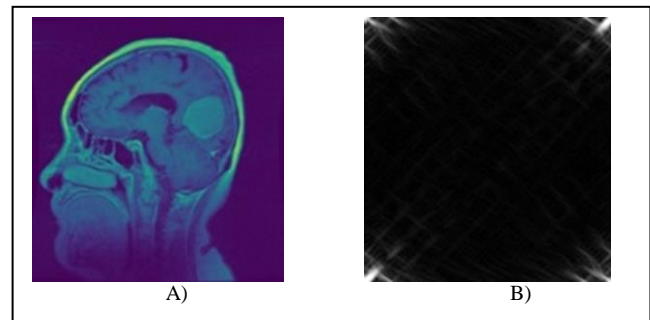


Fig. 2. A) Original image, B) DFT 2D matrix from the image.

### III. PROPOSED ZERO-WATERMARKING SCHEME

This paper presents a zero-watermarking scheme, focusing on the master share generation aimed to protect digital images. K-means algorithm detects image ROI for feature extraction (Fig. 3).

The selected features from the ROI are robust against image processing attacks. The DFT makes a robust zero-watermarking algorithm, and high-frequencies coefficients are used for master share creation.

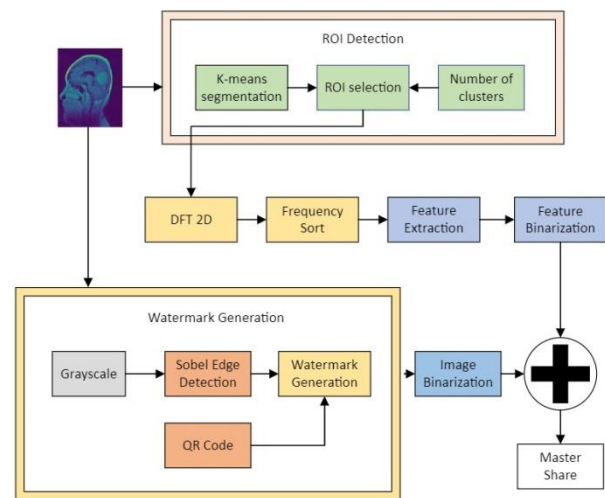


Fig. 3. Master share generation.

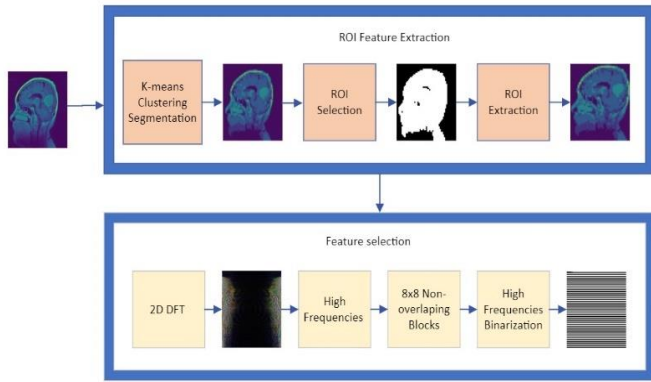


Fig. 4. Features extraction.

The DFT properties increase the robustness against geometric attacks. The master share provides copyright protection and image security.

### C. Region of Interest Feature Extraction

The master share generation (Fig. 4) is based on K-means ROI detection which provides robustness against advanced image processing attacks since the selected features do not change. In addition, combining ROI detection and DFT increases the robustness of the watermark system. Consequently, this method improves the performance and efficiency of the presented method.

The idea of the K-means implementation is to detect the main ROI from the medical image to extract the main image features. To improve the robustness of the watermark the ROI are eliminated. Therefore, the DFT is applied to the new image matrix to obtain the high-frequency coefficients and increase the robustness against geometric attacks. DFT domain correlated patterns to improve the image details. In addition, the matrix with the DFT coefficients is divided into non-overlapping 8x8 blocks for its binarization for the master share construction, using the mean value as a threshold (Fig. 4). In addition, the DFT coefficients are sorted from the higher to lower frequencies, and a matrix with a size of 160 x 160 is created.

### D. Watermark Construction

The watermark is unique for each image using the characteristics from the image. Generating this type of watermark avoids conflicts in the detection stage and increases the system's robustness. Therefore, it becomes a useful method for image security and copyright protection. The watermark generation process consists of the patient's information encrypted in a QR code with an image of the edge detection with the Sobel filter on the QR code center (Fig. 5).

QR codes are modules in which the patient's information can be stored, as well as their doctor, or redirect the user to their electronic file. On the other hand, QR codes can be detected by different devices, such as cell phones, computers, or tablets regardless of a loss of information.

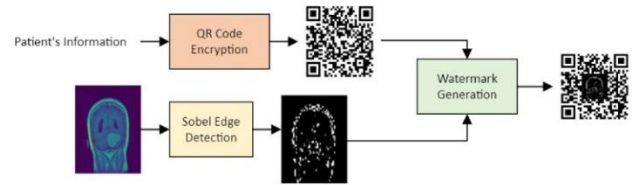


Fig. 5. Watermark generation.

In addition, these types of identification codes are quickly accessible, facilitating the identification of patients. Therefore, the QR codes can be used as a watermark for images.

The features from the edge detection reduce the watermark retrieval error and avoid ambiguity since the watermark is unique for each image. Furthermore, edge detection identifies key points from the image and applies them for image protection. In addition, the watermark is resized to a matrix of 52 x 52. These features increased the efficiency of the zero-watermarking scheme.

### E. Master Share Generation

The master share is the element that provides the image security, certifies it, and protects the copyright protection, and must be stored in an external device. The master share (MS) is generated by fuzzing the image's unique features (imf) with the constructed watermark (Ws) with an XOR ( $\oplus$ ) logic operation (7). The image features are stables and invariants as a requirement.

$$MS = imf \oplus Ws \quad (7)$$

The master share (Fig. 6) is unique for each image and is created for the efficient protection of the digital image.

### F. Master Share Detection

In the detection phase (Fig 7.), the ownership authentication is validated verifying the image and certifying its authenticity. The generated master share and the unique features reveal the watermark. The watermark is detected by applying the logical XOR operation between the image features and the stored master share corresponding to the original image.

The watermark is recovered using the extracted features and the Master Share, this procedure is described as follows.



Fig. 6. A) Constructed watermark, B) Master share.

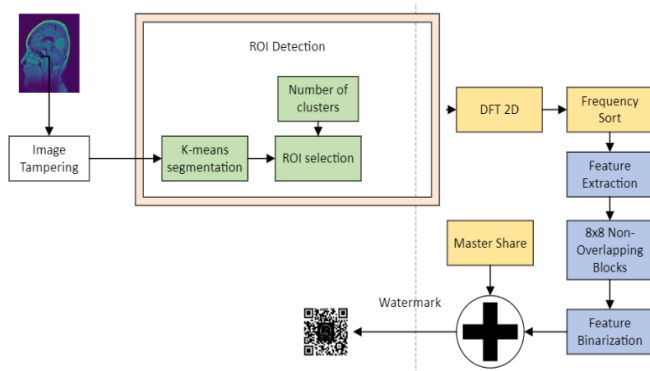


Fig. 7. Master share detection.

Step 1: The image is segmented using the K-means clustering algorithm for the localization of the regions of interest.

Step 2: The DFT high-frequency coefficients are obtained.

Step 3: The extracted features are binarized.

Step 4: It is applied an XOR operation between the binarized sequence and the Master Share.

Step 5: The watermark is recovered, and it is verified.

#### IV. EXPERIMENTAL RESULTS

Many experiments were realized to evaluate the performance of the proposed algorithm. The testing image database contains 708 images with a size of 512 X 512. In addition, the watermark is 160 x 160. The dataset was obtained from [34].

Some advanced image processing (blurring, median filter, gaussian filter, denoising, jpeg compression) and geometric attacks (rotation, scale, translation, cropping) were performed to evaluate the zero-watermarking scheme.

As an evaluation metric the bit error rate (BER) (8) is used to measure the detected bit errors between the watermark ( $W$ ) and the retrieved watermark ( $W'$ ). A low BER indicates stronger watermark robustness [16].

$$BER = \frac{\text{Error bits}}{M \times N} \quad (8)$$

In addition, the normalized cross-correlation (NCC) (9) evaluates the similarity between the watermark and the extracted watermark [19].

TABLE I. GEOMETRIC ATTACKS ROBUSTNESS TEST

Attack	BER	NCC	Attack	BER	NCC
No attack	0.0058	0.9944	Bottom left crop	0.0077	0.9929
Radom rotation	0.0091	0.9900	Upper right crop	0.0055	0.9941
Roll translation 150	0.0064	0.9942	Center crop	0.0072	0.9931
Scale	0.0053	0.9945	Translation	0.0095	0.9904

TABLE II. ADVANCED IMAGE PROCESSING ATTACKS ROBUSTNESS TEST

Attack	BER	NCC	Attack	BER	NCC
JPEG 90	0.0041	0.9958	Scale and blurring	0.0094	0.9900
JPEG 70	0.0053	0.9950	Gaussian filter	0.0041	0.9955
JPEG 30	0.0061	0.9941	Scale and Gaussian filter	0.0071	0.9929
Gaussian noise	0.0060	0.9930	Denoising	0.0062	0.9939
Scale and Gaussian noise	0.0054	0.9945	Median filter	0.0052	0.9946
Blurring	0.0070	0.9923	Scale and median filter	0.0056	0.9947

$$NCC = \frac{\sum W(i,j) \oplus W'(i,j)}{M \times N} \quad (9)$$

where  $m$  and  $n$  are the dimensions of the watermark.

Table I and Table II demonstrate the robustness of the proposed zero-watermarking scheme. The BER and NCC metrics ensure the effectiveness of the algorithm.

The BER value is closer to 0, indicating that the recovered watermark has a low error. The NCC is closer to 1, showing a great similarity between the detected watermark and the embedded watermark.

TABLE III. RETRIEVED WATERMARK AGAINST DIFFERENT TAMPERING ATTACKS

Tampere d Image	Watermar k	Retrieved Watermar k	Tampere d Image	Watermar k	Retrieved Watermar k
No attack			Roll translation		
Center crop			Rotation		
Median filter			Scale 170 x 170		
JPEG 30			Gaussian noise		

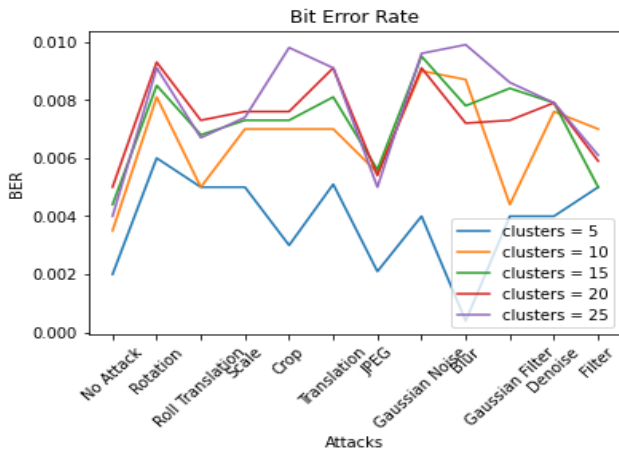


Fig. 8. Bit error rate for different numbers of clusters.

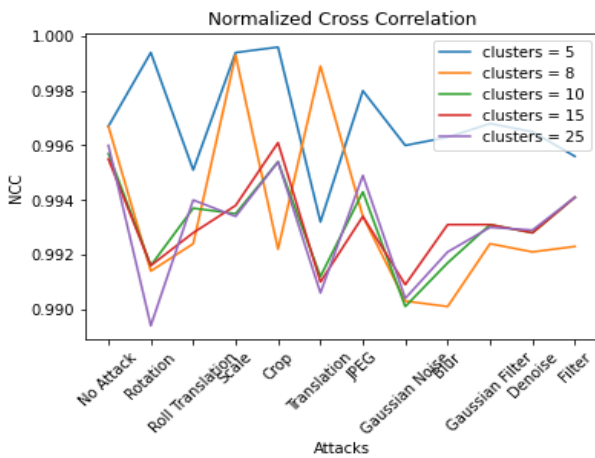


Fig. 9. Normalized cross correlation for a different number of clusters.

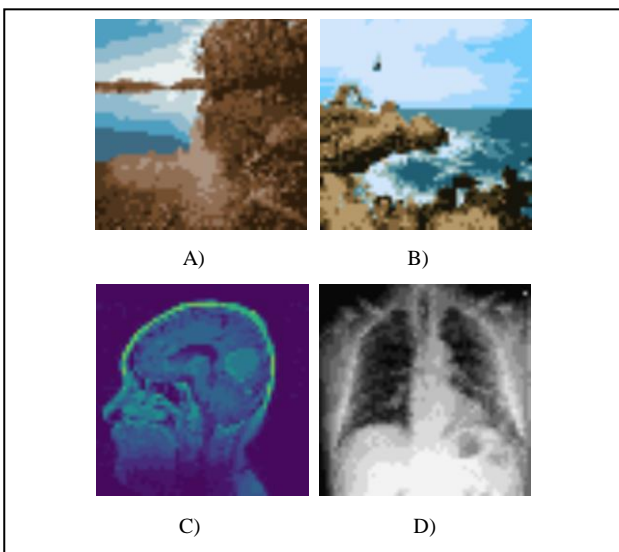


Fig. 10. ROI detection with different number of clusters for different images and tasks.

Table III shows the efficiency of the watermark detection stage and the robustness of the proposed method. The retrieved

watermark is very similar to the original watermark, which can be seen in Table I and Table II. The efficiency of the zero-watermarking scheme is similar regardless of the selected clusters.

Fig. 8 shows the variations on the BER with different numbers of clusters against different advanced image processing attacks and geometric attacks. Fig. 9 demonstrates mage certification stage recovers a similar retrieved watermark to the original watermark. Hence the selection of clusters will depend on the task and the image type. Since the selection of ROI will depend on the requirements of the application of the watermarking system. ROI selection may be necessary to determine a zone with user-specified characteristics for master share creation, as in Fig. 10.

The proposed algorithm is compared with other ROI zero-watermarking lossless algorithms. The comparison of our proposed zero-watermarking scheme with other schemes (Zhang et al. [35], Huang et al. [36], Cheng et al. [37], Zhou et al. [38] and Jing et al. [39]) was made in terms of the following aspects: 1) robustness against geometric attacks (no attack, rotation, translation, scale, crop). 2) Robustness against (blurring, noise addition, and JPEG 30 compression). 3) The BER is used for the analysis of the recovered watermark. 4) To evaluate its similarity with the original watermark, the NCC was used. 5). For a fair comparison, the same dataset is used and the same conditions from the experimental environment. In addition, some of the authors from the comparison schemes increased the robustness of their algorithms, this can be observed in the variations from the BER values and the similarity measures that they presented. The results are in Fig. 11 and Fig. 12.

The proposed method presents a better performance against different geometric and advanced image processing attacks.

The high-frequency coefficients from the DFT provide robustness against geometric attacks and the ROI detection increases the efficiency against advanced image processing attacks.

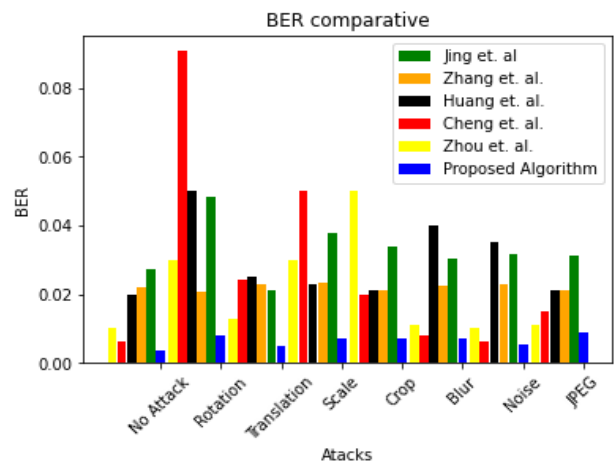


Fig. 11. Bit error rate comparative.



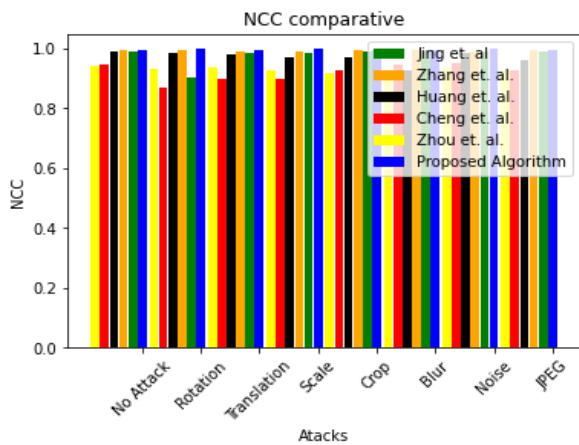


Fig. 12. Normalized cross correlation comparative.

The method presented in this paper better satisfies the lossless requirements and provides robustness against the different geometric and advanced image processing attacks (Table I and Table II). Comparing our method with other zero-watermarking has a better performance. The recovered watermark can be easily distinguished and provides security for copyright protection related to digital images. On the other hand, the features related to the image as a watermark provide an effective protection system.

#### V. CONCLUSIONS

In this paper, a zero-watermarking algorithm is presented based on ROI detection for image certification and authentication. The results demonstrate the robustness of the zero-watermarking system and the similarity of the retrieved watermark, generating continuous image protection, verification, authentication, and certification. On the other hand, the features related to the image as a watermark increases image security. Moreover, the ROI detection based on K-means generated a better performance of the zero-watermarking system. The results show a minimum loss on the watermark recovery. The use of different ROI areas does not significantly modify the results obtained, however, when using a greater number of clusters, the processing time increases.

In future work, the use of a specific ROI for the extraction of the characteristics is proposed. The user can focus on image analysis to perform artificial intelligence tasks related to robotics and computer vision. The system would generate a verification method for images related to security areas and avoid their misuse. In the same way, image databases could be generated for various tasks with protection and a system for user verification.

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# Kalman Filter-based Signal Processing for Robot Target Tracking

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**Abstract**—In the field of computer vision, the signal tracking of moving objects is a highly representative problem. Therefore, how to accurately and quickly track the target unit has become the focus of the research. Based on this, a Cam Shift algorithm improved by Kalman filtering algorithm is introduced to realize fast tracking of moving targets. This method uses the prediction function of the Kalman filter to predict the moving target of the next frame, transforms the global search problem into a local search problem, and improves the real-time performance. The experimental results show that, in the case of complete occlusion, the trajectory of the unimproved algorithm will deviate compared with the actual trajectory of the improved trajectory tracking curve, but the improved algorithm has no trajectory deviation. The error of the improved algorithm is about 4%, while the maximum error of the unimproved algorithm is about 90%. The improved algorithm reached the expected target accuracy after 110 and 78 trainings in X and Y coordinates, respectively, while the CamShift algorithm without Kalman filtering still failed to reach the expected error after 200 trainings in X and Y coordinates. This indicates that the performance of the improved CamShift algorithm based on Kalman filter has been greatly improved. In conclusion, the improved algorithm proposed in this study is highly practical.

**Keywords**—Motion target tracking; Kalman filter; CamShift algorithm; occlusion processing

## I. INTRODUCTION

The research object of moving target tracking is video sequence, or image sequence, which refers to the spatial-temporal changes of the moving target in the whole sled [1], such as the appearance and disappearance of the target, the position, size and shape of the target, etc. [2]. It is caused by the presence of illumination changes, background interference, shadows, camera jitter, and occlusion between moving signals. Therefore, it is necessary to process the video image sequence [3]. The research on tracking technology of moving targets in the sequence image is to organically combine image processing, automatic control, information science and other technologies to form a fast detection of moving targets from the image information, and to extract the location information of the target for real to ground tracking [4]. Vision is the most important organ of human perception, and it is the main way for humans to obtain external information. With the rapid development of information technology in the 21st century [5], the demand for multimedia information is increasing, and computer vision technology is gradually becoming a hot spot in today's computer research [6]. Computer vision is a comprehensive and interdisciplinary discipline involving numerous aspects such as image processing, intelligent pattern recognition, artificial intelligence, automatic control, and

neural networks [7]. Research in computer vision aims to enable computers to sense and understand the external environment, so that they can simulate human vision [8]. Motion target tracking is an important topic in the field of computer vision [9], which focuses on detecting, locating and tracking targets in video frames, obtaining the motion characteristics of the targets, and further processing and analyzing them to achieve higher-level tasks [10]. Based on this, the research aims to propose a Kalman filter-based signal processing algorithm for robot target tracking. The second part is a review of the current status of domestic and international research on Kalman filter-based robot target tracking signal processing algorithms. The third part is the pre-processing of sound signals and the construction of a model for a neural network-based smart home interactive speech fuzzy enhancement algorithm, and the fourth part is the performance analysis of Kalman filter-based robot target tracking signal processing applications.

In this study, Kalman filter algorithm is used to improve CamShift algorithm, and a robot model based on wheel incomplete constraint is proposed, which is taken as a marker column. In the real robot test, the object motion model based on the velocity model is established based on the odometer motion model and the linear characteristics as the background. Finally, the experimental results are analyzed to verify the accuracy of the model tracking ping pong ball. This study chose this algorithm because in the field of computer vision, signal tracking of moving objects is a representative problem, and how to accurately and quickly track target units has become a focus of research. Compared to other algorithms, this algorithm is improved by the Kalman filter, which can use the prediction function to predict the moving target of the next frame, transforming the global search problem into a local search problem, and improving real-time performance. The experimental results show that compared to the unimproved algorithm, the improved algorithm has higher accuracy, smaller error, and no problem of trajectory deviation. Therefore, this algorithm exhibits superiority in moving object tracking. The main contribution of this study is to propose a robot target tracking signal processing algorithm based on a Kalman filter, which can effectively avoid the impact of factors such as lighting changes, background interference, shadows, camera shake, and motion signals on moving target tracking. Compared with other methods, the algorithm in this study has higher real-time performance and accuracy, and can better adapt to different environments and scenarios. In addition, this study also proposed a robot model marked by incomplete wheel constraints, and established an object motion model based on velocity model, providing a more complete and

accurate description for robot target tracking. In the experiment, this study also conducted tests on table tennis movement, and verified the accuracy and practicality of the model tracking table tennis through the analysis of the experimental results. In summary, the innovation and practicality of this study can provide new ideas and methods for the research and application of robot target tracking.

## II. RELATED WORK

The reason why motion target tracking techniques have evolved and developed so well is by no means a one-off and has been explored in depth in recent years to advance the field. By integrating the extended Kalman filter (EKF) and direction-of-arrival (DOA) based geolocation into a factor graph (FG) framework, Cheng et al. [11] proposed a new location tracking algorithm. The study also proposed the use of a predicted Cramer-Rao lower bound (P-CRLB) to dynamically estimate the observation error variance, exhibiting more robust tracking performance than methods using only a fixed mean variance approximation. By considering the uncertainty of the network and the target A reliable sensor selection method with, Anvaripour et al. [12] proposed an updated traceless Kalman filter (U2KF) to achieve effective tracking of the target through sensor selection, and the results of the study verified the effectiveness and practicality of the proposed scheme. Wang et al. [13] proposed how to unify the coordinate system and data when using multiple sensors for tracking case and data pre-processing. Then, the method of combining fuzzy sets with a novel trajectory optimization method based on the extended Kalman filter (EKF) and nested probabilistic numerical linguistic information (NPN-EKFTO) is investigated and the feasibility of their method is verified with a study case of unknown maneuvering target trajectory optimization in Sichuan Province. Zhou et al. [14] proposed to study the target and pursuit satellite approach operation between the target and the pursuing satellite for the positional tracking control problem, and proposed an updated controller which has better adaptive capability for the initial estimation of inertial parameters as this updated controller estimates the pursuer's inertial parameters through UKF, and finally numerical simulations are given to prove the effectiveness of the proposed controller. Zhao et al. [15] proposed a new adaptive square root volumetric joint probabilistic data association (ASRCJPDA) and constructed a virtual vehicle target tracking scenario in PreScan software to better simulate real traffic conditions. The simulation of the target tracking example showed the effectiveness and superiority of the method.

Shmaliy et al. [16] modified the KF and unbiased finite impulse response (UFIR) filters using a backward Eulerian (BE) method for models with colored measurement noise (CMN). This method is more suitable for systems without feedback. The study showed that the equivalence of the KF algorithm was demonstrated analytically and confirmed by simulations, giving numerical examples of target tracking and providing visual object tracking for experimental validation, demonstrating the high efficiency of the designed algorithm in CMN removal. Yang et al. [17] proposed a novel and effective method to investigate further applications of algebraic filtering processing, including Gaussian filtering for background removal and extended Kalman filtering for target prediction, to

maintain the advantage of real-time tracking. Blair [18] found that when tracking maneuvering targets using a near-isovelocity (NCV) Kalman filter with discrete white noise acceleration, the choice of process noise variance is complicated by the fact that process noise errors are modeled as white Gaussian and target maneuvers are deterministic or highly deterministic. The study provided information on the use of the NCV Kalman filter for the NCV. Bhat et al. [19] proposed a particle filter-based tracking algorithm to track targets in vivid and complex environments in video, based on the similarity between features extracted from the target and possible candidate features in consecutive frames, using a particle filter algorithm to build the target's trajectory. For the color distribution model, Bhattacharya coefficient is used as a similarity metric, and the nearest neighbor distance ratio is used for matching the corresponding feature points in the KAZE algorithm. The study shows that the performance of the proposed tracking scheme is significantly better than contemporary feature-based iterative target tracking methods. Fraser and Ulrich [20] solved the NEO spacecraft formation mission by designing two unique adaptive extended Kalman filter algorithms for relative navigation problem. The proposed adaptive Kalman filter approach uses maximum likelihood estimation techniques to derive analytical adaptation laws. The study shows that the proposed adaptive navigation algorithm is significantly more robust in filtering initialisation errors, dynamics modeling defects and measurement noise.

The research on robot target tracking signal processing based on Kalman filtering by domestic and foreign scholars shows that there are more studies on Kalman filtering tracking, but there are relatively few studies on the fusion and optimisation of Kalman filtering and CamShift algorithms to achieve signal processing for robot target tracking and signal recognition of obscured targets. Thus, this study focuses on the fusion of Kalman filtering and CamShift algorithms for robotic target tracking signal processing, which improves the recognition rate compared to a single algorithm and also significantly enhances the recognition of occluded targets during motion.

## III. DEVELOPMENT OF A KALMAN FILTER-BASED APPROACH TO ROBOT TARGET TRACKING SIGNAL PROCESSING

### A. Development of a Mathematical Model for Robot Target Tracking Signal Processing based on Kalman Filtering

In order to accurately determine the specific position of a moving object at each time to achieve the purpose of tracking, the object being tracked can be extracted from the feature points, which can be a simple geometric figure, a three-dimensional point, or the centre of a solid, so that the analysis of a target is transformed into the analysis of data from certain specific points. Since the study takes the observation information acquired by the camera about a moving object as angular information, the equation for the observation of a moving object is shown by Equation (1).

$$\beta = \arctan\left(\frac{x}{y}\right) + \omega = h(x, y) + \omega \quad (1)$$

In Equation (1),  $x$  and  $y$  are the positions of the target points in the  $x$  and  $y$  directions of the coordinate axes, and  $\omega$  is the observed noise with a mean value of 0 and a mean variance of  $\sigma_\beta^2$ . In order to determine the information about the direction of movement, i.e. the position and velocity of the object, to make the state vector  $s(t)$ , the state at the moment of  $t$  is shown in Equation (2), and the noise effect is shown in Equation (3).

$$s(t) = \begin{pmatrix} x \\ y \\ v_x \\ v_y \end{pmatrix} \quad (2)$$

$$\dot{s}(t) = Fs(t) + W \quad (3)$$

In Equation (3),  $F = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$  is its constant

coefficient matrix and  $W$  is its dynamic noise. Since the observations of camera observation are obtained from each frame, Equation (3) is discretized as shown in Equations (4) and (5).

$$s_k = F_T s_{k-1} + W_{k-1} \quad (4)$$

$$F_T = e^{FT} = \begin{bmatrix} 1 & 0 & T & 0 \\ 0 & 1 & 0 & T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

In Equations (4) and (5),  $T$  is the sampling period, and  $W$  is the noise at the  $K$  sampling. After linear discretization, the observed equation of state is shown in Equations (6) and (7).

$$Z_K = H_K s_K + V_K \quad (6)$$

$$H_K = \left[ \frac{y}{x^2 + y^2}, \frac{-x}{x^2 + y^2}, 0, 0 \right] |_{S_{k/K-1}} \quad (7)$$

In Equations (6) and (7),  $V_K$  is the noise of the system at the time of  $K$  sampling and  $H_K$  is its coefficient matrix.

$X_w$  Theand  $Y_w$  axes in an arbitrarily set world coordinate system are parallel to the image coordinate system  $x$  and  $y$  axes respectively, so that the  $X_w$  and  $Y_w$  axes are parallel to the pixel coordinate system  $u$  and  $v$  axes respectively. At this point the robot is moving horizontally, so the coordinates of the  $Z_w$  axis do not change and therefore the coordinates of the  $Z_w$  axis can be ignored for the purposes of the study. In addition, the camera model on the robot is a pinhole model, which is made according to the principle of transmission projection, in a

plane parallel to the  $X_w O Y_w$  plane, by which the angle can be observed. This angle signal is then transmitted to the Kalman filter module to estimate the position of the tracking target.

### B. Establishment of A Kalman Filter-based Signal Processing Method for Robot Target Tracking

Image signal pre-processing work is crucial in the robot target tracking process, based on this, the image pre-processing, can effectively remove noise, reduce the effect on the subsequent processing, improve the accuracy of the detection algorithm, image pre-processing techniques include color image filtering, color image grayscale and binarization, image post-processing is mainly to eliminate interference to the image, thus obtaining a satisfactory image. The post-processing of the image is the elimination of interference to obtain a satisfactory image. Post-processing of video images is the study of mathematical morphological operations and histogram conversion of images. The acquisition, input and processing of images generate noise at every step of the process. Noise can lead to degradation and blurring of the image quality and seriously affect the important characteristics of the image, which causes increased difficulty in the analysis and understanding of the image, especially in the image acquisition and input process. Therefore, the role of noise suppression is particularly prominent [21]. The specific steps are shown in Fig. 1.

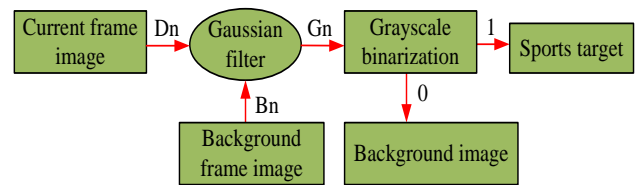


Fig. 1. Image preprocessing steps diagram.

Gaussian filtering is a smooth linear filter and the weight of the template is taken into account when selecting the Gaussian function. The algorithm can effectively filter Gaussian noise, and it is particularly effective in normal conditions. The two-dimensional Gaussian function is shown in Equation (8).

$$h(x,y) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (8)$$

In Equation (8), the amplitude of the Gaussian filter is determined by the parameter  $\sigma$ . Rotational symmetry is an important property in a two-dimensional Gaussian function that ensures that the filter is equally smooth in all directions. In addition, an important property of the Gaussian function is that the Gaussian function is a single function and the Gaussian filter is essentially a weighted average filter, which can be expressed as shown in Equation (9).

$$g(x,y) = \sum_{m=-K}^K \sum_{n=-L}^L W(m,n) f(x+m,y+n) \quad (9)$$

In Equation (9),  $W(m,n)$  is its weighting factor and the viewport of the Gaussian filter is  $(2K+1) \times (2L+1)$ . Mean

filtering is essentially a process where the target pixels are first set as a template (the template is the removal of the target pixels and consists of 8 pixels) and the mean of the pixels in the template is replaced with the target pixels again, as shown in Equation (10).

$$g(x, y) = \frac{1}{(2K + 1)(2L + 1)} \sum_{m=x-K}^{x+K} \sum_{n=y-L}^{y+L} f(x, y) \quad (10)$$

Grayscale binarization refers to setting the grayscale value of the pixels of the original grayscale image to 0 or 255, and converting the grayscale image into a black and white image with only all white. Choosing a suitable threshold that can convert 256 different grayscale images into a binary image, the obtained binarized image still has good local features and overall features. The pixels in the grayscale image are divided into all black or all white according to the set threshold. The selection of a suitable threshold is an important step in this process. The set threshold can be used to segment the target from the background when detecting moving objects, and the processing of the grey-scale image binarisation is shown in Equation (11).

$$g(x, y) = \begin{cases} 1, & f(x, y) \geq \tau \\ 0, & f(x, y) \leq \tau \end{cases} \quad (11)$$

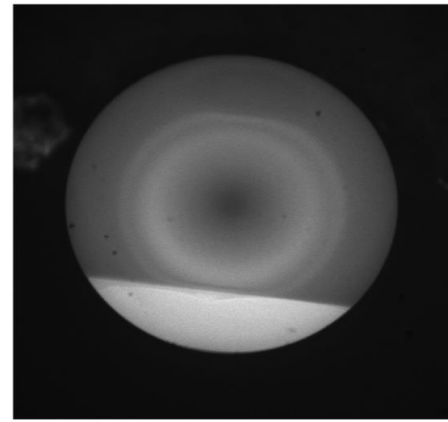
In Equation (11),  $f(x, y)$  represents the greyscale value of  $(x, y)$  in the initial grayscale image and  $g(x, y)$  represents the greyscale value of the pixel  $(x, y)$  after conversion to a binary image. First, a suitable threshold  $\tau$  is set, which is compared to  $\tau$ . The pixel is white if its grey value is greater than the threshold  $\tau$  and black if it is below the threshold  $\tau$ . Fig. 2 shows the difference between the original table tennis image before and after the grey-scale binarisation pre-processing.

Fig. 2(a) shows the original image of table tennis, and Fig. 2(b) is the image obtained after gray binarization. Image gray binarization means that the gray value of each pixel in the pixel matrix of the image is 0 (black) or 255 (white), that is, the effect of the entire image is only black and white, and the gray value range of the image after binarization is 0 or 255.

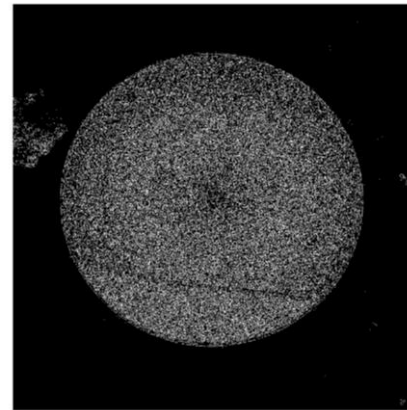
Kalman filtering (Kalman) it is an algorithm for minimum variance estimation of a dynamic system state sequence based on an a priori model describing the random variables in the dynamic system, and then a system of KF equations to obtain a best estimate of the target state based on global information in real time. Kalman filtering algorithm includes both state model and observation model [22], as shown in Equations (12) and (13).

$$X_k = A_k X_{k-1} + B_k W_k \quad (12)$$

$$Z_k = H_k X_k + V_k \quad (13)$$



(a) The original image.



(b) Image after grayscale binarization.

Fig. 2. Comparison of table tennis before and after greyscale binarization.

In Equations (12) and (13),  $X_k$  is the  $n \times 1$  dimensional state vector matrix;  $A_k$  is the  $n \times n$  dimensional state transfer matrix;  $B_k$  is its input matrix;  $W_k$  is a random vector of dynamic disturbances (white noise);  $Q$  is the covariance;  $Z_k$  is the  $m \times 1$  dimensional observation vector set;  $H_k$  is the  $m \times n$  dimensional observation coefficient matrix, and  $V_k$  is the observation noise vector in the covariance dimension  $R$ . Based on the above model, the Kalman filter can be divided into two categories, one for algorithmic forecasting and the other for correction of subsequent observations. The detailed process of the algorithm is as follows [23]. Firstly, the state prediction equation of the algorithm is shown in Equation (14).

$$X_k = A_k X_{k-1} + B_k U_k \quad (14)$$

The error covariance forecast equation and the updated Kalman gain factors are shown in Equations (15) and (16).

$$P_k = A P_{k-1} A^T + Q \quad (15)$$

$$K_k = P_k H^T (H P_k H^T + R)^{-1} \quad (16)$$

The covariance correction equation for its state correction and error is shown in Equations (17) and (18).

$$X_k = X_k + X_k(Z_k - HX_k) \quad (17)$$

$$P_k = (I - K_k H)P_k \quad (18)$$

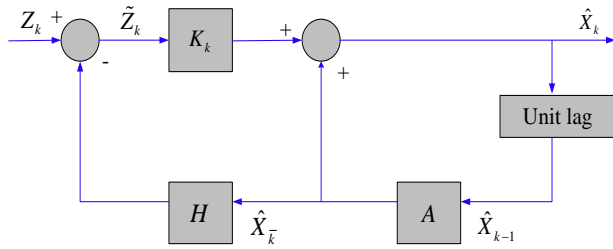


Fig. 3. Block diagram of Kalman filter for stochastic linear discrete system.

Fig. 3 is a block diagram of the Kalman filter for the stochastic linear discrete system (Kalman) obtained from Equations (14) and (17), with the observed variable as the input signal and the resulting optimal estimate as its output signal. Tracking process using Kalman filter: Kalman filter uses the observed value to estimate the motion state. The process is divided into two steps: prediction and update. The prediction part is responsible for estimating the state of the next moment by using the current state and error covariance, and obtaining a priori estimate; the update section is responsible for feedback, taking the new actual observations into account with the prior estimates to obtain a posteriori estimate. After each completion of prediction and update, the priori estimate of the next moment is predicted by the posterior estimate, and the above steps are repeated. The Kalman filter Recursion is the principle. It directly acts on all previous data to estimate the current state value. Thus, Kalman filter is very easy to implement, which is also one of the significant advantages of Kalman filter.

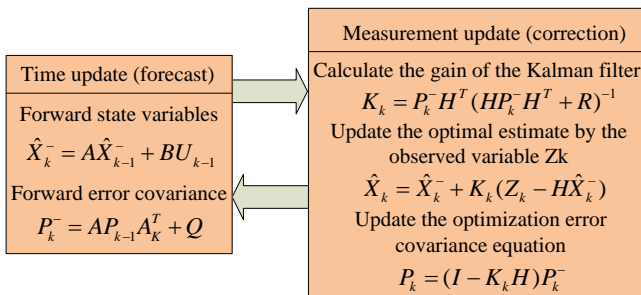


Fig. 4. Kalman filter algorithm flow chart.

On this basis, the posterior estimate derived from the system observation equation and the time update equation is used as the next a priori estimate, which is iterated. The Kalman filter has a recursive repetitive feature that makes it highly time-sensitive, and on this basis, the current state can be recursively estimated from the observed variables and the posterior estimate of the previous point only [24]. The Kalman filter approach can be illustrated in Fig. 4, which divides the Kalman filter into two parts, the measurement update and the time update. In this case, the covariance of the errors can be

calculated separately, with  $\hat{X}_{k-1}$  and  $P_{k-1}$  as their initial estimates. From the theory of Kalman filtering, it was found that when tracking a moving object, the position of the moving object in the next frame can be accurately predicted to reduce the search distance. In the case of partial occlusion, the object can be tracked quickly and accurately, and the algorithm is simple and convenient to enable real-time tracking of the target. The traditional Camshift algorithm is an expansion of the Meanshift algorithm and is currently the most widely used tracking method. This method uses a colour histogram to obtain a color probability distribution which changes as the object moves, allowing the object to be tracked using the change in color probability distribution. The method mainly consists of transforming the sequence image in RGB color space into HSV space and using the H component as the color histogram, so that the size of the random distribution can be visualised. In addition, the inverse projection method is used to obtain the color probability distribution map. In fact the color probability distribution map is a grey scale image. By finding the zero order distance and first order spacing, the distance between the centre of the viewport and the shape centre can be found, so that the essence of the Camshift algorithm is to perform Meanshift operations on each frame to track the target object by repeated iterations [25]. The probability curve of the CamShift algorithm is obtained through an inverted histogram. For the convenience of the study, a normalisation method is prescribed for the histogram, as shown in Equation (19).

$$q = \{q(u)\}_{u=1,2,\dots,m} \quad (19)$$

In Equation (19), the eigenvalues of  $\sum_{u=1}^m q(u) = 1$ ;  $u$  refers to indicators of a rectangle in the histogram;  $m$  is the number of its rectangles, and the probability value of its  $u$ -th square is shown in Equation (20).

$$q(u) = \frac{1}{n} \sum_{(x,y) \in R_m} \delta[c(R(x,y)) - u] \quad (20)$$

In Equation (20),  $R(x,y)$  is the image function of the image block  $R_m$ ;  $n$  is the number of its pixels;  $(x,y)$  is the value of the pixels, expressed in coordinates, and  $\delta(\square)$  is the Kronecker function;  $R$  has the following relationship with the corresponding pixels of its image block  $I$  of the same size, as shown in Equation (21).

$$I(x,y) = \sum_{u=1}^m q(u) \delta[c(R(x,y)) - u] \quad (21)$$

In Equation (21),  $R(x,y)$  is the image function of the image block  $R$  and the image block  $I$ . It is a mono which has a glow between [0,1] and must be linear in the range [0,226] in order to meet the display requirements. Both the MeanShift and CamShift algorithms use iterative operations on the weight map in the tracking frame to achieve tracking of objects, but their methods are. MeanShift assigns a weight to each pixel  $\sqrt{q_u / p_u} \cdot q_u$  and  $p_u$  are the current pixel values in the target

model and the corresponding probabilities in the candidate patterns, while CamShift assigns a weighting factor to each pixel  $q_u$ . Based on the calculation of the target size and colour probability distribution, the centre of mass and size of the moving object in the current frame is found and a circular frame is used to target the moving object. Fig. 5 shows the flow chart of the CamShift tracking algorithm.

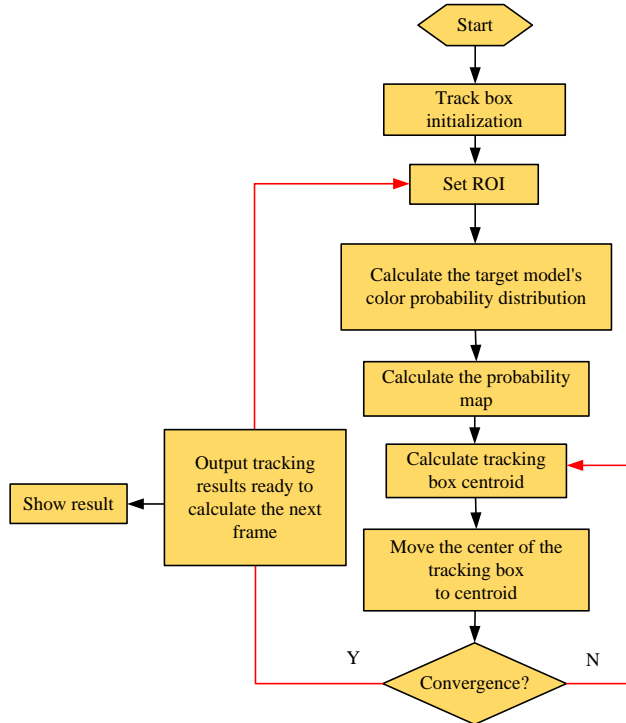


Fig. 5. CamShift tracking algorithm flowchart.

CamShift algorithm can achieve fast tracking of the object and meet the real-time demand. Its specific steps are as follows, the first step is to initialize the size and position of the search window, and the algorithm can be done automatically based on the object detection. The second step is to obtain the probability distribution of the color in the search box. The third step is to set the region of interest (ROI), based on the current object position, size and the maximum of a single frame motion distance. The fourth step is to solve for the centre of mass of the search square using the MeanShift algorithm. The fifth step is to cross out the position of the object if the distance between the centre point and the centre of mass is below a certain threshold. Otherwise, return to the fourth step. The sixth step is to perform adaptive calculations for the orientation and size of the tracked object. As the CamShift motion target tracking algorithm lacks a motion prediction module, the combination of Camshift and Kalman filtering allows the position of the moving object to be effectively estimated using the Kalman filter when the target is partially occluded, the targets are interfering with each other, the target is moving too fast and the tracking fails due to background interference in the approach. The  $Z_k$  obtained from the iterations of the algorithm has a great influence in the Kalman filter, thus affecting the prediction of the Kalman filter.

#### IV. PERFORMANCE ANALYSIS OF KALMAN FILTERING BASED ROBOT TARGET TRACKING SIGNAL PROCESSING APPLICATIONS

The experiment adopted 28 frames per second, 360\*240 resolution of rolling ping-pong image video. The processor is Intel(R) Core(TM) i5-8250 CPU@1.60GHz, and the memory is 8GB. The OpenCV library is used to detect and track the extracted objects. In order to test the performance of the research algorithm, the study designed a robot to track the motion of table tennis. Based on this, a wheel-based non-complete constraint robot model was proposed and used as a marker column. In the physical robot experiments, based on the odometer motion model and taking the linear characteristics as the background, the object motion model based on the velocity model was established. First, the robot starts with the pre-processing of the captured table tennis images. By pre-processing the images, the method effectively removes noise from the images and reduces the impact on subsequent processing, as shown in Fig. 6.

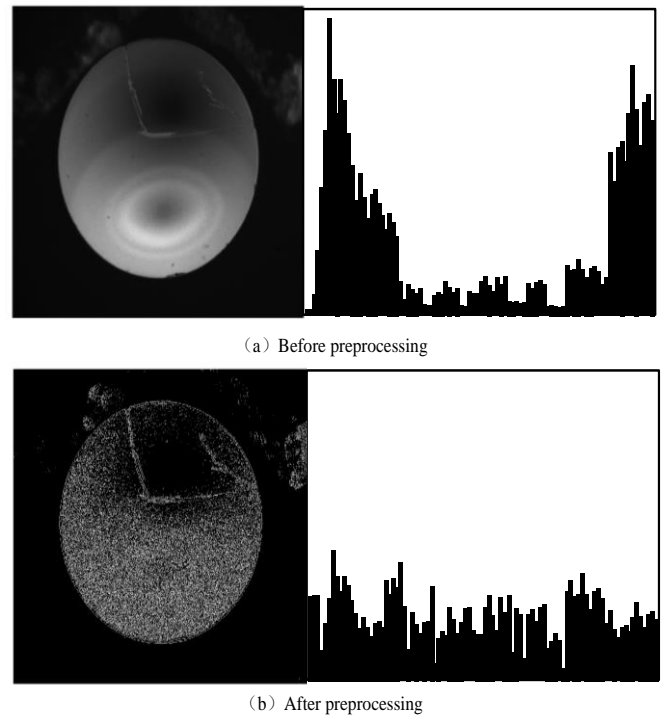


Fig. 6. Comparison of the effect before and after preprocessing the collected table tennis image signal.

As can be seen in Fig. 6, the histogram of the table tennis image signal captured by the robot changes significantly after pre-processing, which makes the grey intervals of the image larger and more uniform. This increases the contrast and makes the details in the image clearer, eliminating individual noise points to achieve the enhancement effect. Some images have the disadvantage of higher contrast due to factors such as lighting, blurring the details, and comparative suppression of irrelevant grey areas to bring out relevant objects or grey areas. The algorithm proposed in the study explores whether the improved CamShift algorithm based on Kalman filtering can effectively solve the problem of robot tracking of target motion



trajectories when moving objects are heavily obscured. 28 frames per second video with 360\*240 resolution of a rolling table tennis ball image was chosen for this experiment. The actual motion trajectory and robot tracking of the target trajectory are shown in Fig. 7.

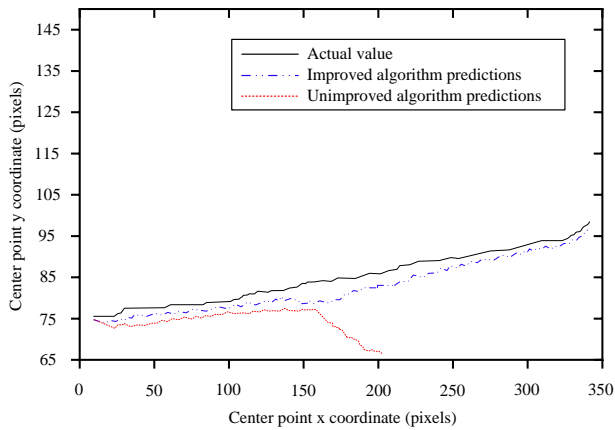


Fig. 7. Comparison of trajectory tracking of occluded table tennis balls before and after the improvement of Kalman filter algorithm.

It is evident from Fig. 7 that the target trajectory signal tracking graphs for the algorithm improved by Kalman filtering and the algorithm not improved by Kalman filtering are compared with the true values of the target. The graph shows that after encountering complete occlusion, the ping pong ball trajectory deviates from the true trajectory under the unimproved algorithm, while the corrected algorithm shows no track deviation with its improved by Kalman filtering. The bullseye coordinates of the CamShift algorithm for target unit tracking are shown in Table I.

TABLE I. THE COORDINATES OF THE TARGET CENTER POINT BEFORE AND AFTER THE IMPROVEMENT OF THE TRACKING ALGORITHM

Frame number	Target real coordinates	Real coordinates before algorithm improvement	The real coordinates after the algorithm is improved	Algorithms must be improved error
Frame 7	(100, 74)	(99, 67)	(99, 72)	3.98
Frame 11	(148, 78)	(148, 69)	(143, 75)	4.56
Frame 15	(189, 89)	(181, 56)	(183, 62)	23.66
Frame 18	(208, 84)	(183, 56)	(208, 79)	34.02
Frame 23	(258, 94)	(183, 54)	(246, 88)	90.95

Table I shows the relative error between the improved central position and the actual position during tracking, namely the relative absolute deviation between the two points. It can be seen that the target signal coordinates of Frames 7, 11, 15, 18 and 23 are selected in the research. When the target is blocked, the tracking accuracy of the improved algorithm based on Kalman filtering is greatly improved. The improved method

can ensure its tracking accuracy, and its iteration time comparison is shown in Fig. 8.

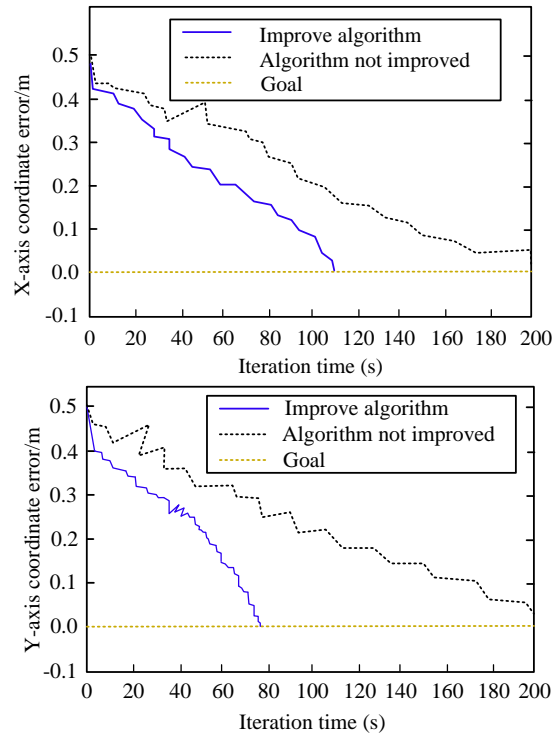


Fig. 8. The variation of the target X, Y coordinate error with time.

Fig. 8 clearly shows that the algorithm improved by Kalman filtering achieves the expected target accuracy after 110 and 78 training cycles for X and Y coordinates respectively, while the CamShift algorithm without Kalman filtering does not reach the expected error after 200 training cycles for both X and Y coordinates, indicating that its training effect is poor. This shows that the CamShift algorithm with Kalman filtering has better performance and can reach the intended training accuracy in a very short period of time.

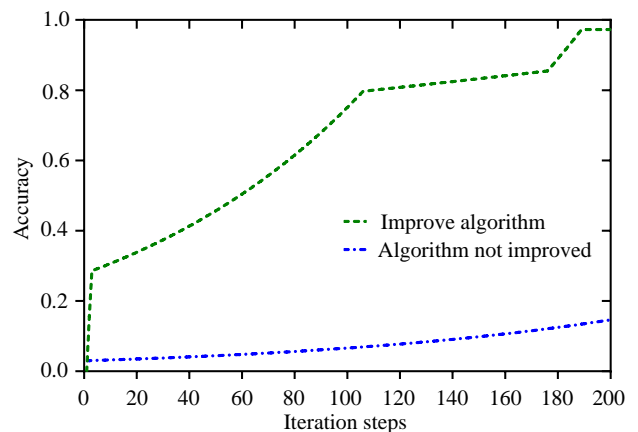


Fig. 9. Comparison of the accuracy of the algorithm before and after the improvement.

As can be seen from Fig. 9, the initial value of the CamShift algorithm improved by Kalman filtering increases

with the number of iterations of the model, and its correctness gradually stabilizes when the number of iterations of the model reaches a certain level. After stabilization, the accuracy of the model constructed by the improved CamShift algorithm based on Kalman filter was 99.69%. After 200 iterations, the improved algorithm showed a qualitative improvement in its performance over the previous algorithm, perhaps due to the combination of CamShift and Kalman filter. As a result, the targets were partially occluded, interfered each other, and moved too fast in approaching background interference caused by tracking failure. The position of the moving object can be effectively estimated using the Kalman filter, which affects the prediction of the Kalman filter. Table tennis tracking images are shown in Fig. 10.

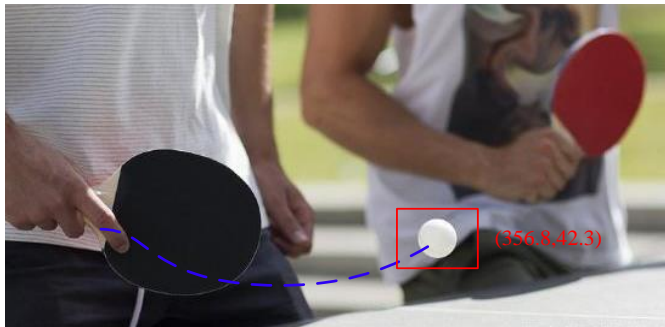


Fig. 10. Table tennis trajectory tracking image.

As can be seen from Fig. 10, the improved Kalman filtering algorithm proposed in this study has an excellent tracking effect on table tennis, with the confidence interval reaching 99%. In the frame 10, the coordinates of table tennis are determined as (356.8, 42.3), and its track tracking effect is excellent, without trajectory deviation and other phenomena. Therefore, the algorithm proposed in this study has excellent practicability.

## V. RESULTS AND DISCUSSION

The results of this study indicate that the signal processing algorithm for robot target tracking based on Kalman filter has great application potential in solving the difficult problems in moving target tracking. This algorithm achieves fast tracking of moving targets by tracking and predicting target signals, with higher real-time performance and accuracy. In addition, the adaptive ability and robustness of the algorithm have also been well verified. The experimental results show that the improved Kalman filter algorithm can quickly and accurately capture targets when they are occluded, making the tracking of the target continuous and stable, thereby solving the error when the target is occluded in global search and improving real-time performance. Therefore, this algorithm can be widely applied in fields such as robot target tracking, video surveillance, and intelligent transportation.

In addition, this study also has certain reference value for the establishment of robot models. By establishing a robot model marked by incomplete wheel constraints and establishing an object motion model based on the velocity model, a more complete and accurate description of robot target tracking is provided, and it also provides a certain reference for research in other robot application fields.

It should be pointed out that although this study has achieved good results in experimental results, it still needs to be adjusted and optimized according to specific situations in practical applications. At present, research methods have certain limitations in solving the problem of target occlusion. Although the improved Kalman filtering algorithm can quickly and accurately capture targets, if the target is completely occluded, the algorithm still has errors. In addition, the performance of the algorithm may also be affected by specific environments and scenarios, and needs to be adjusted and improved. Therefore, in future research, it is necessary to further improve the robustness and adaptability of the algorithm to cope with more complex practical situations. At present, research has implemented a robot target tracking signal processing algorithm based on Kalman filter, and has achieved good results in experimental results. This algorithm can quickly and accurately capture moving targets, with higher real-time and accuracy, and solves the error of target occlusion in global search. There are two aspects to the unfinished work: on the one hand, adjustments and improvements are made to different environments and scenarios to improve the robustness and adaptability of the algorithm. On the other hand, it is necessary to further improve the real-time and accuracy of the algorithm to cope with more complex practical situations. Therefore, in future research, it is necessary to further optimize and improve algorithms to meet the needs of different scenarios, and explore new methods to improve the performance and practicality of algorithms.

## VI. CONCLUSION

Moving target tracking is an important research direction in computer vision. This paper introduces the principle of Kalman filter algorithm and CamShift algorithm. Kalman filter technology is used to realize target tracking, which makes up for the loss of Camshift algorithm in target tracking. In the case that the target is seriously blocked, the algorithm can capture the target quickly and accurately, and make the tracking of the target continuous and stable, with good adaptive ability and robustness. The research shows that the contrast of the target signal is improved after the preprocessing. The enhancement effect is achieved, and the single noise point is eliminated. By comparing the tracking curve of the target track signal of the improved Kalman filtering algorithm with the real motion curve of the target, it can be seen that, when the target meets the complete occlusion, the ping pong track under the unimproved algorithm deviates from the real track, while the improved algorithm almost coincides with the target motion track. The algorithm improved by Kalman filtering reached the expected accuracy in X and Y coordinates after 110 and 78 training times respectively, while the algorithm without Kalman filtering still did not reach the expected error in X and Y coordinates after 200 training times. The accuracy of the model based on the improved algorithm of Kalman filter is 99.69%. After 200 iterations, the performance of the improved algorithm is significantly improved compared with the previous algorithm, indicating that the proposed robot target tracking signal processing algorithm based on Kalman filter has strong practical significance. This method realizes the fast tracking of moving target, solves the error when the target is blocked in the global search, transforms the global search

problem into the local search problem, and improves the real-time performance.

#### DATA AVAILABILITY STATEMENT

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

#### CONFLICTS OF INTEREST

It is declared by the authors that this article is free of conflict of interest.

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# Vehicle Path Planning Based on Gradient Statistical Mutation Quantum Genetic Algorithm

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**Abstract**—In the field of vehicle path planning, traditional intelligent optimization algorithms have the disadvantages of slow convergence, poor stability and a tendency to fall into local extremes. Therefore, a gradient statistical mutation quantum genetic algorithm (GSM-QGA) is proposed. Based on the dynamic rotation angle adjustment by the chromosome fitness value, the quantum rotation gate adjustment strategy is improved by introducing the idea of gradient descent. According to the statistical properties of chromosomal change trends, the gradient-based mutation operator is designed to realize the mutation operation. The shortest path is used as the metric to build the vehicle path planning model, and the effectiveness of the modified algorithm in vehicle path planning is demonstrated by simulation experiments. Compared with other optimization algorithms, the path length planned by the improved algorithm is shorter and the search stability is better. The algorithm can be effectively controlled to fall into local optimums.

**Keywords**—Quantum genetic algorithm; path planning; gradient descent; adaptive mutation operator; quantum rotation gate

## I. INTRODUCTION

With the continuous development of artificial intelligence, automation technology [1] has shown strong applicability. Autonomous vehicles have become the future direction of the vehicular sector. Its core is autonomous driving technology. Autonomous driving technologies mainly include environment sensing, path planning, behavioral decision-making, and tracking control. Path planning [2] [3], as one of the key aspects of autonomous driving technology, has become a hot research topic in the field of autonomous driving. It has important value in engineering applications [4]. Path planning is mainly to plan a drivable path avoiding obstacles from the starting point to the target one based on the road environment [5]. Planning the shortest path is an NP-hard problem [6]. Thus, the path planning problem has high computational complexity. From the development of path planning algorithms, there are traditional algorithms represented by Dijkstra's algorithm [7], A\* algorithm [8], artificial potential field (APF) method [9], and dynamic window algorithm (DWA) [10]. As well as genetic algorithm (GA) [11], ant colony optimization (ACO) [12], and particle swarm optimization (PSO) [13] are as the representative of intelligent optimization algorithms. The high computational cost of traditional algorithms makes it difficult to further improve the efficiency of path search, leading to a gradual decline in utilization [14].

ZHU [7] studied the path planning problem considering intersection properties and proposed a reverse labeling Dijkstra

algorithm (RLDA) with minimizing travel time from the origin to the terminus as the optimization objective. The RLDA algorithm has low polynomial time complexity. The convergence efficiency and computational speed of the proposed algorithm are improved. LI [8] introduced a bidirectional alternating search strategy in the A\* algorithm and weighted the heuristic function with an exponential decay to improve the search efficiency of the algorithm. In addition, a path node filtering function was introduced to effectively reduce the turning angle. LI [15] proposed a path planning method combining an APF and a dynamic enhanced fireworks algorithm for autonomous vehicles. This real-time path planning method effectively improved smoothness and safety of paths. Hou [16] proposed an enhanced ant colony algorithm with a communication mechanism for path planning, which accelerates the integration of historical paths through direct communication between individuals, and improved the path selection rules and heuristic functions to increase the convergence speed and search efficiency. LIU [17] proposed a path planning method based on the improved gray wolf algorithm, introducing interference factors and dynamic weights based on the lion optimization algorithm to avoid the loss of diversity. However, the ability to jump out of the local optimum needs to be enhanced. Kumar [18] proposed a path planning method combining artificial bee colony and evolutionary planning algorithms, using an artificial bee colony algorithm to perform an initial search based on an improved strategy, followed by an evolutionary algorithm to refine the obtained feasible paths and reduce the search cost. Martinez [19] proposed the integration of an autonomous motion planning strategy for a differential robot. It combined the PSO with a Proportional-Integral-Derivative controller to ensure the stability of a differential robot path planning in complex environments.

Intelligent optimization algorithms have become one of the mainstream methods for solving path planning problems due to their better search capabilities and higher computational efficiency compared to traditional path planning algorithms. The GA has stronger global search capabilities than other intelligent optimization algorithms, as well as the ability to easily extend other algorithms. Although genetic algorithms have the above characteristics, there is a problem with early convergence [20] [21] due to high chromosome similarity in the later stages. In response to the GA problem, many researchers have proposed different modified algorithms. HE [22] proposed a GA to improve the fitness function. It added the knowledge in the problem domain as guiding information to the search process of the algorithm and took full advantage

of the trend of the function to improve the convergence rate of the algorithm. XU [11] introduced a disaster strategy and a dynamic mutation operator embedded in the A\* algorithm into the GA to reduce prematureness and improve the local search ability of the algorithm at later stages. The fitness function with multiple constraints enhanced the smoothness of the planned path. However, the initialization of the population with each catastrophe reduces the computational efficiency. ZHANG [23] proposed a hybrid initialized genetic algorithm, where a portion of individuals use a greedy algorithm to acquire paths, introducing deletion operations and reversal operations to prevent the algorithm from falling into local optimums.

The quantum genetic algorithm [24] (QGA) is an emerging intelligent optimization algorithm arising from the GA combined with the quantum computing. Depending on the superposition and entanglement of quantum states, quantum coding and quantum rotation gate update operations are introduced to enable better population diversity and convergence speed of the QGA compared to the GA. However, the QGA mainly relies on the quantum rotation gate for population updating. When solving combinatorial optimization problems [25] [26], it has problems such as low stability, poor convergence, and difficulty in jumping out of local optimums. In recent years, researchers have proposed many improvement strategies. WANG [27] introduced the quantum NOT gate mutation and quantum catastrophe operation and proposed an adaptive rotation angle strategy based on genetic algebra. However, the quantum NOT gate mutation operation is prone to population turbulence, and the randomness of the quantum catastrophe operation may cause the algorithm to fail to converge. XIAO [28] introduced the grouping optimization strategy of hybrid frog-jumping algorithm to divide the population and given the acceptance probability of feasible solutions using simulated annealing reception criterion. The search probability is somewhat improved. ZHANG [29] proposed an adaptive rotation angle strategy based on fitness-based values, and also introduced a quantum NOT gate mutation operation. CHENG [30] proposed an improved double-linked quantum genetic algorithm that uses an inverse sine function to construct the corner step function. The search accuracy of the algorithm is improved.

In this paper, we propose a vehicle path planning method based on a gradient statistical mutation quantum genetic algorithm. A dynamically adjusted quantum rotation gate strategy is used to improve the convergence of the algorithm and the stability of the global search by introducing the idea of gradient descent based on dynamically adjusting the rotation angle according to the fitness value of the chromosomes. Based on the statistical properties of the trend of chromosome change, the mutation operator is designed to implement the mutation operation instead of the quantum NOT gate. An adaptive mutation strategy based on the quantum bit probability density is proposed to improve the ability of the algorithm to jump out of the local optimum. The effectiveness of the proposed algorithm is demonstrated through experimental analysis of path planning simulations.

The rest of the paper is structured as follows: In Section II, the vehicle path planning problem is formulated and the cost function for path planning is described. In Section III, the main

steps of QGA are introduced and the principles of chromosome update and mutation operations in the GSM-QGA are presented. The GSM-QGA is applied to path planning. Section IV presents the simulation of global path planning for vehicles using the GSM-QGA.

## II. PROBLEM STATEMENT

For the vehicle path planning problem, the main objective in this paper is to obtain a feasible path with the shortest distance based on avoiding static obstacles.

### A. Assumptions

The following assumptions are made:

- The vehicle moves from the starting point to the target one in a finite plane space at a uniform speed.
- The shape and size of obstacles and their geographic locations never vary during vehicle movement.
- The vehicle can be considered a mass point concerning static obstacles in the environment map [31].

### B. Cost Function of Path Planning

The path planning mainly considers safety and path cost. In this work, the shortest path is used as the path cost in vehicle path planning. To facilitate the computation of path planning, a sequence of spatial location points is often used to represent the travel path of a vehicle, and this representation needs to only take into account the feasibility of each spatial location point. Therefore, two cost functions are constructed: The path point cost function (*point\_fit*) and the path cost function (*way\_fit*). The path point quantum state updating is determined with *point\_fit*, and the path selection is determined based on *way\_fit*. The Euclidean distance is used to construct *point\_fit* [32]. The cost of a path can be estimated by calculating the sum of distances from its points to both the original position and the goal one. Notably, the smaller such the distance is, the lower the overall cost will be.

$$\min \text{point\_fit} = \sqrt{(x_{ir} - x_s)^2 + (y_{ir} - y_s)^2} + \sqrt{(x_{ir} - x_g)^2 + (y_{ir} - y_g)^2} \quad (1)$$

Where  $(x_{ir}, y_{ir})$  denotes the coordinates of the  $r$ th path point in the  $i$ th drivable path.  $(x_s, y_s)$  indicates the coordinates of the starting point.  $(x_g, y_g)$  indicates the coordinates of the target one.

To calculate the total path length of all path points connected in sequence, *way\_fit* is defined as follows.

$$\min \text{way\_fit} = \sum_{r=1}^{M-1} \sqrt{(x_{ir} - x_{ir+1})^2 + (y_r - y_{ir+1})^2} \quad (2)$$

Where  $M$  is the number of all path points in a feasible path.

## III. OPTIMIZATION ALGORITHM

In path planning problems, an improved algorithm is needed for problems where the QGA is not sufficiently stable and tends to fall into a local minima or maxima. In this section, the GSM-QGA for vehicle path planning will be introduced. The key process of the QGA will be described. Principles of

chromosome updating and mutation operations in the GSM-QGA are presented along with the vehicle path planning process.

### A. Quantum Genetic Algorithm

A quantum bit (qubit) is the smallest information unit of a quantum computer. In a two-state quantum system, the state of a qubit can be described as [33].

$$|\varphi\rangle = \alpha|0\rangle + \beta|1\rangle \quad (3)$$

Where the state of a qubit  $|\varphi\rangle$  is the superposition of uncertainty between the state of qubit  $|0\rangle$  and qubit  $|1\rangle$ .  $\alpha$  and  $\beta$  are the probability amplitudes. They satisfy the normalization conditions as follows [33].

$$|\alpha|^2 + |\beta|^2 = 1 \quad (4)$$

The use of qubit coding for population initialization enables the inclusion of complex population information at a small population size. An initialized quantum population is represented as follows.

$$Q(0) = \{q_i(0)\}, (i = 1, 2, \dots, m) \quad (5)$$

Where  $m$  is the population size. An individual is defined by one chromosome, denoted as  $q_i(0)$ . In addition,  $q_i(0)$  is represented as a feasible solution too. Its coded form is expressed as follows.

$$q_i(0) = \left| \begin{array}{cccc} \alpha_{i1}^1(0) & \alpha_{i1}^2(0) & \dots & \alpha_{i1}^k(0) \dots \alpha_{im}^1(0) & \alpha_{im}^2(0) & \dots & \alpha_{im}^k(0) \\ \beta_{i1}^1(0) & \beta_{i1}^2(0) & \dots & \beta_{i1}^k(0) \dots \beta_{im}^1(0) & \beta_{im}^2(0) & \dots & \beta_{im}^k(0) \end{array} \right| \quad (6)$$

Where  $q_i(0)$  denotes the  $i$ th individual in the initialized population.  $n$  is the number of gene points contained in a feasible solution, and  $k$  is the number of qubits contained in gene coding. When the population is initialized, in order to ensure the equilibrium of the population distribution, the probability magnitude of each qubit in an individual is expressed as (7).

$$\alpha_{ir}^j(0) = \beta_{ir}^j(0) = \frac{1}{\sqrt{2}} \quad (7)$$

Where  $i = 1, 2, \dots, m$ ;  $r = 1, 2, \dots, n$ ;  $j = 1, 2, \dots, k$ .

QGA uses a quantum rotation gate to update the probability amplitude of the qubit in order to search for the optimal solution of the problem. The quantum rotation gate is commonly adapted as follows [34].

$$U(\theta) = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \quad (8)$$

Where  $\theta$  is the rotation angle, obtained by looking up the table.

The updated state  $|\varphi'\rangle$  is denoted as

$$|\varphi'\rangle = \begin{bmatrix} \alpha' \\ \beta' \end{bmatrix} = U(\theta) \times |\varphi\rangle = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \end{bmatrix} \quad (9)$$

Where  $\alpha'$  and  $\beta'$  denote the probability magnitudes after updating of states  $|0\rangle$  and  $|1\rangle$ .

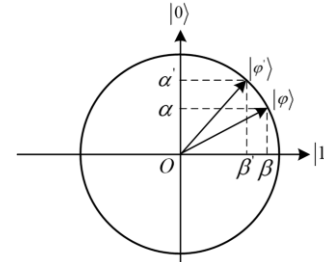


Fig. 1. The Update Of Qubits Probability Amplitudes.

In the two-state quantum system, the update of qubits probability amplitudes is shown in Fig. 1. The probability amplitudes of qubits are taken with continuity. In this way, the QGA has continuous spatial search capability.

### B. Gradient Statistical Mutation Quantum Genetic Algorithm

1) Adaptive quantum rotation gate: The rotation angle of the quantum rotation gate plays a key role in chromosome renewal. The size and direction of  $\theta$  determine the speed and direction of individual evolution. In the QGA,  $\theta$  is obtained by looking up the table. This approach does not give a basis for the choice of rotation angle depending on the specific problem to be solved. Moreover,  $\theta$  obtained in this way fails to consider not only the differences between chromosomes in the population, but also the trends in the search points. In the GSM-QGA, differences between different chromosomes in a population of the same generation are taken into account, and trends in chromosomal gene points between populations of different generations are considered to influence population evolution. In this paper, we relate the magnitude of the rotation angle to the chromosome fitness value. At the same time, the idea of gradient descent was introduced to study the trend of chromosomal gene points. Thus, a strategy for adaptive adjustment of the rotation angle is proposed as follows.

$$\theta_{ir}^j = -\text{sgn}(A) \theta_0 \exp\left(a \frac{|fit_{best} - fit_i|}{fit_{best}} + (a-1) \frac{|\nabla f(X_{ir}) - \nabla f_{rmin}|}{\nabla f_{rmax} - \nabla f_{rmin}}\right) \quad (10)$$

$$\nabla f_{rmax} = \max \left\{ \left| \frac{\partial f(X_i)}{\partial X_{ir}} \right| \right\} (i = 1, 2, L, m) \quad (11)$$

$$\nabla f_{rmin} = \min \left\{ \left| \frac{\partial f(X_i)}{\partial X_{ir}} \right| \right\} (i = 1, 2, L, m) \quad (12)$$

Where  $\theta_{ir}^j$  denotes the rotation angle of the  $j$ th qubit in the  $r$ th gene point of the  $i$ th chromosome.  $-\text{sgn}(A)$  indicates the



direction of rotation angle.  $\theta_0$  denotes the initial rotation angle step. The weight  $a \in (0,1)$  is used to reflect the effect of fitness function values and gene point gradients on the degree of chromosome evolution.  $fit_i$  is the fitness value of the  $i$ th chromosome in the current generation.  $\nabla f(X_{ir})$  is the gradient at the  $r$ th gene point of the  $i$ th chromosome.  $\nabla f_{r,\min}$  and  $\nabla f_{r,\max}$  are the minimum and maximum values of the gradient at the  $r$ th gene point in the current population.  $A$  is

$$A = \begin{bmatrix} \alpha_0 & \alpha_1 \\ \beta_0 & \beta_1 \end{bmatrix} \quad (13)$$

Where  $(\alpha_0, \beta_0)^T$  is the probability amplitude of the corresponding qubit in the current optimal chromosome and  $(\alpha_1, \beta_1)^T$  is the probability amplitude of the corresponding qubit in the current chromosome.

The direction of the rotation angle is chosen as follows: When  $A \neq 0$ , the direction of the rotation angle is  $-\text{sgn}(A)$ ; when  $A = 0$ , the direction is chosen randomly [35].

The dynamic adjustment strategy of a quantum rotation gate considers both the fitness values of chromosomes and the trends of chromosome loci. When the chromosome fitness value is far from the optimal chromosome and the quantum position gradient changes weekly, the rotation angle is increased to expedite convergence. Conversely, in order to prevent missing the optimal chromosome, the rotation angle must be diminished, thereby enhancing both the speed of convergence in the algorithm and the stability of the global search.

2) *Quantum mutation*: Despite the strong global search capability of the QGA, it is easy to get trapped in local optima by updating the population only through a single quantum rotation gate. Therefore, a certain perturbation operation is needed to reduce the occurrence of "premature" population. Improved QGA [36] usually uses the quantum NOT gate to perform variation on the probability magnitudes of individual qubits in the population, which can avoid the local optimum to a certain extent. When a chromosome performing the mutation is very close to the optimal chromosome, the quantum NOT gate mutation will cause the reversal of the direction of qubit update, which may cause the population turbulence and the loss of excellent chromosome information. In addition, this operator fails to consider the effect of chromosomal information contained in the population and perturbative factors such as external environment on chromosomal gene mutations, resulting in a lack of population perception.

Therefore, in this paper, we propose a mutation operator that includes the past information of individuals in the population. It enables the quantum mutation operation to impose reasonable perturbations during population evolution to avoid premature convergence of the population. Genetic information decreases with increasing number of generations,

and current chromosomal gene points are most affected by paternal chromosomes. As a result, we only consider the effect of paternal chromosomes on the current chromosomal gene point. The gradient ( $\nabla Z_{ir}$ ) of statistical past chromosomal gene point fitness values is expressed as (14).

$$\nabla Z_{ir} = \nabla f(X_{ir}) + o(\nabla f(X_{ir})) \quad (14)$$

Where  $o(\nabla f(X_{ir}))$  is the higher order infinitesimal of the gradient of the offspring and parent.

The probability density function is designed according to the trend of chromosomal gene points as follows.

$$f(\nabla Z_{ir}) = \sum_l b_{l1} \exp\left(-((\nabla Z_{ir} - b_{l2}) / b_{l3})^2\right) \quad (15)$$

Where  $b_{l1}$ ,  $b_{l2}$  and  $b_{l3}$  are Gaussian mixture distribution parameters, respectively.

Transforming (15) into a probability distribution function as follows.

$$F(\nabla Z_{ir}) = \sum_l b_{l1} \int_{-\infty}^{\nabla Z_{ir}} \exp\left(-((\nabla Z_{ir} - b_{l2}) / b_{l3})^2\right) \quad (16)$$

The mutation operation is performed on the qubit probability amplitude, and the probability distribution of the qubit gradient is used as the mutation operator.

$$\begin{cases} \alpha_{ir}^j(t) = \sqrt{1 - F(\nabla Z_{ir})} \\ \beta_{ir}^j(t) = \sqrt{1 - \alpha_{ir}^j(t)^2} \end{cases} \quad (17)$$

Where  $\alpha_{ir}^j(t)$  and  $\beta_{ir}^j(t)$  denote the probability amplitude of the state  $|0\rangle$  and  $|1\rangle$  at the  $j$ th gene point of the  $r$ th chromosome in the  $t$ th generation, separately.

In addition, a reasonable mutation probability is beneficial for improving diversity and stability of population evolution. Thus, according to the evolutionary trend of chromosomes in the population, an adaptive mutation mechanism based on the qubit probability density is proposed as follows: The mutation probability of the current qubit is determined based on the gradient of gene points. When chromosome evolution is relatively "flat", a large perturbation probability is given to make chromosomes jump out of the local optimum and increase population diversity. On the contrary, a small perturbation probability is given to avoid destroying individuals with good genes and to improve the stability of the population. Random selection of qubits in an individual based on adaptive mutation probability is used to apply mutation operations. The adaptive mutation probability ( $p_m$ ) is expressed as:

$$\begin{aligned} p_m &= P(\nabla Z \geq \nabla Z_{ir}) \\ &= 1 - F(\nabla Z_{ir}) \\ &= 1 - \sum_l b_{l1} \int_{-\infty}^{\nabla Z_{ir}} \exp\left(-((\nabla Z_{ir} - b_{l2}) / b_{l3})^2\right) \end{aligned} \quad (18)$$

The flowchart of the GSM-QGA is shown in Fig. 2.

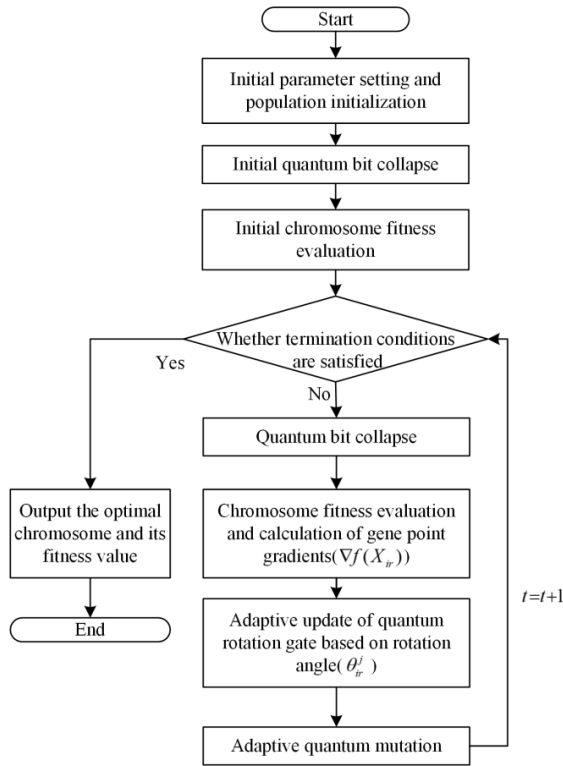


Fig. 2. The flowchart of the GSM-QGA

### C. Vehicle Path Planning Based on Gradient Statistical Mutation Quantum Genetic Algorithm

To plan a vehicle path based on the GSM-QGA, the path is first encoded, where path points on the same parallel line are encoded with qubits in a grid map. Then, the quantum encoded path points are arranged to form a feasible path, which constitutes a chromosome. The encoding form of the chromosome is shown in Fig. 3.

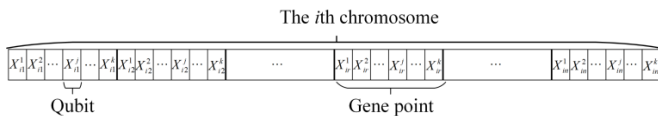


Fig. 3. Chromosome coding

Fitness values at the path points are discretize. Thus, the gradient of path points in the chromosome is represented using the first-order difference between two adjacent generations as follows.

$$\nabla f_{r \max} = \max \left\{ \left| f \left[ X_{ir} (t-1) \right] - f \left[ X_{ir} (t) \right] \right| \right\} \quad (19)$$

$$\nabla f_{r \min} = \min \left\{ \left| f \left[ X_{ir} (t-1) \right] - f \left[ X_{ir} (t) \right] \right| \right\} \quad (20)$$

Where  $i = 1, 2, L, m$ .

By statistically analyzing the gradient information of path points in past chromosomes, we obtain parameter values of formula (15).

$$\left( b_1 \ b_2 \ b_3 \right)^T = \begin{bmatrix} 0.7521 & 0.1421 & 0.1519 & -0.6852 & 0.04352 \\ 0.5204 & 2.072 & 0.1908 & 0.4204 & 5.743 \\ 0.9951 & 2.126 & 0.6099 & 1.01 & 2.565 \end{bmatrix} \quad (21)$$

Here are the steps of vehicle path planning based on the GSM-QGA.

Step 1: The environmental map construction. Building a grid map based on a known planning space.

Step 2: Initial parameters configuration and the population initialization. The population size ( $popsiz$ ) is  $m$ . The number of genetic generations is  $t$  and the initial value of the rotation angle is  $\theta_0$ . The starting point and ending one must be defined prior to initialization. After quantum encoding of path points, the initialized population ( $Q(0)$ ) is generated. All probability amplitudes of path point qubits in the primitive chromosome are represented by  $\alpha_{ir}^j(0) = \beta_{ir}^j(0) = 1/\sqrt{2}$ .

Step 3: Initial qubits collapse. All  $Q(0)$  undergo measurement, causing their respective qubits to collapse into a predetermined state ( $p(0)$ ). The resulting  $p(0)$  set of collapsed qubits represents the desired path points for the vehicle.

Step 4: Initial path adaptation evaluation.  $point\_fit_r(0)$  and  $way\_fit_r(0)$  are computed.  $way\_fit_r(0)$  in the population are compared, and the chromosome indicating the current shortest path ( $q_{best}$ ) and its corresponding fitness value ( $way\_fit_{best}$ ) are recorded.

Step 5: Qubits collapse. All  $Q(t)$  undergo measurement, causing their respective qubits to collapse into a predetermined state ( $p(t)$ ).

Step 6: Path adaptation evaluation.  $point\_fit_r(t)$  and  $way\_fit_r(t)$  are calculated, as well as  $\nabla f(X_{ir})$ .  $way\_fit_r(t)$  in the population are compared, and the chromosome that represents the current  $q_{best}$  and its corresponding  $way\_fit_{best}$  are recorded.

Step 7: The quantum rotation gate adaptive updating.  $\theta_{ir}^j$  is obtained by (10) to (13), and the chromosome is updated adaptively using a quantum rotation gate.

Step 8: Quantum mutation operation.  $p_m$  is determined by an adaptive mutation mechanism. Qubits in a chromosome are chosen randomly by  $p_m$ , and an adaptive mutation operator is used to apply mutation operations to these qubits.

Step 9: Determine if the maximum number of iterations or convergence condition is satisfied. If it is satisfied, the algorithm ends and the shortest path is output. Otherwise, the number of iterations  $t = t + 1$ , and return to step 4.

#### IV. RESULTS AND DISCUSSION

This section presents a vehicle path planning simulation based on the GSM-QGA aimed at demonstrating its effectiveness in this field. In this paper, we explore vehicle path planning within an industrial park, which is set against an area of  $1 \times 10^6$  m<sup>2</sup>. The environment map was generated by adopting the grid approach consisting of splitting the industrial park into grids that measure 0.05 km in length, forming a total of  $20 \times 20$  grids. White grids represent traversable areas for vehicles, whereas black grids indicate obstructions. The starting point of the vehicle is situated at the coordinate (1, 1) and denoted with a pentagram, whereas the destination is marked using a similar symbol at coordinate (20, 20). Finally, initialization parameters were established. The maximum number of genetic generations is  $t = 50$ . The population sizes of the GA are  $popsiz = 20$  and  $popsiz = 100$ . The crossover probability and mutation probability of the GA are  $p_c = 0.8$  and  $p_m = 0.1$ . The population size of the QGA is  $popsiz = 20$ . The population size for the Quantum Genetic Algorithm of quantum NOT gate mutation (N-QGA) is  $popsiz = 20$ . The mutation probability of the N-QGA is  $p_m = 0.1$ . The population size of the GSM-QGA proposed in this paper is  $popsiz = 20$ . The initial rotation angle of the GSM-QGA is  $\theta_0 = 0.1\pi$ . The solution accuracy and convergence speed of these four algorithms are compared to verify the performance of our algorithm in path planning.

show the path iteration convergence curves for the four algorithms run 5 times.

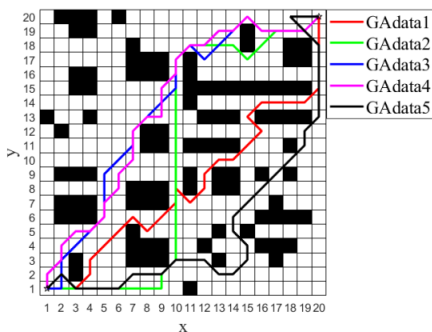


Fig. 4. The path planning simulation results of the GA with  $popsiz=20$  run 5 times.

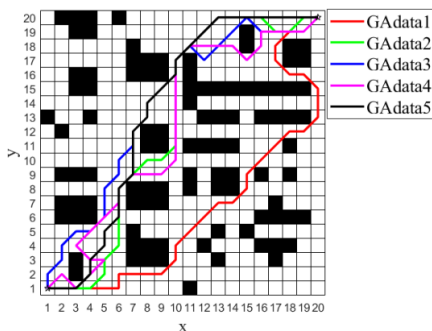


Fig. 5. The path planning simulation results of the GA with  $popsiz=100$  run 5 times.

Fig. 4 to 8 show the path planning simulation results of the four algorithms run 5 times in a  $20 \times 20$  grid map. Fig. 9 to 13

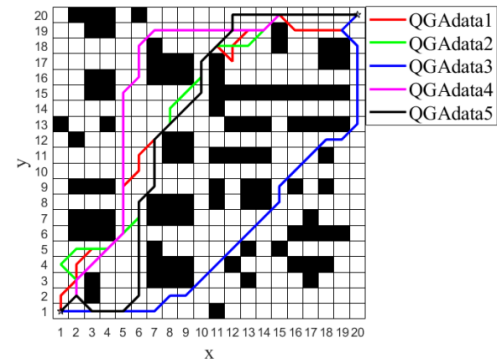


Fig. 6. The path planning simulation results of the QGA run 5 times.

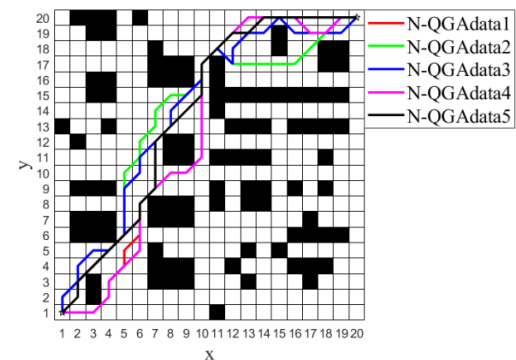


Fig. 7. The path planning simulation results of the N-QGA run 5 times.

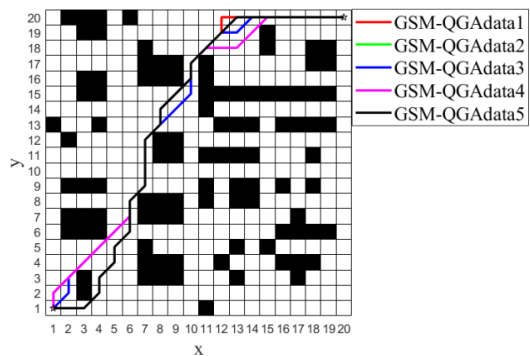


Fig. 8. The path planning simulation results of the GSM-QGA run 5 times

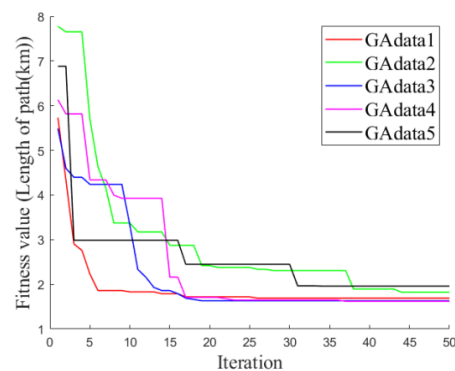


Fig. 9. The path iteration convergence curves for the GA with  $popsiz=20$  run 5 times.

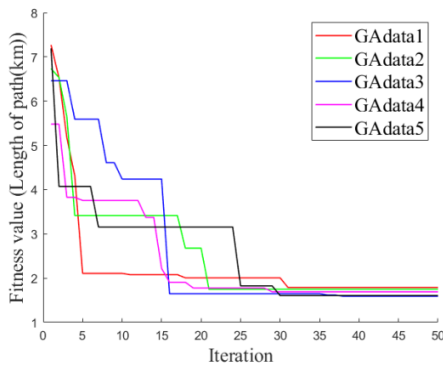


Fig. 10. The path iteration convergence curves for the GA with popsize=100 run 5 times.

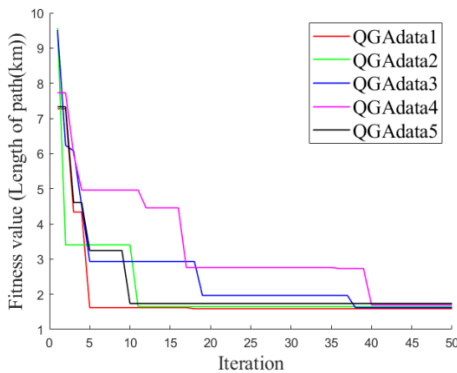


Fig. 11. The path iteration convergence curves for the QGA run 5 times.

Since these algorithms have a certain degree of search randomness, we count the results gathered from five runs of each algorithm, as displayed in Table I. “Length of path” in the Table I indicates the path distance from the start point to the target one. “Number of iterations” in Table I expresses the number of generations for population update when converging to the optimal solution. “Optimum path length”, “Worst path length”, and “Average path length” in Table I represent the minimum, maximum, and average values of the path distance among the five runs of the algorithm, respectively. With the condition of keeping population sizes and iteration times constant, as can be seen visually in Fig. 4 and Fig. 9, When the population size is small, the paths planned by the GA are too long and the optimal paths obtained differ significantly each time. The difference between the optimal path and the worst path is 0.3415 km. The GA converges slowly, with an average number of 32 iterations, and is easily trapped in a local optimum. By increasing the population size to 100, the GA method yields improved path length and convergence speed. The optimal path length is 1.5899 km. However, it is clear from Fig. 5 that there is still significant redundancy in the path distance. While both the QGA and the N-QGA are capable of further optimizing the path distance, it can be shown from Fig. 6 and Fig. 7 that the searched paths still vary considerably and the stability of the algorithm is not good. The difference between the optimal path and the worst path is 0.1475 km and 0.1293 km, respectively. As shown in Fig. 11 and Fig. 12, the overall convergence speed still requires further enhancement. As illustrated in Fig. 8 and Fig. 13, the GMS-QGA proposed in

this paper can break away from local optimization. The obtained optimal path is 1.5485 km and an average number of iterations is 15.8. Meanwhile, the results obtained from 5 runs confirm the good stability of the algorithm. The difference between the optimal path and the worst path is only 0.0586 km.

Fig. 14 and Fig. 15 provide a more intuitive comparison of the four path planning algorithms in terms of solution accuracy and convergence speed. Evidently, the GA exhibits slow convergence and susceptibility to premature optimization. Its planned paths exhibit a higher degree of redundancy. The QGA converges in the 18th iteration with an optimal path of 1.5889 km. While it converges quickly, it struggles to break away from local optima. By leveraging mutation operators based on the quantum NOT gate's local perturbation, the N-QGA effectively escapes local optima. It obtains an optimal path of 1.5485 km. However, the magnitude of its mutations is large, which can easily lead to population turbulence. The N-QGA has slow convergence and poor algorithmic stability. In contrast, the GSM-QGA updates quantum coding path points using adaptive quantum rotation gate, exhibiting faster path convergence. The optimal path of 1.5485 km is obtained by the 16th iteration. Furthermore, through a mutation operator and variation strategy designed based on past path data, this algorithm can better perturb the path planning process while mitigating premature optimization, thereby achieving shorter planned path distances. The average path obtained by GSM-QGA is 1.56608 km. From the calculation of the data in Table I, compared to the other three algorithms, the GSM-QGA averages 10.26%, 7.06%, 5.52%, and 2.99% reduction in length while increasing the average speed of convergence by 50.63%, 46.98%, 32.48%, and 26.85%, all while maintaining superior algorithm stability.

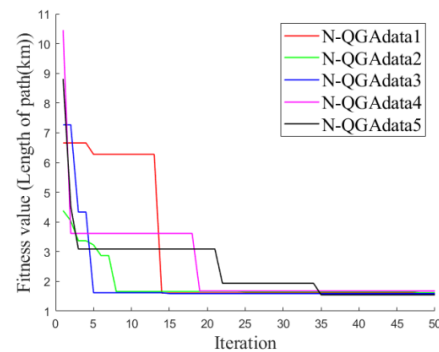


Fig. 12. The path iteration convergence curves for the N-QGA run 5 times.

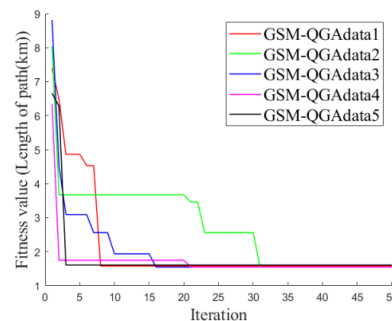


Fig. 13. The path iteration convergence curves for the GSM-QGA run 5 times.

TABLE I. STATISTICAL TABLE OF THE RESULTS FOR THE FOUR ALGORITHMS RUN 5 TIMES

Algorithm	Result statistics of different algorithms					
	Running of ith time	Length of path(km)	Number of iterations	Optimum path length(km)	Worst path length(km)	Average path length(km)
GA (popsize=20)	1	1.6899	26	1.6192	1.9607	1.7451
	2	1.8243	44			
	3	1.6314	19			
	4	1.6192	37			
	5	1.9607	34			
GA (popsize=100)	1	1.7899	31	1.5899	1.7899	1.68506
	2	1.7485	21			
	3	1.5899	38			
	4	1.6899	29			
	5	1.6071	30			
QGA	1	1.5889	18	1.5889	1.7364	1.6576
	2	1.6485	11			
	3	1.6192	38			
	4	1.695	40			
	5	1.7364	10			
N-QGA	1	1.6071	14	1.5485	1.6778	1.61436
	2	1.6485	25			
	3	1.5899	15			
	4	1.6778	19			
	5	1.5485	35			
GSM-QGA	1	1.5778	8	1.5485	1.6071	1.56608
	2	1.5485	31			
	3	1.5485	16			
	4	1.5485	21			
	5	1.6071	3			

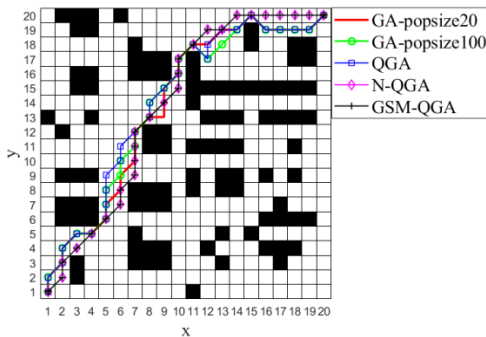


Fig. 14. The path planning simulation results of the four algorithms.

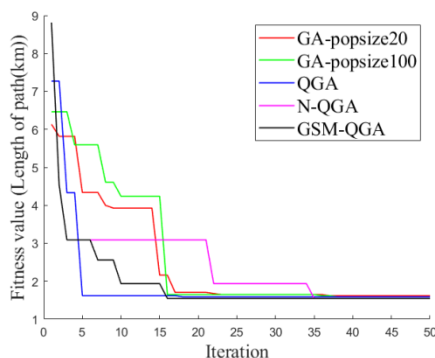


Fig. 15. The optimal path iteration convergence curves for the four algorithms.

## V. CONCLUSION

In the vehicle path planning problem, the path planning method based on a gradient statistical mutation quantum genetic algorithm was proposed for the problems that GA is prone to early maturation and slow convergence.

In this paper, we proposed a dynamic adjustment strategy for a quantum rotation gate that considered both the chromosome fitness values and the trend of gene point changes. The convergence speed of the algorithm and the stability of the search for superiority are improved. Moreover, based on the statistical properties of the trend of chromosome change, a mutation operator was designed, and an adaptive mutation strategy based on the qubit probability density was proposed to effectively control the algorithm into a local optimum. Simulation results reveal the superiority of our GSM-QGA over GA, QGA and N-QGA: the average path length is reduced by 10.26%, 7.06%, 5.52%, and 2.99%; the average convergence speed increases by 50.63%, 46.98%, 32.48%, and 26.85%, respectively. The GSM-QGA has advantages over GA, QGA and N-QGA in terms of path length, convergence speed and algorithm stability. The effectiveness of the GSM-QGA in path planning is demonstrated.

Future work includes further extension of the algorithm in combination with other algorithms for application to more complex traffic environments. On the other hand, an attempt is made to design a new quantum gate as a transition matrix for population updating to address the problem that the quantum

rotation gate has a finite range of rotation angles in the high-dimensional space.

#### ACKNOWLEDGMENT

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# Apache Spark in Healthcare: Advancing Data-Driven Innovations and Better Patient Care

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**Abstract**—The enormous amounts of data produced in the healthcare sector are managed and analyzed with the help of Apache Spark, an open-source distributed computing system. This case study examines how Spark is utilized in the healthcare industry to produce data-driven innovations and enhance patient care. The report gives a general introduction of Spark's architecture, advantages, and healthcare use cases, such as managing electronic health records, predictive analytics for disease outbreaks, individualized medicine, medical image analysis, and remote patient monitoring. Additionally, it contains several case studies that highlight Spark's effects on lowering hospital readmission rates, detecting sepsis earlier, enhancing cancer research and therapy, and speeding up drug discovery. The report also identifies obstacles with data security and privacy, scalability and infrastructure, data integration and quality, labor and skills shortages, and other aspects of employing Spark in healthcare. Spark has overcome these obstacles by enabling efficient data-driven decision-making processes and enhancing patient outcomes, revolutionizing healthcare solutions. Additionally, the study looks at potential future advancements in healthcare, including the use of Spark with AI and ML, real-time analytics, the Internet of Medical Things (IoMT), enhanced interoperability and data sharing, and ethical standards. In conclusion, healthcare businesses can fully utilize Spark to transform their data into actionable insights that will enhance patient care and boost the efficiency of healthcare systems.

**Keywords**—Apache spark; healthcare; patient; styling; predictive analysis

## I. INTRODUCTION

Information has always been essential for stimulating innovation and improving organizational efficiency by optimizing existing procedures. As a result, gathering data has become crucial to every organization. This information can be used to predict future events and present trends. Authors have used technological improvements to produce and collect data across many facets of life, including social interactions, science, employment, and health, understanding of this potential has risen. Existing literature demonstrates that there is a situation described as a "data deluge", when there is an abundance of data. Although technological breakthroughs have made it possible for humans to produce previously unheard-of amounts of data, it is getting harder to do so with currently available technologies. As a result, the term "big data" was created to denote massive, difficult-to-manage datasets. It is necessary to devise creative ways to organize and glean valuable insights from this data to meet society's demands now and in the future. The requirement for efficient data management is especially critical in the healthcare

industry. Healthcare organizations are producing data at an astonishing rate, similar to other industries, which presents both potential and challenges. Big data is effective in healthcare, ultimately enhancing patient care and fostering innovation within the sector by creating unique methods to handle and analyze this data [1]. Data generation in the healthcare industry has increased unprecedentedly due to developments in medical technology, electronic health records (EHRs), and wearable technology. Big Data has become a potent instrument for revolutionizing health care and spurring industry innovation [2]. This in-depth analysis explores big data's ramifications, difficulties, and opportunities in healthcare, emphasizing how it has completely changed several facets of the industry. The enormous amount, diversity, velocity, authenticity, and value of the healthcare industry's data define big data. This information comes from various sources, including clinical trials, wearable sensor data, patient records, medical imaging, and genomic data. Healthcare workers can process and analyze this data to derive valuable insights, resulting in enhanced diagnosis, personalized therapies, and better patient outcomes using sophisticated analytics, machine learning, and artificial intelligence approaches [3]. This in-depth analysis explores Apache Spark's contribution to the advancement of healthcare through its powerful data processing and analytics capabilities. Apache Spark is an open-source distributed computing platform.

The problems posed by Big Data in healthcare can now be effectively addressed thanks to Apache Spark. Its tremendous capacity for handling massive amounts of data, support for several computer languages, and interoperability with various data sources have made it a valuable tool for researchers and healthcare practitioners. Spark is appropriate for various healthcare applications because of its fault-tolerance and in-memory computing capabilities, allowing quick, scalable, and reliable data processing [4]. This case study provides an in-depth study of Apache Spark's multifarious effects on the healthcare sector. It also examines some of its applications in population health management, genomics, personalized medicine, and medical imaging analysis. The evaluation also examines the difficulties and restrictions of using Spark in the healthcare industry, such as data security issues, privacy worries, and the requirement for qualified employees. The evaluation also discusses technological developments and integrations, including machine learning libraries, cloud-based deployment choices, and seamless connection with other big data tools and platforms, that have aided Spark's acceptance in the healthcare industry. This review encourages additional research and development by thoroughly understanding

Apache Spark's potential in the healthcare industry, ultimately assisting in developing a more effective, data-driven healthcare system.

The rapid technological improvements and the rising amount of data being produced have recently caused a substantial transformation in the healthcare sector. Due to the complexity of this data flood, organizations now need creative and effective data management solutions to help them deal with it. With its strong capabilities for data processing and analysis, Apache Spark has emerged as a key tool in tackling these issues. This study paper's introduction lays the groundwork for a thorough investigation of the many aspects of Apache Spark's influence on healthcare.

The background of big data in healthcare is established at the outset, along with any consequences for innovation and patient care. The qualities of healthcare data are then explored, emphasizing their volume, diversity, velocity, authenticity, and worth as well as the potential advantages of utilizing these data through sophisticated analytics, machine learning, and artificial intelligence techniques. The relevance of Apache Spark in tackling the problems caused by big data in healthcare is then highlighted in the introduction. It highlights how the platform is an excellent choice for a variety of healthcare applications because to its fault tolerance, in-memory computing capabilities, scalability, and support for numerous programming languages.

The introduction then goes over a few of the specific uses of Apache Spark in the medical field, including population health management, genomics, customized medicine, and medical image analysis. These instances highlight Apache Spark's potential to transform several facets of healthcare, resulting in better patient outcomes and more effective healthcare systems. The introduction clearly addresses the difficulties and restrictions of using Apache Spark in healthcare environments, such as the necessity for trained employees and worries about data security and privacy.

It emphasizes the significance of continuing research and development to address these issues and utilize Apache Spark's advantages in the healthcare industry. The introduction also emphasizes how critical it is to keep up with new technological developments and integrations that facilitate the use of Apache Spark in the healthcare industry. Examples include machine learning libraries, cloud-based deployment options, and seamless integration with other big data tools and platforms. This research paper intends to contribute to the development of a more efficient, data-driven healthcare system that benefits patients, healthcare providers, and stakeholders by recognizing and utilizing Apache Spark's potential in healthcare.

The study is organized as follows: Section I provides a literature review on problem formulation and various existing methodologies; Section II describes the digitization of healthcare and spark, Section III explains the apache spark in medical imaging analysis. Section IV talks about apache spark in genomics research while Section V discusses apache spark in population health management. Technological advancements and integrations are presented in Section VI, challenges and limitations of implementing apache spark in

healthcare, future researches and development, conclusion described in Section VII, VIII, and IX, respectively.

## II. DIGITIZATION OF HEALTHCARE AND SPARK

Electronic Medical Record (EMR), like electronic health records (EHRs), store typical clinical and medical data gathered from patients. Medical practice management software (MPMs), electronic health records (EHRs), electronic medical records (EMRs), personal health records (PHRs), and other healthcare data elements have the potential to improve healthcare quality, service effectiveness, and cost management while lowering medical errors [5]. Spark in healthcare includes information obtained from payer-provider relationships (such as EMRs, prescription drug records, and insurance records), genomics-driven research (such as genotyping and gene expression data), and the network of connected Internet of Things (IoT) devices.

Early in the twenty-first century, EHR adoption was modest but has significantly increased since 2009 [6]. Healthcare data management and use now depend more and more on information technology. Developing and deploying wellness monitoring devices and related software capable of producing warnings and sharing patient health data with pertinent healthcare professionals have gained traction, particularly in forming real-time biomedical and health monitoring systems. These devices generate vast amounts of data that can be analyzed to offer real-time clinical or medical care. Apache Spark architecture is shown in Fig. 1.

### A. Management of Electronic Health Records (EHRs)

By making it possible for healthcare practitioners to efficiently store, retrieve, and share patient information, electronic health records (EHRs) play a critical role in contemporary healthcare. However, real-time access requirements and the sheer amount and variety of EHR data present significant challenges for data processing and storage. With its distributed data processing and analytics characteristics that enable more effective handling of huge datasets, Apache Spark has become a potent tool for EHR management. Healthcare businesses may enhance interoperability and data exchange by utilizing Spark, enabling improved collaboration amongst many stakeholders. A number of case studies show how the deployment of Apache Spark has improved EHR management.

### B. Disease Outbreak Predictive Analytics

To preserve the public's health and ensure the effective use of healthcare resources, illness outbreak predictions and prevention are essential. More precise predictions of disease outbreaks may be made by the integration of data from many sources, including social media, public health records, and environmental factors. Apache Spark is an effective solution for predictive analytics in this situation due to its real-time analytics and pattern identification capabilities. Healthcare organizations can improve the precision and speed of outbreak predictions by combining Spark with machine learning techniques. Numerous case studies demonstrate how Apache Spark has been used to predict disease outbreaks, reducing their impact.

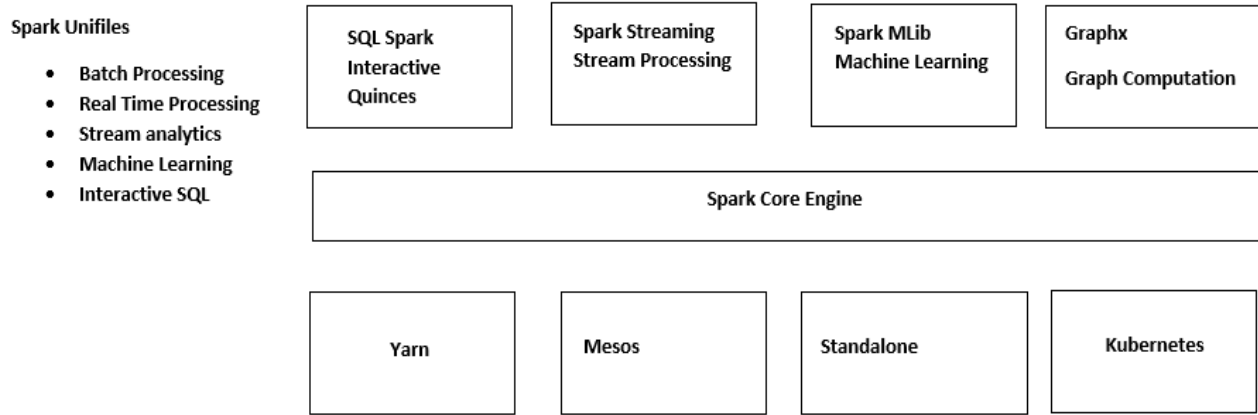


Fig. 1. Apache spark architecture.

### C. Genetics and Personalized Medicine

The idea of personalized medicine tries to customize medicines and treatments based on a person's genetic profile, potentially allowing for more precise and successful interventions.

However, the generation of enormous amounts of complex data in the field of genomics poses difficulties for processing, analysis, and integration. Because it makes it possible to handle large-scale genomic investigations and variant analysis effectively, Apache Spark has proven to be invaluable in genomics research. Numerous case studies show how the use of Apache Spark has significantly improved personalized medicine, which has ultimately improved patient outcomes.

### D. Analysis of Medical Imaging

Medical imaging, which includes procedures like X-rays, MRIs, and CT scans, is an essential diagnostic tool in the healthcare industry. Healthcare workers face difficult problems because of the growing volume of medical imaging data and the requirement for swift and precise interpretation. Through distributed image processing and integration with deep learning frameworks for advanced image recognition, Apache Spark has the potential to revolutionize the analysis of medical imaging. These capabilities result in more accurate diagnosis & quicker treatment choices. The effects of Apache Spark-based medical imaging analysis on patient care and clinical effectiveness are demonstrated in case studies.

### E. Telemedicine and Remote Patient Monitoring

Healthcare providers can now monitor patients' health and give care remotely thanks to telemedicine and remote patient monitoring, which have grown in popularity in recent years. Challenges in this area include the necessity for real-time analytics and the growing volume of data produced by remote monitoring devices. By providing real-time data processing and analytics for remote patient monitoring, improving the standard of care, and enabling predictive analytics to foresee potential health risks, Apache Spark can address these challenges. Numerous case studies highlight Apache Spark's potential to enhance patient outcomes and optimize healthcare

delivery by showcasing its positive effects on telemedicine and remote patient monitoring systems.

### III. APACHE SPARK IN MEDICAL IMAGING ANALYSIS

An essential advancement in the healthcare sector has been using Apache Spark for medical imaging analysis. Spark, a powerful distributed computing platform, has played a crucial role in overcoming the difficulties of processing and analyzing substantial image datasets. This part explores Apache Spark's effects on medical imaging analysis, demonstrating how it could be used to speed up diagnosis and enhance patient care [7].

Medical imaging analysis is looking at different imaging data types, including MRI, CT scans, and X-rays, to spot patterns and anomalies that can indicate illnesses or other abnormalities. The complexity and volume of medical imaging data are increasing, necessitating the employment of powerful processing and analysis systems that can effectively manage massive datasets [8]. Because of its distinctive features, such as in-memory computation, fault tolerance, and scalability, Apache Spark is the perfect tool for analyzing medical images. Healthcare professionals and researchers can use Spark to speed up the processing and analysis of massive imaging datasets, resulting in faster and more accurate diagnoses. Furthermore, Spark can be easily integrated into current healthcare workflows because of its compatibility with a wide range of data sources and programming languages. Developing sophisticated algorithms for image classification, segmentation, and feature extraction is also made possible by its machine-learning libraries, further boosting the diagnostic capabilities of medical imaging analysis [9]. The use of Apache Spark for medical imaging analysis has the potential to significantly impact the healthcare sector by accelerating the diagnostic process and eventually enhancing patient care. The use of powerful tools like Spark is becoming increasingly essential to preserving the efficiency and quality of medical diagnostics as the volume and complexity of medical imaging data continue to increase. Fig. 2 depicted the workflow of big data analytics, using analytical pipelines.

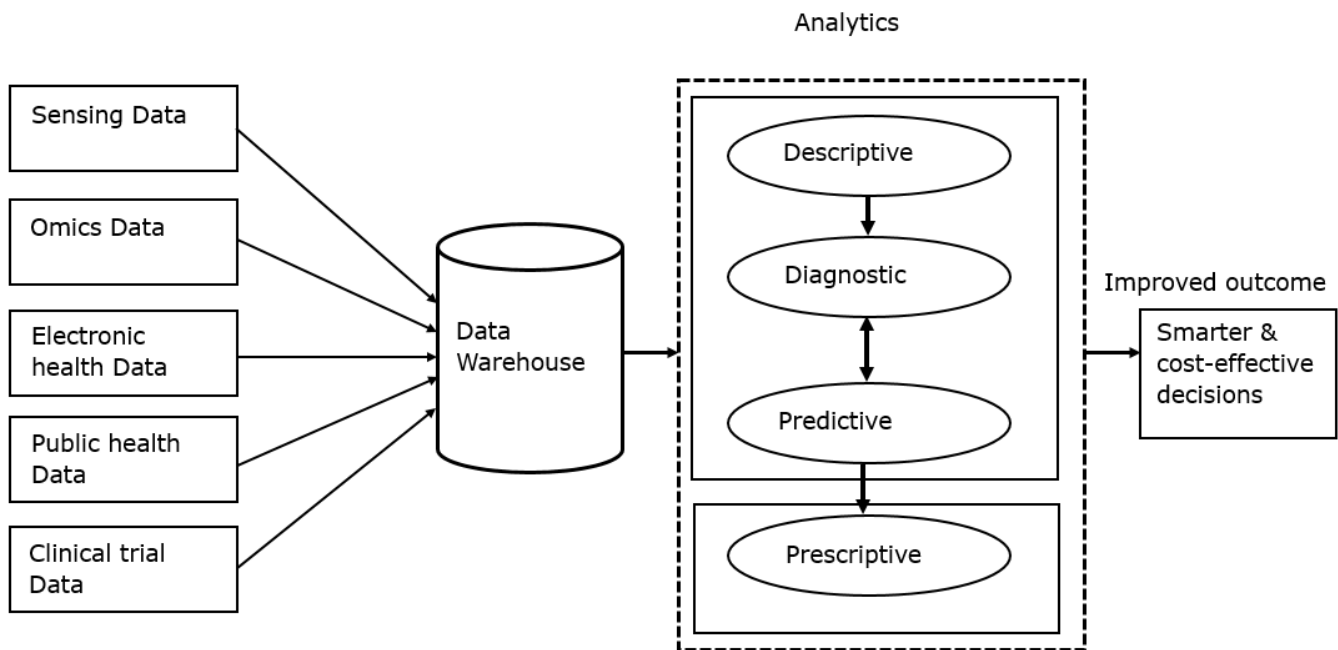


Fig. 2. Workflow of big data analytics, using analytical pipelines to obtain smarter and healthcare options.

#### A. Hospital Readmission Reduction

Reducing hospital readmissions is one of Apache Spark's healthcare success stories. Not only do high readmission rates affect patient outcomes, but they also raise the price of healthcare. Healthcare businesses have been able to pinpoint trends and risk factors related to hospital readmissions by using Apache Spark to analyze EHR data, demographic data, and other pertinent elements. Spark provides predictive modelling with the integration of machine learning algorithms, assisting healthcare practitioners in identifying high-risk patients and implementing targeted treatments to lower readmission rates. Following the adoption of Apache Spark-based analytics, several hospitals have reported noticeably lower readmission rates, which has improved patient care and decreased healthcare costs.

#### B. Early Detection of Sepsis

If sepsis is not promptly identified and treated, it can result in organ failure and death. Sepsis is a condition that can be fatal and is brought on by the body's reaction to infection. Real-time analysis of vital signs, laboratory findings, and other clinical data has been made possible using Apache Spark, which has been crucial in the early detection of sepsis. Spark can assist medical professionals in spotting early indicators of sepsis and starting prompt interventions by processing this data using machine learning algorithms. Several case studies show how Apache Spark works well for early sepsis detection, which lowers mortality rates and improves patient outcomes.

#### C. Cancer Research and Treatment Optimization

Cancer research and therapy optimization have benefited greatly from Apache Spark. For both researchers and physicians, the complexity of cancer and the enormous amount of genetic, proteomic, and clinical data related to it provide considerable obstacles. The rapid processing and analysis of massive datasets with Apache Spark has made it possible to

identify cancer biomarkers, subtypes, and prospective therapeutic targets more effectively. Additionally, Spark has made it easier to create individualized treatment plans that maximize the effectiveness of cancer therapies while minimizing side effects by integrating with machine learning and AI technologies. Numerous success stories in cancer research and treatment planning demonstrate Apache Spark's revolutionary effects in this field.

#### D. Accelerating Drug Discovery

Drug discovery is often a time-consuming, expensive, and complicated process. By enabling quick analysis of enormous amounts of data from numerous sources, such as genomic, proteomic, and chemical databases, Apache Spark has become an important tool in speeding up drug discovery. Researchers can more effectively identify prospective medication candidates and forecast their efficacy and safety by using Spark's sophisticated analytics capabilities. Additionally, the use of machine learning and AI approaches streamlines the drug discovery process by enabling more precise predictions of drug-target interactions. Numerous case studies demonstrate how Apache Spark has been successfully used to speed up drug discovery, resulting in the development of new treatments more quickly and better patient care.

### IV. APACHE SPARK IN GENOMICS RESEARCH

Precision medicine has undergone a sea change due to the adoption of Apache Spark in genomics research. Spark, a cutting-edge distributed computing platform, has proven to have an extraordinary ability to overcome the difficulties in processing and analyzing big genomic datasets. This section examines the influence of Apache Spark on genomics research, focusing on its potential to promote personalized medicine and provide fresh discoveries. Genomic research analyses enormous genomic datasets to find genetic differences and connections with certain diseases or disorders [10]. Because of



the size and complexity of genomic data, it is essential to deploy robust processing and analysis methods that can effectively handle massive datasets. Because of Apache Spark's unique capabilities, including in-memory computation, fault tolerance, and scalability, genomics research can benefit from its use. Researchers may quickly process and analyze massive genomic datasets using Spark, leading to the discovery of new information about the genetic relationships between diverse diseases [11].

Additionally, Spark's flexibility with numerous data sources and programming languages enables easy integration into current processes for genomics research. Its machine-learning libraries also make it easier to create complex genetic data analysis algorithms, which advances our understanding of the connections between genes and illness [12]. In conclusion, by maximizing the potential of massive genomic data, the use of Apache Spark in genomics research holds enormous promise for developing personalized medicine. The use of reliable tools like Spark is crucial for advancing genomic breakthroughs and the advancement of precision medicine as the volume and complexity of data keeps growing. programs by allowing data-driven decision-making and enhancing general population health and well-being. Adopting powerful technologies like Spark becomes increasingly essential for optimizing public health initiatives and resource allocation as the volume and complexity of population health data continue to increase [15].

#### V. APACHE SPARK IN POPULATION HEALTH MANAGEMENT

Public health projects have significantly benefited from the use of Apache Spark in the field of population health management. Spark, a state-of-the-art distributed computing platform, provides exceptional capabilities for overcoming the difficulties in processing and analyzing massive datasets important to population health. Authors discuss Apache Spark's effects on population health management, highlighting its potential to promote data-driven decision-making and enhance the results of public health initiatives. Assessment of large datasets is required for population health management to comprehend patterns, trends, and health determinants in each population. This information is essential for guiding public health policies, resource allocation, and preventive measures.

Population health data are complicated and extensive; powerful processing and analytic technologies that effectively manage massive datasets are essential [13]. Apache Spark is the perfect choice for population health management thanks to its distinctive capabilities, including in-memory processing, fault tolerance, and scalability. By using Spark, academics and public health practitioners can expedite the processing and analysis of large datasets [14], allowing for discovering health trends and patterns that guide evidence-based decision-making. Additionally, Spark can be easily integrated into current population health management workflows due to its compatibility with various data sources and computer

languages. Its machine learning libraries also enable the construction of sophisticated population health data analysis algorithms, which advance knowledge of the variables affecting public health outcomes. In conclusion, using Apache Spark in population health management can profoundly influence public health.

#### VI. TECHNOLOGICAL ADVANCEMENTS AND INTEGRATIONS

The growing use of Apache Spark in the healthcare sector can be ascribed to several technology developments and integrations that have improved its functionality and industry compatibility. To facilitate data-driven innovations and better patient care, this part outlines significant advancements, such as machine learning libraries, that have aided in the broad adoption of Spark in healthcare settings. Spark's robust machine learning libraries, including MLlib, are one of the main factors influencing its growth in the healthcare industry. These libraries offer a complete set of tools and methods for jobs, including dimensionality reduction, clustering, regression, and classification. By utilizing these resources, healthcare workers and academics can create complex models for forecasting patient outcomes, spotting illness patterns, and comprehending the connections between numerous health parameters [16]. Integration of machine learning with spark is shown in Fig. 3.

Additionally, Spark can be easily integrated into current healthcare workflows thanks to its compatibility with a wide range of computer languages, including Python, Java, Scala, and R. This adaptability lowers adoption hurdles by enabling healthcare organizations to use Spark without having to redesign their current infrastructure. Cloud-based deployment possibilities have also assisted Spark in healthcare. These choices offer scalable, on-demand computing resources that are simple to modify to meet the organization's demands. Healthcare organizations that deal with variable data quantities and need quick data processing capabilities would benefit from this flexibility.

Apache Spark's acceptance in the healthcare industry has been aided by its ability to connect with other big data tools and platforms, like Hadoop and NoSQL databases. Due to Spark's powerful processing and analytics capabilities, healthcare organizations can utilize their current investments in extensive data infrastructure [17]. In conclusion, many technological developments and integrations have significantly promoted Apache Spark's use in the healthcare industry. Spark has established itself as a versatile and essential tool for healthcare organizations looking to harness the potential of big data for enhancing patient care and fostering innovation. This is due to Spark's powerful machine learning libraries, compatibility with numerous programming languages, cloud-based deployment options, and seamless integration with other big data tools. ML-based variant spark for genomic variants are shown in Fig. 4.



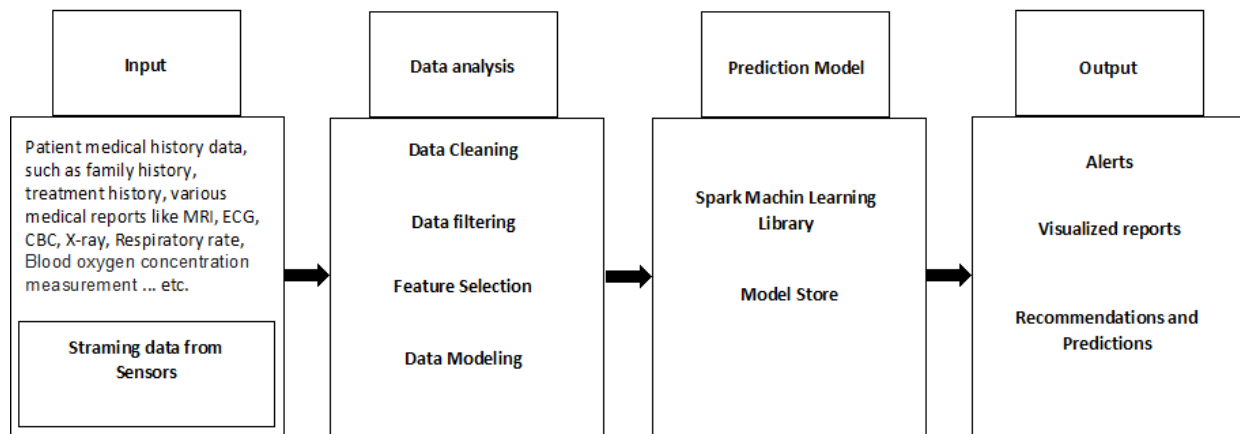


Fig. 3. ML framework for spark.



Fig. 4. Variant Spark (ML Framework for Genomic Variants).

#### A. Integration with Artificial Intelligence and ML

Integrating Apache Spark with AI and ML technologies will be more and more important as healthcare adopts big data. More sophisticated analytics, enhanced pattern recognition, and predictive capacities will be made possible by this convergence, further increasing patient care, and streamlining healthcare procedures. Future advancements in AI and ML algorithms will open new avenues for innovation and support the healthcare sector's ongoing transformation, especially when combined with Spark's distributed computing capabilities.

#### B. Real-time Analytics and Internet of Medical Things (IoMT)

The interconnected network of medical equipment, sensors, and applications that gather and distribute healthcare data is known as the Internet of Medical Things (IoMT). Real-time analytics will be more crucial in healthcare as IoMT is more adopted. Apache Spark is an essential tool for maximizing the potential of IoMT because of its capacity for real-time data processing and analysis. The combination of Apache Spark with edge computing and real-time data streaming systems will probably lead to future developments in IoMT, giving healthcare practitioners more effective and timely insights and improving patient care.

#### C. Enhanced Interoperability and Data Sharing

Data sharing and interoperability are essential elements of a data-driven healthcare environment. Apache Spark's role in improving interoperability and facilitating data exchange across many stakeholders will become even more important as it continues to gain traction in the healthcare industry. Future advancements in data standards, APIs, & data sharing protocols will make it possible to integrate Apache Spark with other healthcare systems more easily, enhancing collaboration and enabling more thorough analyses of healthcare data.

#### D. Ethical Considerations and Guidelines

Ethics relating to data privacy, security, and fairness will become more important as healthcare organizations use big data technologies like Apache Spark more frequently. To ensure the ethical use of new technologies in healthcare, it will be crucial to create and abide by ethical standards for data use, analysis, and sharing. The development of industry best practices and legislative frameworks that address these moral questions may be a future trend, encouraging a more open and accountable approach to healthcare data analytics. Healthcare businesses can increase trust with patients and stakeholders by addressing these ethical issues, assuring the sustainable and ethical use of big data technologies like Apache Spark

## VII. CHALLENGES AND LIMITATIONS OF IMPLEMENTING APACHE SPARK IN HEALTHCARE

While Apache Spark has shown much promise for revolutionizing healthcare through sophisticated data processing and analytics, it also has some issues and restrictions that must be resolved for successful adoption. This section covers the main issues with Spark's adoption in the healthcare industry, such as data security, privacy issues, and the need for qualified employees, and looks at potential solutions [18].

Spark implementation in the healthcare industry must take data security seriously because healthcare data is frequently sensitive and governed by strong privacy laws. Compliance with regulatory standards, such as HIPAA, necessitates careful handling and preserving Spark data processing. Organizations must implement robust security features, including encryption, access limits, and audit trails, to protect the sensitive data handled and analyzed [19]. Spark adoption raises privacy issues as well in the healthcare industry. When analyzing healthcare data, a fine line must be drawn between gaining insightful knowledge and protecting patient privacy. To safeguard patient privacy while enabling valuable data analysis, it is necessary to create robust anonymization techniques and data handling protocols [20].

The need for qualified employees with skills in both technical and domain-specific understanding of the healthcare industry presents another difficulty in deploying Spark in the healthcare sector. A lack of such people may hamper Spark's efficient adoption and integration into healthcare workflows. Organizations might invest in training and educational activities to create staff skilled in Spark and healthcare subject knowledge to close this skills gap. Even though Apache Spark presents the healthcare sector with several prospects for innovation and advancement, obstacles connected to data security, privacy issues, and the lack of competent labor must be carefully reviewed and resolved. Healthcare organizations can successfully utilize Apache Spark's promise while minimizing the dangers and difficulties involved by implementing extensive security measures, reliable data handling methods, and investments in workforce development.

### A. Data Security and Privacy Concerns

Despite Apache Spark's many advantages in the healthcare industry, privacy and data security issues continue to be major obstacles. Strong security measures are required to safeguard patient information due to the sensitive nature of healthcare data and strict rules like HIPAA in the US. When using distributed data processing systems like Apache Spark, it might be difficult to ensure data encryption, safe access management, and privacy standards compliance. Healthcare companies must address these issues by putting in place suitable security safeguards and regularly reviewing and upgrading their data security plans.

### B. Scalability and Infrastructure Constraints

Even though Apache Spark is scalable, healthcare companies could encounter infrastructure limitations that prevent them from taking full advantage of the technology's potential. A distributed computing environment can be

resource-intensive to deploy and manage, necessitating hefty hardware, networking, and storage expenditures. It may be difficult for smaller healthcare companies, in particular, to scale their infrastructure to meet the rising needs of big data processing. Organizations may want to use cloud-based solutions that provide scalable, managed infrastructure for Apache Spark deployment to lessen the impact of these limitations. Various Performance Interferences in Apache Spark are discussed in [21].

### C. Data Integration and Quality Issues

Integrating data from disparate sources and ensuring data quality are crucial aspects of leveraging big data in healthcare. Apache Spark's ability to process and analyze data from various sources is a significant advantage, but it also presents challenges in terms of data integration and quality. Healthcare organizations must contend with issues such as data inconsistency, missing values, and duplication. Ensuring data quality and integration requires robust data governance processes, including data cleansing, validation, and standardization. Implementing these processes can be time-consuming and complex, but they are essential for deriving meaningful insights from healthcare data.

### D. Skills Gap and Workforce Challenges

A skilled staff that can manage and efficiently use the technology is necessary for Apache Spark to be adopted in the healthcare industry. However, the healthcare industry suffers from a severe skills gap, with a dearth of experts in big data technology, machine learning, and advanced analytics. Healthcare firms must engage in training and development programs to create internal knowledge in Apache Spark and comparable technologies to solve this obstacle. Fostering partnerships with academic institutions, research facilities, and business associates can also aid in closing the skills gap and spur innovation in healthcare data analytics.

### E. Future Challenges

The ability to unearth priceless insights from big data and improve patient care has made Apache Spark a disruptive force in the healthcare industry. Healthcare organizations can successfully incorporate Spark into their workflows by overcoming the accompanying difficulties and constraints, opening up new possibilities for innovation and data-driven advancements in the healthcare industry. This study report concludes by highlighting Apache Spark's substantial contribution to the advancement of patient care and data-driven innovations in the healthcare industry. The following is a summary of the major findings:

- Due to its distributed computing capabilities, fault-tolerance, and in-memory processing characteristics, Apache Spark has become a potent tool for managing and Analysing large- scale healthcare data.
- Personalized medicine, genomics, medical image analysis, and remote patient monitoring are just a few of the many uses for Apache Spark in the healthcare industry. Other uses include EHR management, predictive analytics for disease outbreaks, and genomics.

- The early diagnosis of sepsis, improved cancer research and treatment, decreased hospital readmissions, and accelerated drug discovery are just a few of the success stories that demonstrate Apache Spark's disruptive potential in the healthcare industry.
- Despite the many advantages, there are still difficulties and restrictions in using Apache Spark in the healthcare industry. These include issues with data security and privacy, scalability and infrastructure, data integration and quality, and a skills gap in the workforce.
- The integration of Apache Spark with AI and ML, real-time analytics and IoMT, improved interoperability and data sharing, and the introduction of ethical concerns and norms are future trends and prospects in the healthcare sector.

Apache Spark can change the healthcare sector by solving the issues and constraints and utilizing upcoming trends and possibilities, which will ultimately result in improved patient care and more effective healthcare delivery.

### VIII. FUTURE WORK

Several proposals for upcoming research and development will help Apache Spark's adoption and use as it continues to have an impact on the healthcare sector:

- Create and improve Apache Spark-based algorithms for use cases particular to the healthcare industry: Algorithms' effectiveness and uptake can be greatly increased by customizing them to meet the specific objectives and challenges of the healthcare industry. To address issues unique to the healthcare industry, such as forecasting illness progression, streamlining treatment regimens, and evaluating intricate medical data, researchers should concentrate on creating and improving Spark-based algorithms.
- Examine unique Apache Spark applications in the healthcare industry: Investigating novel Apache Spark applications in the healthcare industry can result in creative solutions and advancements in patient care. Future studies should investigate topics like preventive care, rare diseases, and mental health because these are all areas where big data analytics may make a significant difference.
- Encourage cross-disciplinary cooperation: Promoting cross-disciplinary cooperation among researchers, engineers, data scientists, and healthcare practitioners can spur creativity and hasten the creation of Apache Spark-based healthcare solutions. Collaborations between healthcare practitioners, business, and academics can help to share resources, exchange knowledge, and create best practices.
- Improve data privacy and security measures: Future research should concentrate on establishing cutting-edge methods for safeguarding sensitive patient data within Apache Spark and other big data platforms, as these issues continue to be major hurdles in the healthcare industry. Federated learning, homomorphic

encryption, and differential privacy are a few examples of these strategies that can assist assure compliance with rules while facilitating useful data analysis.

- Examine the ethical implications of big data use in healthcare: As Apache Spark and other big data technologies are being used in healthcare, it is important to recognize and address the ethical implications. Future studies should investigate the moral issues around data ownership, privacy, justice, and openness, and they should also establish standards and best practices for the ethical application of big data in healthcare.
- Make a concerted effort to educate and cultivate a workforce skilled in Apache Spark and comparable technologies to close the skills gap in healthcare data analytics. To create curricula, training programs, and continuing education opportunities that advance expertise in big data analytics and promote a culture of data-driven decision-making in healthcare, educational institutions, industry partners, and medical institutions should work together. Focusing on these suggestions will help researchers, healthcare providers, and industry partners realize Apache Spark's full potential in the healthcare sector, resulting in better patient outcomes, more effective healthcare delivery, and greater innovation overall.

### IX. CONCLUSION

Apache Spark's adoption in the healthcare industry has shown incredible promise for fostering innovation, enhancing patient care, and enabling data-driven decision-making. Healthcare organizations can handle the problems caused by the complexity and volume of healthcare data by utilizing Spark's powerful processing capabilities, scalability, and machine learning frameworks. Applications of Spark in population health management, genomics research, and medical imaging analysis have shown how it has the potential to revolutionize many different facets of the sector. However, to successfully implement Spark in the healthcare industry, it is vital to solve critical issues, including data security, privacy concerns, and the need for qualified staff. Healthcare organizations need to have robust security protocols in place to safeguard sensitive data and guarantee regulatory compliance to use Spark's advantages. A culture of continuous learning and workforce development investments can also assist in closing the skills gap and give healthcare personnel the know-how they need to utilize Spark fully.

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# Weight Optimization Based on Firefly Algorithm for Analogy-based Effort Estimation

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**Abstract**—Proper cost estimation is one of the vital tasks that must be achieved for software project development. Owing to the complexity and uncertainties of the software development process, this task is ambiguous and difficult. Recently, analogy-based estimation (ABE) has become one of the popular approaches in this field due to its effectiveness and practicability in comparing completed projects and new projects in estimating the development effort. However, in spite of its many achievements, this method is not capable to guarantee accurate estimation confronting the complex relation between independent features and software effort. In such a case, the performance of the ABE can be improved by efficient feature weighting. This study introduces an enhanced software estimation method by integrating the firefly algorithm (FA) with the ABE method for improving software development effort estimation (SDEE). The proposed model can provide accurate identification of similar projects by optimising the performances of the similarity function in the estimation process in which the most relevant weights are assigned to project features for obtaining the more accurate estimates. A series of experiments were carried out using six real-world datasets. The results based on the statistical analysis showed that the integration of the FA and ABE significantly outperformed the existing analogy-based approaches especially for the ISBSG dataset.

**Keywords**—Analogy-based estimation; firefly algorithm; software cost estimation; weight optimization

## I. INTRODUCTION

Software development effort is considered one of the most significant measures estimated in the software projects owing to the fact that planning, developing, and all other vital processes of the project largely rely on correct estimation of the development effort [1]. Accurate estimation of software development metrics has become a critical issue for researchers in recent years in the software project management field [2-4]. The unstable nature of software project requirements, related hardware platforms, and the continuous change in software development frameworks complicate the process of estimation [5, 6]. Uncertain and insufficient available information to be used in equations, relations, formulas, and so on, become a major problem confronted by researchers in this field [4, 7].

Recently, analogy-based estimation has been found by many researchers as the most adaptable technique in software effort estimation [8, 9]. Analogy Based Estimation (ABE) can be defined as the selection of the previously completed projects similar in nature to the target project and deriving effort estimation based on these selected projects [10, 11]. Although the analogy-based estimation method is a simple and

straightforward process, the process is extremely difficult due to the non-normality of software development data. [12]. Generally, the non-normality of software projects is the major issue that affects all comparison based approaches including the analogy based estimation method [13-15]. To address these issues thereby improving the estimation performance, appropriate weights of project attributes are evaluated in several research works [16, 17]. The weighting process is affected by irrelevant and complex projects and those projects that are out of the overall trend of the dataset [18, 19].

Various project attributes must be taken into consideration in the weighting process, compatible with principles of software engineering [20-22]. The inaccurate software development effort will result from attributes that are given the same weight even though they have different level of influence on estimation accuracy [23]. However, determining attribute weights used in the similarity function is a challenging issue in the ABE methods. Optimization, intensive search, and correlation analysis are the most prominent methods for attribute weighting. Correlation analysis tries to figure out the degree of dependency between software effort and other project attributes [24-26]. Intensive search applies in-depth search to determine the best subset of attributes [17, 27, 28]. Generally, the optimization methods tend to enhance the attribute weighting or feature selection in the ABE similarity function component [3, 29, 30].

Essentially, the majority of literature optimization approaches are motivated by nature, for example particle swarm optimization (PSO) which imitates fish schooling behaviour and bird flocking, ant Colony Optimization which imitates the ants' behaviour and the artificial Bee Colony (ABC) technique which mimics the bees' behaviour in searching for diet [31, 32]. Recently, the firefly algorithm (FA) which imitates some tropic firefly swarms has been introduced as a new metaheuristic algorithm [33]. Essentially, fireflies tend to be attracted to each other with higher intensity. This technique is typically different from other algorithms such as PSO and the Artificial Bee Colony (ABC). As such the FA can have two benefits: automatic regrouping and local attractions. As the intensity of light changes with distance, depending on the absorbing factor, the attraction between fireflies can be global or local, and therefore all global and local manners will be visited. Additionally, fireflies can also sub-divide and hence reorganize into sub-groups as neighbouring attraction is stronger than distant attraction; therefore it could be likely that each sub-group will group around a local mode [33-35]. This



behaviour particularly helps the FA to be fit for the optimization problem.

Comparative studies revealed that the FA algorithm is very promising and could outperform many state-of-the-art optimization techniques like PSO and GA [36], and Artificial Bee Colony ABC [37]. Therefore, inspired by the above motivations among others, this research attempt to integrate FA with the ABE method to better optimize feature weights for improving the software development effort estimation. The main goal of this study is to improve the ABE model by optimizing the feature weights. To our knowledge, no research investigation has been conducted on the impact of FA on feature weighting for the ABE model.

Rest of the paper is organized as follow. Section II explains research background. The related work of the study is presented in Section III. The detail of the proposed work is described in Section IV. The experimental design is elaborated in Section V. Results and discussion of the study is detailed in Section VI. Section VII presents statistical analysis of the proposed model compared to related models. Section VIII concludes this research study.

## II. BACKGROUND

This section presents the background of the FABE model. We first discuss the concept of analogy-based estimation, which includes different steps of the ABE process. Further, each analogy estimation metric is described, which includes the similarity function and the solution function. Finally, in this section, the concept of the Firefly algorithm is also presented.

### A. Analogy-Based Estimation (ABE)

The ABE method was initiated as a substitute for algorithmic-based software development effort estimation. In this technique, software project estimation is carried out by comparison with earlier accomplished projects and identifying the most similar projects to the board projects [38]. Owing to its suitability, the analogy-based estimation method has been popularly applied for software development in several studies. Essentially, ABE comprises four main modules, namely, historical dataset, K-nearest neighbours, similarity function, and solution function. More specifically, the ABE process is made up of steps as follows:

- Historical data creation through artificial or real datasets.
- Acquisition of new project features in a consistent manner with previous datasets.
- Applying predetermined similarity functions for example the Euclidean function to retrieve projects similar to the new projects.
- Predefined solution function is used to determine the new project's cost.

A similarity function is used in ABE for estimating the resemblance between two projects based on their feature comparison [38]. There are different similarity functions which include Manhattan similarity (MS) and the Euclidean similarity (ES). The Euclidean distance (ED) is the most popular

similarity function which particularly involves distance between particular points. The similarity function is commonly used in optimization problems where distances are compared. MS is another popular similarity function in which the normal distance of Euclidean space is substituted by a new measurement where the distance between the locations is the sum of their coordinate's differences. These metrics are popularly applied for measuring the similarity in ABE. The nature of the projects at the normality level and the dataset can considerably affect the performance of similarity functions. ES function is shown in Equation 1:

$$Sim(p, p') = \frac{1}{\sqrt{\sum_{i=1}^n w_i Dis(f_i f'_i) + \delta}} \quad (1)$$

$$Dis(f_i f'_i) = \begin{cases} (f_i - f'_i)^2 & \text{if } f_i \text{ and } f'_i \text{ are numerical or ordinal} \\ 0 & \text{if } f_i \text{ and } f'_i \text{ are nominal and } f_i = f'_i \\ 1 & \text{if } f_i \text{ and } f'_i \text{ are nominal and } f_i \neq f'_i \end{cases} \quad (2)$$

Where,  $w_i$  is the weight (which ranges between 0 and 1), allocated to each feature,  $p$ , and  $p'$  are the projects.  $f_i$  and  $f'_i$  represents the  $i$ th feature of each project,  $\delta$  is used to gain a nonzero result and  $n$  represents the number of features.

The MS representation is like the ES formula, but it calculates the complete difference between features. The mathematical representation of the MS function can be given as:

$$Sim(p, p') = \frac{1}{\left[ \sum_{i=1}^n w_i Dis(f_i f'_i) + \delta \right]} \quad (3)$$

$$Dis(f_i f'_i) = \begin{cases} |f_i - f'_i| & \text{if } f_i \text{ and } f'_i \text{ are numerical or ordinal} \\ 0 & \text{if } f_i \text{ and } f'_i \text{ are nominal and } f_i = f'_i \\ 1 & \text{if } f_i \text{ and } f'_i \text{ are nominal and } f_i \neq f'_i \end{cases} \quad (4)$$

After identifying the K most similar projects, it would be possible to calculate the target project's effort based upon the selected features or attributes. The commonly used solution function include the Closest Analogy (CA) [11], the inverse weighted mean (IWM) [39], the average, and median of the most similar projects [40]. Mean is the average of effort for  $K > 1$  while median is considered as effort median for similar projects with  $K > 2$ . In practice, Equation 5 adjusts the proportion of each project by using Inverse Weighted Mean (IWM).

$$C_p = \sum_{k=1}^K \frac{Sim(p, p')}{\sum_{i=1}^n Sim(p, p')} C_{p_k} \quad (5)$$

Where  $p$ , and  $p_k$  represents the new projects and the most similar  $k$ th project, respectively.  $C_{p_k}$  demonstrates the value of effort of  $k$ th  $p_k$  and  $K$  denotes the total number of the projects.

### B. Firefly Algorithm

Yang developed the Firefly algorithm (FA) which reflects the characteristic flashing behaviour of fireflies [33]. Firefly algorithm comes with three assumptions: i) fireflies are unisexual: fireflies could attract each other irrespective of their gender. ii) The degree of attraction of fireflies is proportional



to the brightness and both are inversely proportional to distance. If there are no brighter fireflies then fireflies will have random movement. iii) Firefly brightness is dependent on the objective function. In FA, fireflies show up in a swarm to resolve a particular optimization task through brightness which is identified by the fitness function, and movements of low brightness fireflies to high brightness which is determined by attractiveness.

In FA, the attraction between the flies involves two aspects; the various light intensities and the modeling of attraction. For a particular firefly at position  $X'$  brightness  $I$  is given as  $I(X') \propto f(x)$  while attraction  $\beta$  is proportional to the flies and is associated with the distance  $R_{i,j}$  among fireflies  $i$  and  $j$ . Equation (6) demonstrates the inverse square of intensity  $I(r)$  in which  $I_0$  denotes the intensity of light from the source.

$$I(r) = I_0 e^{-\gamma r^2} \quad (6)$$

Supposing an absorption factor of the environment  $\gamma$ , intensity is given in Equation 7 in which  $I_0$  is the original intensity.

$$I(r) = \frac{I_0}{1+\gamma r^2} \quad (7)$$

Essentially, the ED is given in Equation 8, which signifies the distance between a firefly at position  $X_i$  and another at position  $X_j$ . Where  $X_{jk}$  is the  $k^{\text{th}}$  constituent of the spatial coordinate  $X_i$

$$R_{i,j} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^d (x_{i,k} - x_{j,k})^2} \quad (8)$$

A firefly  $i$  attracts a brighter one  $j$  as demonstrated in Eq. 9 in which attraction can be given by  $\beta e^{-\gamma_{i,j}^2} (x_i - x_j)$ , and  $\alpha \left[ \text{rand} - \frac{1}{2} \right]$  denotes the randomness based on the randomization parameter  $\alpha$ .

$$x_i = x_i + \beta e^{-\gamma_{i,j}^2} (x_i - x_j) + \alpha \left[ \text{rand} - \frac{1}{2} \right] \quad (9)$$

Additionally, variations of attractiveness are controlled by  $\gamma$  which in turn influences the behavior and convergence speed of FA.

### III. RELATED WORK

For the past years, several research works have been employed by different researchers to apply weighting techniques for improving ABE. One of these methods is using correlation coefficient analysis which is considered for feature selection and weighting in terms of software development effort estimation (SDEE) [41, 42]. In this case, project features with weak correlation are considered the low features and are assigned low weights while the features with higher correlation are given the higher weight and considered the most similar. The project features with no correlation are removed from the set of historical projects.

Weighting-based methods, known as Rough Set Analysis have been proposed for feature selection to better enhance the ABE performance [17, 43, 44]. In rough set analysis, feature dependency analysis generates several sub-sets of features

named classes [45]. The most similar features are obtained by considering the intersection of all the classes. The frequency of attributes in reducts, the number of attributes in a core set, and the frequency of presence of attributes in decision rules are used to build the weighting model in the rough set technique. Another non-algorithmic method for estimation is Gray Theory (GT) in which gray depicts the fuzzy process, where the white and black represent known and unknown information respectively [45]. It is a statistical technique for finding the similarity degree by comparing two projects' features. Since it also uses a comparison technique, it was employed to enhance the ABE performances [46, 47]. One of the vital aspects of ABE is the solution function since it greatly influences the estimation performance's correctness. According to various studies, several attempts have been made to adjust expressions as the solution function to enhance performance [15, 48-50].

Over many years, to modify the feature weighting of the software estimation model, several optimization techniques have been introduced. The genetic algorithm (GA) is considered widely used optimization techniques for feature weights computation in the ABE. Huang and Chiu [51] utilized Genetic Algorithm to identify the best parameters in their defined non-linear/linear equation(s). The parameters involved in equations were determined as an improvement in the ABE's performances. There has been a combination of various methods with a Genetic Algorithm for enhancing accuracy of estimation model such as the Gray Relational Similarity (GRS) method [46], regression techniques [52], and also linear adjustment [15]. For example, Bardsiri, et al. [12, 53] integrates Genetic Algorithms with fuzzy logic and artificial Neural Network, to develop a localized effort estimation process.

PSO has also been applied in many studies for improving the software development effort estimation. For example, Sheta, et al. [54, 55], Lin, and Tzeng [55] utilized the PSO technique to enhance the performances of the COCOMO estimation technique. In some scenarios, PSO has been shown to be more computationally efficient than GA [56]. Wu et al. applied the PSO algorithm for feature weight optimization in the predefined similarity measure of the software estimation approach [57]. Liu, et al. used PSO to reduce errors during the training phase and enhance estimation [58]. Azzeh, et al. [2] utilized the PSO algorithm to identify the optimum decision variable where the trade-off between several evaluation metrics is illustrated. Differential evolution have been used for feature weight optimization in ABE [23]. ABC has also been applied for the ABE optimization and indicated to outperform the PSO method [3]. Bardsiri, et al. integrated PSO with simulated annealing (SA) for feature weight optimization in ABE model [59]. Ferrucci, et al. [60] conducted a research on the influence of the fitness function. They showed that the model performance could be enhanced by choosing suitable and optimized performance measures. Essentially, the optimization of the fitness functions performs an important impact in estimation due to the complexity of software project.

#### IV. THE PROPOSED FA-BASED OPTIMIZATION FOR ANALOGY BASED ESTIMATION (FABE)

In the proposed approach, the FA is integrated with the ABE model for improving the estimation accuracy. Adaptability and Flexibility are two important properties of the FA which make it capable to mitigate the issue of the vagueness and complexity of software project attributes [33, 61]. Essentially, the main purpose of the FA is to identify the most suitable feature weights that are to be used in the similarity function. Weights are allocated for parameter optimization to enhance the ABE performance. The system architectures of the training and testing of the proposed approach are illustrated in Fig. 1 and Fig. 2 respectively, whereas Algorithm 2 shows the Pseudo-code of FABE.

##### A. Training Stage

Fig. 1 illustrates the training phase architecture of the FABE approach. In the training stage, historical project data is utilized for predicting the efforts of the training dataset.

In this stage, the model adjusts the weights of features based on the FA in the Analogy-based Estimation similarity function. The dependent feature is the development effort; all others are considered independent features. In the training phase all available dataset projects are divided into (basic, train, test) subsets. For model construction in training stage basic and training subsets are used. For model evaluation in testing stage the basic and test subsets are involved. Training projects are compared with basic projects to find suitable weights and also testing projects are compared with basic for performance evaluation. A project is taken away from the training set and applied to the similarity function as a new project that is to be determined.

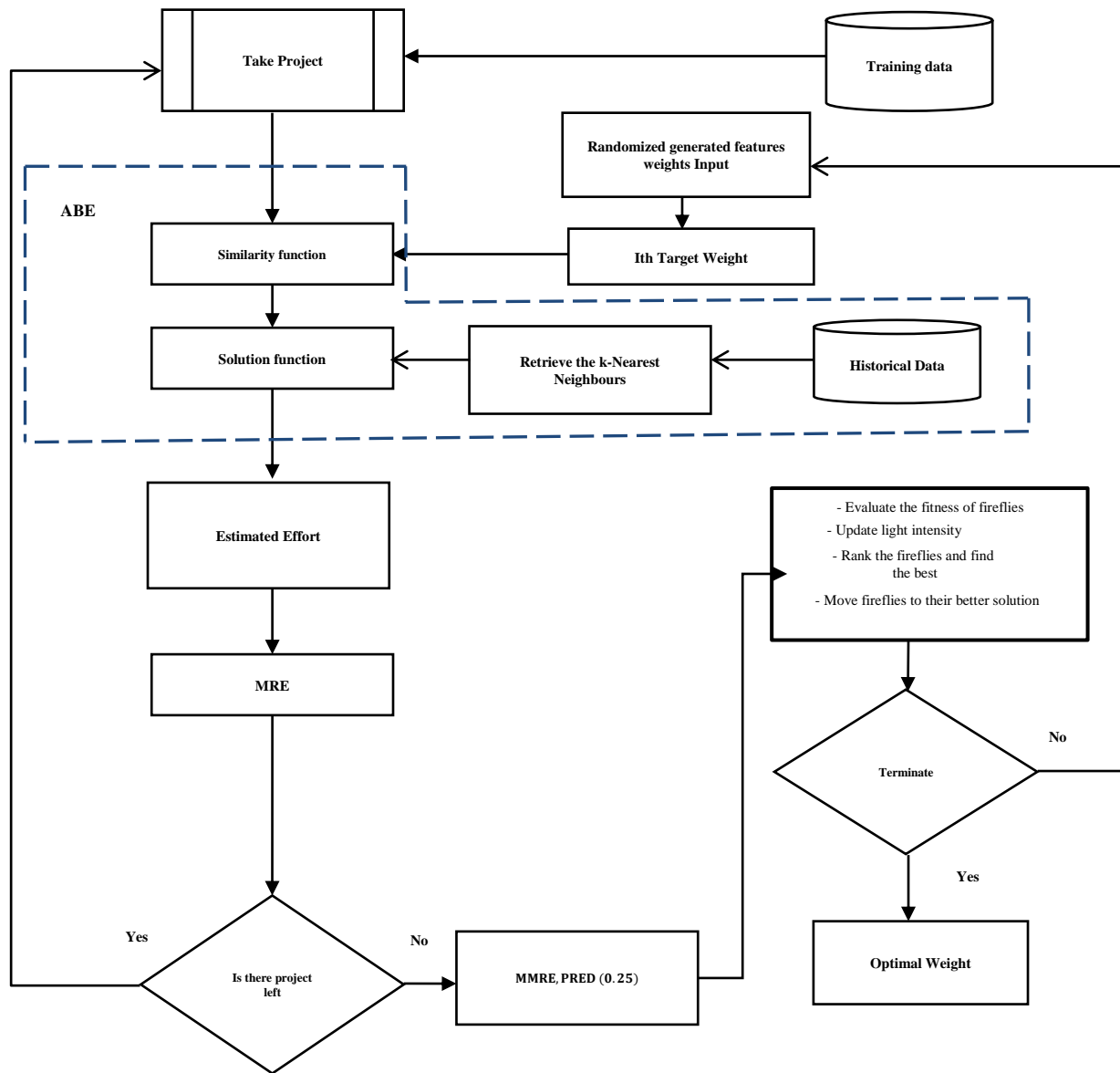


Fig. 1. Training stage.

### Algorithm 1: FABLE Algorithm

**Inputs :**

$f(.)$  objective function  $f(x)$

□ randomized parameter

□□ attraction coefficient

□ Light Absorption Coefficient

**POP** population Size

Step 1: Initialize the population of  $n$  fireflies.

Step 2: new project is selected form training dataset, and the remaining others projects are processed by ABE as historical projects.

Step 3: FABLE feature weight parameter vector is encoded for the training project.

Step 4: weight vector of range  $[0, 1]$  is generated randomly.

Step 5: The training project similarity metric is evaluated for the weight vector selected randomly from pop.

Step 6: From the historical dataset obtain  $K$  closest analogies used in ABE, and then predict effort value of the training project using different solution functions.

Step 7: Until all training cases are treated with the same identical random weight vector (created for the first training case) repeat steps 2-6.

Step 8: MRE for each individual is calculated based on the objective function.

Step 9: Training projects set accuracy metrics (MMRE, PRED (0.25)) are evaluated.

Step 10: The Evolution step // Given that stopping criteria is not fulfilled.

Step 10.1: Evaluate the fitness of fireflies using objective function

Step 10.2: Update light intensity of the fireflies

Step 10.3: Rank the fireflies and find the best

Step 10.4: Move fireflies to their better solution

Step 10.5: Go to step 12 if the stopping criteria have been met. (maximum number of iterations)

Step 11: Go to Step 10.

Step 12: EXIT.

**Output: The best Candidate solution with the optimal weight vector is chosen for the following Testing Stage.**

The FA algorithm assigns weights to the independent features used in the similarity function. The considered project is compared with the basic projects based on the Equation (1). The most similar projects are discriminated by the similarity function to the removed project and take them to the solution function, and the MRE is calculated. This procedure is continued until all training projects are estimated. In the next step, the error and prediction performances MMRE and PRED (0.25) are calculated for a training group based on the MRE values. Reduce the value of MMRE and increases PRED (0.25) are the main goal of any estimation method which motivates this study to Fine-tune FA for MMRE value minimization.

The weights are recorded to be used in the testing stage if the termination requirements are met; otherwise, the FA updates the weights taking into account the obtained performance parameters. The similarity function is given new weights, and all computations are carried out once more for the training projects. Until the termination criteria are met, this process is continued. The training phase of the model is shown in Fig. 1. There are two rounds in the training phase, as shown in the image, with the first one having to do with calculating the MMRE for training projects and the second one having to do with adjusting weights using the FA approach.

### B. Testing Stage

The primary purpose of this phase will be to assess the model's performance using hypothetical projects. Basic and testing projects are used as the inputs for the similarity function at this stage to examine how the suggested model performs. Additionally, the training stage's optimized weights are used to modify the similarity function. A project is separated from testing projects, as was done in the training stage, and then put up against basic projects through similarity function. Most resemble projects to the removed project are chosen and forwarded to predefined solution function. The amount of MRE is calculated after estimating the effort. This procedure is repetitive for all testing projects and, eventually, the value of MMRE and PRED are calculated. Fig. 2 illustrates the test phase of the proposed model. As previously mentioned, the project feature weights proposed by FA are produced to help the ABE accurately estimate the training projects effort as possible.

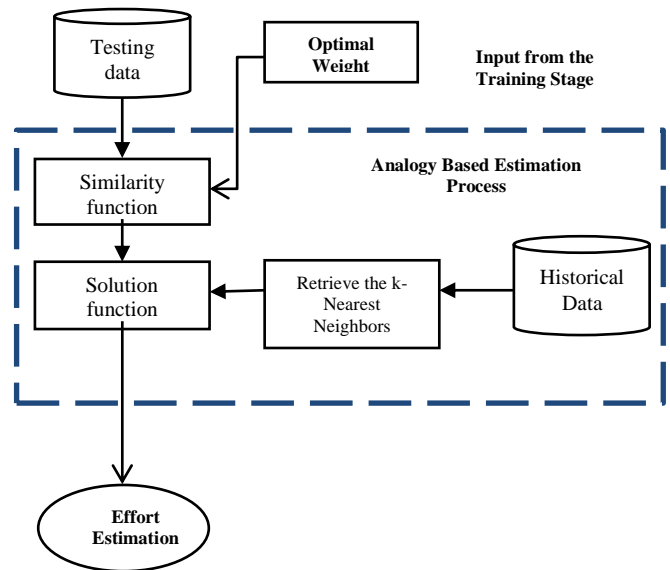


Fig. 2. Testing phase.

The ABE uses basic projects in this instance for comparison reason. Thus, two thirds of the current projects available in the given dataset (basic and training subsets) are utilized to obtain possible best weights, and the rest of the projects available are treated as a test set. To achieve the required precision, FA randomly produces the weights and modifies them over the iterations.

In the suggested approach, feature weighting is done thereby helping the ABE in producing better performances. The ideal set of feature weight vectors could differ from one execution run to the next because FA is a dynamic process that generates variable weights at each iteration. As a result, the weight allocated to a feature cannot be taken as the feature's importance but rather as a component that ABE must use.

### V. EXPERIMENTAL DESIGN

The experimental strategy employed in this study is presented in the following section. First, the datasets used for the experiment to evaluate the accuracy of the proposed FABLE

technique are described, then the performance evaluation metrics. Further in this section, the process involved in the experimental setup, as well as the validation method, is explained and presented.

#### A. Dataset Description

To evaluate the performances of the proposed model, we employ six different datasets, namely, Desharnais, Maxwell, COMMMO, China, NASA, and International Software Benchmarking Standard Group (ISBSG) The Desharnais dataset contains Canadian projects. China dataset is based on Chinese software projects. United States software projects are contained in Cocomo81 and Nasa93 datasets. The Maxwell dataset is constructed based on of Finnish banking projects. Dejaeger et al. [62] claimed to group dataset to categories such as size, development, project data, and environment features. The Statistics of the datasets are given in Table I. Datasets effort values skewness is up to 6.6 [62, 63] Indicating asymmetrically distributed of effort for each dataset which is a thread for accurate estimation models.

International Software Benchmarking Standard Group (ISBSG) is established Australia software based non-commercial organization, which gathers data on software projects from numerous countries globally [64]. In this study ISBSG Release 11 dataset is employed. 5052 completed software projects detailed information have been collected. Software projects data collected from 24 countries are exist in the historical dataset. Majority of projects origin are come from USA with 30.7% percentage of all dataset, followed by Japan with 16.7%, Australia 15.9%, and Finland with 10.2%.

#### B. Cross Validation

The performance evaluation will typically be rather optimistic if the model accuracy is calculated based upon that projects that are used during the implementation phase.

As the errors will always be small, it might result in a biased model evaluation for estimating accuracy [56]. Thus, to better evaluate the model accuracy, a cross-validation approach is applied, which splits the entire dataset into several train and test sets. The results of datasets that are utilized during model construction are contained in the training sets. In testing stage, unseen datasets are utilized for evaluating the accuracy and the performance of all training and testing sets are merged for cross-validation. In this research, we used a three-fold cross-validation method for proposed model performance evaluation as illustrated in Table II.

As can be seen from Table II, six different arrangements can be considered for the model. Where S1, S2, and S3 are the three subsets randomly selected from the set of all projects as basic, training and testing sets accordingly. The sets involve the similar number of projects. At each fold, evaluation measure is calculated for two different arrangements, and the mean is considered as the result of that fold. Finally the accuracy is determined based on the mean of results computed from all three stages.

TABLE I. DATASETS USED IN EXPEREMENTS

Dataset	Projects count	Features	Unit	Max	Min	Mean	Median
Maxwell	62	27	Hours	63,694	583	8223.2	5189.5
Nasa93	18	3	Months	138.3	5	49.47	26.5
Cocomo81	63	17	Months	11,400	6	686	98
Desharnais	77	12	Hours	23,940	546	5046	3647
China	499	18	Hours	54,620	26	3921	1829

TABLE II. ILASTRATION OF CROSS-VALIDATION

S			
S1	S2	S3	
Possible arrangements			
	Basic set	Train set	Test set
Fold 1	Set – 1	Set – 2	Set – 3
	Set – 1	Set – 3	Set – 2
Fold 2	Set – 2	Set – 1	Set – 3
	Set – 2	Set – 3	Set – 1
Fold 3	Set – 3	Set – 2	Set – 1
	Set – 3	Set – 1	Set – 2

#### C. Evaluation Metrics

Several metrics have been used by different studies for evaluating the performance of the comparison-based software estimation method. Accordingly, the most widely used measures include Relative Error (RE), Mean Relative Error (MRE), Percentage of Prediction (PRED) and Mean Magnitude of Relative Error (MMRE). The mathematical representation of these metrics can be given as follows:

$$RE = \frac{\text{estimated} - \text{Actual}}{\text{Actual}} \quad (10)$$

$$MRE = \frac{|\text{Estimated} - \text{Actual}|}{\text{Actual}} \quad (11)$$

$$MMRE = \sum \frac{MRE}{N} \quad (12)$$

$$PRED(X) = \frac{A}{N} \quad (13)$$

$$AE = \text{Estimated} - \text{Actual} \quad (14)$$

$$EF = \frac{PRED(25)}{1 + MMRE} \quad (15)$$

$$SA = 1 - \frac{MAR}{MAR_{p_0}} \quad (16)$$

$$\Delta = \frac{MAR - \overline{MAR}_{p_0}}{s_{p_0}} \quad (17)$$

Projects with  $MRE \geq X$  ( $X$  is usually reserved at 0.25) is denoted as  $PRED(X)$  as shown in Equation 6 and 7 where  $N$  denote the number of projects. Increase  $PRED$  and decrease  $MMRE$  is the main target of all software development effort estimation models, accordingly Araújo, et al. [65] proposed Evaluation Function (EF) measure that combined both  $MMRE$  and  $PRED$  in equation 9 to improve accuracy evaluation for software prediction model.  $MRE$  considered as a biased performance metric since its produce asymmetric distribution [22, 66].  $MMRE$  and  $PRED$  both are derived from  $MRE$  they are also considered as biased performance measure.

Mean Absolute Error (MAE) produced non-symmetric distribution on other side. Equation 8 and 9 shows how MAE can be calculated. Because of non-standardized residual MAE is difficult to interpret. SA was introduced by [22] it can be calculated by Equation 10 (in large number of runs the mean of random guessing is denoted as Mean Absolute Residual (MAR<sub>po</sub>) ) which is enhanced by [67] and used later to estimates effect size as seen in Equation 11 (sample standard deviation for the random guessing is denoted as S<sub>po</sub> ). Reliability of the estimation model can be measured by SA as if the prediction model is stated as useful. SA negative values are not acceptable while zero value shows that the estimation model is unreliable. Effect size ( $\Delta$ ) evaluates the estimation results and the effectiveness of the mode is compared with random guessing. ( $\Delta$ ) categorizes values in small (0.2), medium (0.5) and large (0.8). If the value is equal or greater than to 0.5 the results is considered as favourable [2, 22].

### VI. EXPERIMENTAL RESULTS AND DISCUSSION

As stated earlier, the ABE technique uses three control parameters, including similarity function, solution function and K-nearest neighbour. In the experiment of this research, ED is adopted for similarity function. Median and mean, are considered as the solution function to compute the estimation values. This section presents the performance results of the proposed Fabe model. We first present the experimental results in terms of the MMRE, MdmRE, and PRED based on the different control parameters, namely, Similarity, KNN, and solution function then the later the SA results. Further, the comparison results of the proposed model with existing methods are presented later in the section.

The proposed Fabe model performance is compared and validated with commonly ABE weighting variants techniques, namely traditionally ABE, feature weighting with Genetic Algorithm in ABE (GAABE) [51] , feature weighting with Particle Swarm Optimization in ABE (PSOABE) [53], feature weighting with Differential evolution in ABE (DABE) [23], feature weight optimization with Bee colony optimization in ABE (BABE) [3], these estimation models are trained with historical data and algorithmic settings are tuned automatically.

#### A. Performance of the Proposed Model

Training quality estimation results are extremely affected by data pre-processing before main model execution started. In this study all the independent features were normalized in range (0 to 1) to produce same effect on software effort dependent feature. For the experimentation of the proposed Fabe approach, we first investigate the possibility of getting the best settings of the model. To this end, we use different evaluation metrics namely (MMRE, MdmRE, PRED, and SA) on two different datasets which include Desharnais and Maxwell datasets. Also to assess the effect of the similarity function, the Euclidian similarity metric is employed. The results of the different values of the KNN (from 1 to 5) alongside respective solution function (Median, Inverse Weighted Mean, and Mean) metrics are recorded and shown in Table III to Table VI accordingly. Thus, in this section, the experimental results are presented and discussed. The main purpose of the experiment was to obtain the appropriate ABE

configuration for the proposed model based on the different parameters (k value, similarity Metric, solution function).

Table III and Table IV demonstrate the simulation results of the Fabe technique on the Desharnais and Maxwell datasets indicating various combinations of the key model parameters, such as KNN, similarity function, and solution function, respectively. From the results, it can be observed that the K value at 3 and Mean solution function are the most suitable setting as computed for both MMRE , MdmRE in the training and testing stage of the model on all the datasets, namely, Desharnais and Maxwell.

TABLE III. PERFORMANCE ON DESHARNAIS DATASET

Similarity	K	Solution	Training		Testing	
			MMRE	PRED	MMRE	PRED
Euclidean	1	Closest	0.015	0.685	0.056	0.889
	2	Inverse	0.051	0.127	0.089	0.201
		Mean	0.011	0.115	0.015	0.199
	3	Inverse	0.051	0.185	0.089	0.291
		Mean	0.033	0.131	0.017	0.299
		Median	0.059	0.115	0.021	0.289
	4	Inverse	0.051	0.245	0.089	0.381
		Mean	0.033	0.169	0.054	0.321
		Median	0.044	0.190	0.031	0.377
	5	Inverse	0.051	0.282	0.089	0.480
		Mean	0.049	0.245	0.081	0.488
		Median	0.081	0.245	0.055	0.452

TABLE IV. PERFORMANCE ON MAXWELL DATASET

Similarity	K	Solution	Training		Testing	
			MMRE	PRED	MMRE	PRED
Euclidean	1	Closest	0.041	0.701	0.019	0.095
	2	Inverse	0.059	0.542	0.049	0.091
		Mean	0.084	0.052	0.045	0.081
	3	Inverse	0.059	0.085	0.049	0.302
		Mean	0.044	0.059	0.070	0.069
		Median	0.061	0.042	0.081	0.089
	4	Inverse	0.059	0.117	0.049	0.181
		Mean	0.062	0.082	0.304	0.145
		Median	0.044	0.067	0.480	0.163
	5	Inverse	0.059	0.155	0.049	0.158
		Mean	0.040	0.077	0.271	0.104
		Median	0.039	0.086	0.220	0.126

However, the PRED (0.25) metric test performances showed that the most appropriate ABE setting for both these datasets was K=3 and the “Inverse Weighted Mean” solution function. Thus to further confirm the best configuration of the model thereby obtaining better performance, we also investigate evaluation for another performance measure SA on the Desharnais and Maxwell datasets.

Table V and Table VI demonstrate the SA results of the Euclidean similarity function for the K=3, K=4, and K=5 on the Desharnais and Maxwell datasets respectively concerning

both testing and training stage of the proposed model. The results were evaluated against, maximum, minimum, average, and standard deviation for the SA. Table V demonstrates the SA values for Desharnais datasets. From results analysis, it can be concluded that best values of the SA as maximum and average in the training stage fall at K=3, with values of 95.120 and 39.899 respectively. Likewise based on testing stage, the more suitable values happened at K=3 with an average and maximum value of 63.436 and 93.688 respectively.

The SA results for the Maxwell datasets are demonstrated in Table VI. From observed results, it could be realized that the best performance in the training stage is at K=3 with the value of the Average SA and Maximum SA being 51.955 and 95.900 respectively. Similarly, based on testing stage, the most appropriate performance was observed at K=3 and the maximum and average values of 96.938 and 52.923 respectively. It should be noted that in the experiment, K = 1 and K=2 were not considered for comparison since at these values all solutions functions were not covered. Eventually, we also conducted a simulation study on SA for Maxwell and Desharnais datasets to further support investigation of solution function best suited for the ideal value of K. SA was chosen as a guideline principle for further results analysis in order to its generalization capability.

Table VII and Table VIII demonstrate the SA results on three solution functions, namely, Inverse Weighted Mean,

Median, and Mean on the Desharnais and Maxwell datasets indicating the respective maximum, minimum, average, and standard deviation of the SA respectively. Table VII shows the Minimum, Minimum, Standard Deviation, and Average of the SA of solution function (median, mean, and inverse weighted mean) for the Desharnais dataset. From the results, it can be observed the average and maximum SA values were recorded to be 35.027 and 56.445 respectively for the “mean” as a solution function. Similarly, Table VIII shows lists of the maximum, minimum, average, and standard deviation of SA for the “mean”, median, and inverse solution functions for the Maxwell dataset. The results show that the average and optimal maximum SA values were reported to be 65.157 and 98.019, respectively, for the “mean” solution function. Based on the reported results in this section it was concluded that the most appropriate setting of the ABE is the “Mean “as a solution function and K=3.

### B. Discussion

In this section the performance of the proposed FABE was validated and compared with the state-of-the-art ABE models, namely, traditional Analogy-Based Effort (ABE), GA-based ABE, PSO-ABE, and BABE (Bee Colony-based), and Differential Evolution in ABE(DABE). All estimation methods were adjusted automatically using historical datasets and the algorithm parameters.

TABLE V. SA RESULTS ON DESHARNAIS DATASET

K	Training				Testing			
	Max. SA	Min. SA	Avg.SA	Std.SA	Max. SA	Min. SA	Avg.SA	Std.SA
3	95.120	13.026	39.899	18.113	93.688	36.185	63.436	25.571
4	92.015	10.955	33.791	26.251	86.944	21.978	59.099	14.941
5	54.156	15.304	26.981	9.615	92.871	25.357	67.717	11.833

TABLE VI. SA RESULTS ON MAXWELL DATASET

K	Training				Testing			
	Max. SA	Min. SA	Avg.SA	Std.SA	Max. SA	Min. SA	Avg.SA	Std.SA
3	95.900	19.665	51.955	20.018	96.938	21.677	52.923	9.226
4	91.502	15.255	41.711	13.320	69.933	19.100	31.990	5.340
5	40.351	23.089	22.962	3.054	95.841	27.720	58.65	8.026

TABLE VII. RESULTS OF SOLUTION FUNCTIONS FOR BEST K VALUES ON DESHARNIAS DATASET

Solution Function	Training				Testing			
	Max. SA	Min. SA	Avg.SA	Std.SA	Max. SA	Min. SA	Avg.SA	Std.SA
Mean	56.445	29.843	35.027	3.018	89.825	32.421	56.198	17.220
IWM	89.801	32.086	36.412	37.06	86.522	28.599	71.759	19.001
Median	90.221	23.311	54.082	15.217	84.025	51.512	65.979	14.098

TABLE VIII. RESULTS OF SOLUTION FUNCTIONS FOR BEST K VALUES ON MAXWELL DATASET

Solution Function	Training				Testing			
	Max. SA	Min. SA	Avg.SA	Std.SA	Max. SA	Min. SA	Avg.SA	Std.SA
Mean	88.261	30.483	49.970	17.701	98.019	51.220	65.157	16.551
IWM	87.016	16.921	37.028	28.990	85.990	35.255	59.988	15.071
Median	91.910	44.526	71.990	18.007	72.051	54.044	58.100	13.166



TABLE IX. PRECISIONS VALUES FOR FRIEDMAN STATISTICAL ANALYSIS TEST

Estimation Models	Datasets					
	China	Cocomo81	Nasa93	Maxwell	Desharnais	ISBSG
ABE	12.493	24.531	11.488	13.411	13.235	41.27
GAABE	86.196	91.812	90.324	88.423	89.332	51.638
BABE	97.621	99.201	94.982	84.18	84.205	68.82
DABE	96.509	98.94	94.234	84.91	83.66	65.09
PSOABE	92.88	88.016	93.01	83.63	88.854	56.08
FABE	98.426	99.711	95.009	85.661	85.012	71.803

Table IX shows the SA comparison results of the proposed FABE model with the existing approaches on six datasets namely Desharnais, Maxwell, Nasa93, China, and ISBSG based on the “Mean” solution function and K=3 Euclidian similarity. The SA values of FABE model for training and testing on Cocomo81, Nasa93 and China are (97.005, 99.711), (96.752, 95.009) and (96.973, 98.426) respectively. The  $\Delta$  values for this proposed model on each dataset are as, Cocomo81 (Training:0.234,Testing: 0.129), China (Training:0.219 ,Testing: 0.209) ,and Nasa93 (Training:0.251,Testing:0.159). From the detailed comparison results, it can be observed that the proposed FABE approach outperforms existing models.

87% against GABE, DABE, PSOABE, BABE and traditional ABE respectively. It presented a percentage decrease of 5% and 3% against GABE and PSOABE respectively on desharnais dataset, whereas showed an improvement of 1%, 2%, and 72% against BABE, DABE and traditional ABE. In Maxwell dataset, FABE presented 2%, 2%, 1% and 72% improvement against DABE, PSOABE and traditional ABE respectively whereas it presented a percentage decrease of 3% against GABE. For ISBSG that considered the largest among all given datasets, it presented 20%, 6%, 16%, 3% and 30% against GABE, DABE, PSOABE, BABE and traditional ABE respectively, which is considered as significant improvement.

It can be concluded from result analysis that the size and type of dataset affect weight optimization techniques performance on ABE model. In the ISBSG dataset FABE outperformed existing optimization weight techniques significantly on the selected software projects for ABE model. Statistical analysis to validate FABE model performance is performed since results on different datasets are various.

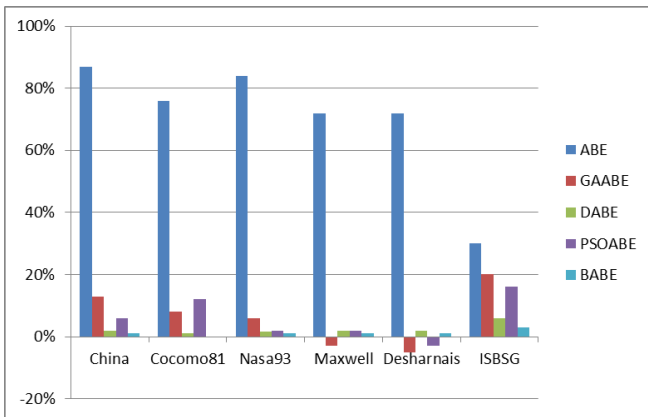


Fig. 3. FABE percentage of improvement against existing models.

TABLE X. FABE PERCENTAGE OF IMPROVEMENT

	ABE	GAABE	DABE	PSOABE	BABE
Cocomo81	76%	8%	1%	12%	0%
Maxwell	72%	-3%	2%	2%	1%
China	87%	13%	2%	6%	1%
Desharnais	72%	-5%	2%	-3%	1%
Nasa93	84%	6%	1.5%	2%	1%
ISBSG	30%	20%	6%	16%	3%

Fig. 3 and Table X demonstrate the average improvements achieved by the proposed FABE model compared to the existing models. For example in Cocomo81 dataset, it presented 8%, 1%, 12%, and 76% against GABE, DABE, PSOABE and traditional ABE. It presented 6%, 1.5%, 2%, 1% and 84% against GABE, DABE, PSOABE, BABE and traditional ABE respectively on Nasa93 dataset. For Cocomo81 dataset FABE performance is found at par BABE. In China, it presented improvements of 13%, 2%, 6%, 1% and

## VII. STATISTICAL PERFORMANCE EVALUATION

Statistical analysis is very important in finding the appropriateness of one technique to another. From the discussion in the previous section, it is obvious that the FABE approach provides the best results compared to the compared methods but now using statistical analysis this will be further confirmed. In this research owing to the fact that software engineering datasets have an issue such that each sub-population has non-contact variance, we employed nonparametric test for the analysis. A null hypothesis would be specified prior performing the test. This determines the differences or equality among the results of the models and enables alternative hypotheses to support the opposite condition to be assessed.

The null hypothesis is denoted as  $H_0$ , and the alternative hypothesis is represented as  $H_n$ . This test can be used to reject the hypothesis at a particular of significance level  $\alpha$ . The p-value is indicated with this level, which represents achieve probability at least as high as expected while null hypothesis is valid. It is recommended to apply p-value instead of  $\alpha$  since it can estimate results significantly (as p value is small this show strong validation against null hypothesis) [68]. Non-parametric tests can be classified into multiple comparisons like Friedman test and pair wise like Wilcoxon Signed test, in case of experiment that considers more than two algorithms or models it is recommended to use multiple comparisons test [69, 70]. In this case, the following hypothesis is considered:

$H_0$ : All feature weight optimization prediction models are equivalent on ABE.

To test the null hypothesis, we employed the Friedman test that is stated by Demšar[70] and García, et al [71]. For Friedman test, initially, original results transformed into ranks each model according to each dataset. Best model value is assigned rank 1; second-best one is assigned rank 2 and so on. Accordingly, we assign ranks  $r_j^i$ , to the  $j$ th of  $k$  models on the  $i$ th of  $N$  data sets based on their accuracy. The Friedman statistic ( $F_f$ ) can be given by equation.

$$F_f = \frac{(N-1)\chi_F^2}{N(K-1)-\chi_F^2} \quad (18)$$

Whereas is Chi-Square value is given by  $\chi_F^2$  in equation.

$$\chi_F^2 = \frac{12N}{K(K+1)} \left[ \sum_j R_j^2 - \frac{k(k+1)^2}{4} \right] \quad (19)$$

The Degree of Freedom (DF) is equal to  $K-1$ , in this performed experiments, value of  $K=6$  and so the value of  $DF=5$ . The sigma value of  $\chi_F^2$  in related studies is considered as 0.01 or less. Based on Chi-square table the value of  $\chi_F^2$  should be greater than 15.086. Friedman test statistic is presented in Table XII. Chi-Square value computed as 19.714, which allows the null hypothesis to be rejected. For each model test ranks are presented in Table XIII and also descriptive statistics of Friedman Test presented in Table XI.

The worst and best-performance model can be identified after the null hypothesis is rejected. From Table XIII which represents mean ranks best-worst performance information can be derived. It can be concluding from Table XIII that FAFE is performing best model followed by BABE. The lowest ranked model among comparative models is ABE.

TABLE XI. DESCRIPTIVE STATISTIC OF FRIDMAN TEST

Model	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles		
						25th	50th	75th
ABE	6	19.40467	11.737169	11.488	41.270	12.24175	13.32300	28.71575
GAABE	6	82.95417	15.456858	51.638	91.812	77.55650	88.87750	90.69600
DABE	6	87.10217	12.525246	65.090	98.940	79.01750	89.20700	97.11675
PSOABE	6	83.74500	13.992835	56.080	93.010	76.74250	88.43500	92.91250
BABE	6	88.28983	11.472514	68.820	99.201	80.35875	89.94600	98.01600
FABE	6	89.60367	10.847327	71.803	99.711	81.70975	91.33500	98.74725

TABLE XII. DESCRIPTIVE STATISTIC OF FRIEDMAN TEST

N	6
Chi-Square	19.714
df	5
Asymp. Sig.	.001

TABLE XIII. MEAN RANKS OF MODELS

Model	Mean Rank
ABE	1.00
GAABE	3.50
DABE	3.50
PSOABE	3.00
BABE	4.50
FABE	5.50

### VIII. CONCLUSION

In this research, we proposed a weight optimization method for analogy-based estimation based on the firefly algorithm (FA). An estimation model is built and assessed during the training and testing phases of the suggested framework. FA considers all potential weights and chooses those that will produce the more accurate estimations. By giving project features the most suitable weights, the ABE method's comparison process quality was enhanced. Six datasets were used to test the accuracy of the proposed approach and a cross-validation method was used to calculate the performance metrics for the MMRE, PRED (0.25), MdmRE, SA, and Size

Measure. The positive outcomes demonstrated that the suggested model can greatly improve the accuracy of estimations based on different metrics. The effectiveness of the proposed FAFE technique was demonstrated in all datasets when the obtained results were contrasted with six widely used estimating models. The combination of FA and ABE resulted in a high-performance model for estimating software development effort, according to the findings from the datasets. In future work we intended to combine existing technique in this study with missing data imputation models to pursue for furthermore improvement on estimation accuracy.

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# Hierarchical and Efficient Identity-based Encryption Against Side Channel Attacks

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**Abstract**—Hierarchical and identity-based encryption (HIBE) is very valuable and widely used in many occasions. In the Internet of Things based on cloud services, efficient HIBE is likely to be applied to cloud service scenarios for the limited computing ability of some terminal devices. What's more, because of the insecurity of cryptographic systems caused by side channel attacks, the design of leakage resilient cryptographic scheme has attracted more and more cryptography researchers' attention. In this study, an efficient leakage resilient HIBE is constructed. (1) In essence, this given scheme contains a hierarchical ID-based key encapsulation system. By using the extractor to act on the encapsulated symmetric key, this proposed scheme may resist the disclosure for the symmetric key due to side channel attacks. The relative leakage ratio of the encapsulated key is close to 1. (2) We also construct a hierarchical identity-based hash proof system that provides the security of our scheme. The proposed scheme can not only resist side channel attacks, but also has short public key parameters and computational efficiency, which is very suitable for applications in the Internet of Things environment. (3) There is no limit to the hierarchy depth of the system, and only the maximum hierarchy length is required to be given when the system is initialized.

**Keywords**—Identity-based encryption; side channel attack; hash proof system; composite order group

## I. INTRODUCTION

The hierarchical identity based encryption (HIBE) scheme has many practical applications. Pavithran et al. [1] constructed a blockchain structure with privacy protection suitable for the Internet of Things (IoT) through HIBE. Their scheme is very suitable for some terminal devices with limited computing resources. The practicability of the scheme is demonstrated through the traffic radar speed measurement system. Fan et al. [2] constructed an efficient data protection scheme of Message Queuing Telemetry Transport (MQTT) through HIBE. MQTT is widely used for the transmission and communication.

The researches [3] and [4] all gave HIBE schemes in the random oracle model. The given scheme in the study [3] does not affect the security of the system due to the hierarchy depth. Based on Bilinear Diffie Hellman (BDH) assumption, HIBE against collusion attack is given in the study [3].

The research [4] introduced the concept of HIBE and security. A concrete two-layer HIBE scheme is given. The upper layer is completely collusion-resistant, while the lower

layer is only partially collusion-resistant. Based on BDH assumption, the security of the scheme is proved in the random oracle model.

The study [5] proposed HIBE which is not affected by the depth of hierarchy, and the key length and decryption cost are fixed. The ciphertext is fixed to three elements, and decryption requires only two bilinear map operations.

The research [6] gave HIBE that is not affected by the depth of hierarchy, and the ciphertext of the proposed scheme has a shorter length. Through the dual system encryption technology, they obtained the full security of the scheme based on the three static assumptions of the composite order group.

The dual system encryption technology is also considered in the research [7], but they constructed secure schemes in prime order groups. In particular, they presented new randomization and parameter-hiding techniques in prime-order groups.

Considering the efficiency of HIBE, the authors in [8] presented an efficient HIBE scheme. This study fully considered the effect of the system parameters, and improved the existing scheme by appropriately reducing unnecessary parameters.

Although there are some leakage resilient (LR) encryption schemes, there are few efficient LR encryption schemes. There are usually two types of means to solve efficiency problems. First, by properly optimizing parameter settings and removing unnecessary parameters, one may obtain an efficient scheme. Second, the scheme in the composite order group is transformed into the scheme in the prime order group. In this research, we will reduce the parameters appropriately by removing unnecessary parameters, so as to achieve the goal of high efficiency. This research constructs an efficient hierarchical identity based LR encryption scheme.

In this research, an efficient leakage resilient encryption scheme is explored. Through the use of extractor technology we obtain leakage resilient encryption scheme. Through the appropriate reduction of parameters we improve the efficiency of the system. Through the hash proof system we prove the security of the given system. This research provides an efficient leakage-resilient hierarchical identity-based encryption scheme that can resist almost all leakage of the encapsulated symmetric key. The relative leakage ratio of the encapsulated key is close to 1.

Other sections are arranged as follows. Section II gives the related works and our research motivation. Section III gives some necessary preparatory knowledge. Section IV gives the concrete scheme. Safety proof and leakage performance analysis are given in Section V. Section VI gives the performance comparison. The conclusion is given in Section VII.

## II. RELATED WORKS

In the research [9], a new HIBE with the maximum hierarchy depth was proposed. When the system is initialized, the maximum hierarchy depth should be given. Considering the absolute trust of the root PKG and the incomplete trust of the sub PKG, it is impossible to delegate a private key for the next layer without the keys of other layers. In this way, the burden of key escrow is reduced.

Jiang et al. [10] presented a secure HIBE against chosen plaintext attacks (CPA). Using lattice theory, its CPA security is proved through learning with errors (LWE) theory. Making an additional point, an efficient HIBE is also proposed against adaptive chosen-ciphertext attacks (CCA). This scheme's security is provided through the shortcut vector problem (SVP) difficult assumption under random oracle model.

Emura et al. [11] has built an efficient HIBE through key isolation technology. They proposed a scheme called key-insulated HIBE (HKIBE). First, the pairing based HKIBE was constructed through the  $k$ -linear assumption under the standard model. Furthermore, they also gave a method to construct efficient HKIBE from general HIBE.

The study [12] gave a revocable identity-based (RIB) and authenticated key exchange (AKE). The scheme has these functions of decentralization and private key revocation. In addition, the general method of constructing hierarchical RIB-AKE from a hierarchical RIB key encapsulation mechanism is also given.

The authors [13] provided a functional encryption based on inner product under public key cryptosystem. When decryption is in progress, the decryptor's identity can be specified and this receiver's identity may be hierarchical. They also gave an experimental result to explain that their presented scheme has certain application value.

Langrehr and Pan [14] presented two adaptive and tight secure HIBE schemes. It is mainly constructed through Matrix Diffie-Hellman assumptions.

In order to resist quantum attacks, this study [15] constructed three hierarchical identity-based (HIB) schemes in the networks which can tolerate time delays. Through the lattice based LWE hypothesis, this study [15] proposed an HIB key agreement scheme, an HIB key update scheme and a non-interactive HIB key agreement scheme.

To avoid key exposure, this research [16] put forward the key isolated encryption technology. Shikata et al. [16] gave a hierarchical key insulated encryption scheme in the standard model.

The study [17] constructed the unbounded HIBE through double system groups and gave an example. This proposed

scheme has shorter ciphertext and private key and has higher computational efficiency.

Zhang et al. [18] constructed anonymous HIBE in prime order groups. Its main advantage is that the private key and ciphertext are fixed in size.

The research [19] gave a CPA secure HIB broadcast encryption. This given scheme is based on prime order group which has high efficiency of computing. Then, the CPA secure scheme was converted to CCA secure scheme by one-time signature.

Some schemes have explored efficiency, such as the schemes [8, 11]. However, these schemes do not take into account the impact of side channel attacks, which may lead to the insecurity of the cryptographic systems.

### A. Side Channel Attacks

In recent years, many side channel attacks have been discovered. The authors [20] made a study on the power analysis of pairing based cryptography implementation. The specific attack towards pairing cryptography scheme was given. Aiming at the typical lightweight encryption scheme LBlock, Weng et al. [21] presented an improved key differential analysis attack. The authors in [22] identified the keys by sound characteristics, and applied this attack to PIN pads. Chen et al. [23] exploited an attack in which an attacker may gain system's secret information from observing this timing and other characteristics of the cryptographic system.

Many researchers engage in leakage resilient (LR) cryptography research, and have constructed some encryption schemes with leakage resilience, such as LR public key encryption schemes [24, 25], LR identity-based encryption schemes [26, 27, 28, 29], LR attribute-based encryption schemes [30, 31, 32], LR certificate based encryption scheme [33, 34, 35], and leakage resilient certificateless encryption scheme [36, 37].

### B. Our Motivations and Contributions

Inspired by the researches [6, 8], this study explores efficient encryption scheme in leakage resilient cryptography. An efficient HIBE with leakage resilience (LR-HIBE) is constructed.

First, the presented scheme has the function of resisting private key disclosure. By using the extractor, the given scheme may resist the leakage for the encapsulated symmetric key. It can resist the leakage of almost the entire encapsulated symmetric key.

Secondly, the presented scheme improves the overall performance of the system by reasonably reducing the parameters. Our scheme has less public key parameters. In addition, it greatly improves the efficiency of private key generation, private key delegation and encryption.

Furthermore, our scheme has good practicability and can greatly share the burden for the root private key generation center. The hierarchical function of the scheme enables the system to delegate private keys layer by layer. For example, we use Fig. 1 to show the information management system about Suqian University. Suqian University is the root. Those



colleges are the secondary nodes. These departments are the tertiary node, and the counselor or teacher is the leaf node. Let U represent the university. Let C represent the college. Let D represent the department. Let T represent the teacher. A member with the identity (Suqian University: School of Information Engineering) can delegate a private key to a member whose identity is (Suqian University: School of Information Engineering: Department of Software Engineering). However, he cannot delegate the private key to a member of (School: School of Management: Department of Accounting).

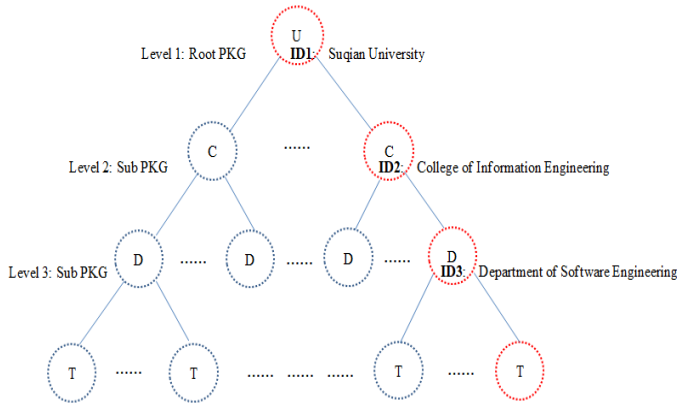


Fig. 1. The hierarchy of the information management system of Suqian University.

### III. PRELIMINARIES

#### A. Bilinear Groups with Composite Order

The research [38] gave the definitions about bilinear groups with composite order (BG-CO). Let  $\Psi$  to denote a BG-CO generation algorithm, which inputs the safety parameter  $\lambda$ , and outputs a BG-CO  $\Omega = \{N = v_1 v_2 v_3, G_1, G_2, e\}$ , where  $v_1, v_2$ , and  $v_3$  are three different primes ( $\text{Log}(v_1) = \text{Log}(v_2) = \text{Log}(v_3)$ ),  $G_1$  is cyclic group with order  $N$  and  $G_2$  is cyclic groups with order  $N$ .  $e$  is a bilinear mapping which satisfies the following two conditions.

1) Bilinearity.

$$\forall g_1, h_1 \in G_1, a, b \in Z_N, e(g_1^a, h_1^b) = e(g_1, h_1)^{ab}$$

2) Non-degenerability.  $\exists g_1 \in G_1$  such that  $e(g_1, g_1) \notin 1_{G_2}$ .

Furthermore, it is required that the operations in groups  $G_1$  and  $G_2$  are computable in terms of the polynomial time about the security parameter  $\lambda$ . We use  $G_{v_1}, G_{v_2}$  and  $G_{v_3}$  to denote these subgroups in the group  $G_1$  whose order is  $v_1, v_2$  and  $v_3$  respectively. In particular, when  $d_i \in G_{v_i}$  and  $d_j \in G_{v_j}$

( $i \neq j$ ),  $e(d_i, d_j)$  is the identity for  $G_2$ . For example, supposing that  $d_1 \in G_{v_1}, d_2 \in G_{v_2}$  and  $p$  is a generator for  $G_1$ , then  $p^{v_1 v_2}$  derives  $G_{v_3}$ ,  $p^{v_1 v_3}$  derives  $G_{v_2}$ ,  $p^{v_2 v_3}$  derives  $G_{v_1}$ . In this way, we can find  $\alpha_1, \alpha_2$  such that  $d_1 = (p^{v_2 v_3})^{\alpha_1}$  and  $d_2 = (p^{v_1 v_3})^{\alpha_2}$ . So,  $e(d_1, d_2) = e(p^{v_2 v_3 \alpha_1}, p^{v_1 v_3 \alpha_2}) = e(p^{\alpha_1}, p^{v_3 \alpha_2})^{v_1 v_2 v_3} = 1$ . The  $G_{v_1}, G_{v_2}$  and  $G_{v_3}$  are orthogonal.

Three complexity assumptions are given here, which is going to be employed in the security proof.

We let  $G_{v_1 v_2}$  to express a subgroup with order  $v_1 v_2$ . Other uses are similar.

Hypothesis 1. Given a composite order bilinear group generation algorithm  $\Psi$  and the distribution as follows.

$$\begin{aligned} \Omega &= (N = v_1 v_2 v_3, G_1, G_2, e) \xleftarrow{R} \Psi, \\ g_1 &\xleftarrow{R} G_{v_1}, X_3 \xleftarrow{R} G_{v_3}, \\ W &= (\Omega, g_1, X_3), \\ T_1 &\xleftarrow{R} G_{v_1 v_2}, T_2 \xleftarrow{R} G_{v_1}. \end{aligned}$$

This advantage that one algorithm  $A$  breaks hypothesis 1 is defined as  $\text{Adv}_{1, \Psi, A}(\lambda) := |\Pr[A(W, T_1) = 1] - \Pr[A(W, T_2) = 1]|$ .

According to the study [6], it is said that the algorithm  $\Psi$  satisfies hypothesis 1, if the advantage  $\text{Adv}_{1, \Psi, A}(\lambda)$  obtained by any probability polynomial adversary is negligible.

Hypothesis 2. Given a composite order bilinear group generation algorithm  $\Psi$  and the distribution as follows.

$$\begin{aligned} \Omega &= (N = v_1 v_2 v_3, G_1, G_2, e) \xleftarrow{R} \Psi, \\ g_1, X_1 &\xleftarrow{R} G_{v_1}, X_2, Y_2 \xleftarrow{R} G_{v_2}, X_3, Y_3 \xleftarrow{R} G_{v_3}, \\ W &= (\Omega, g_1, X_1 X_2, X_3, Y_2 Y_3), \\ T_1 &\xleftarrow{R} G_1, T_2 \xleftarrow{R} G_{v_1 v_3}. \end{aligned}$$

This advantage that one algorithm  $A$  breaks hypothesis 2 is defined as  $\text{Adv}_{2, \Psi, A}(\lambda) := |\Pr[A(W, T_1) = 1] - \Pr[A(W, T_2) = 1]|$ .

According to the research [6], it is said that the algorithm  $\Psi$  satisfies hypothesis 2, if the advantage  $\text{Adv}_{2, \Psi, A}(\lambda)$  obtained by any probability polynomial adversary is negligible.

Hypothesis 3. Given a composite order bilinear group generation algorithm  $\Psi$  and the distribution as follows.

$$\begin{aligned} \Omega &= (N = v_1 v_2 v_3, G_1, G_2, e) \leftarrow^R \Psi, \alpha, s \leftarrow^R Z_N, \\ g_1 &\leftarrow^R G_{v_1}, X_2, Y_2, Z_2 \leftarrow^R G_{v_2}, X_3 \leftarrow^R G_{v_3}, \\ W &= (\Omega, g_1, g_1^\alpha X_2, X_3, g_1^s Y_2, Z_2), \\ T_1 &\leftarrow^R e(g_1, g_1)^{\alpha s}, T_2 \leftarrow^R G_2. \end{aligned}$$

This advantage that one algorithm  $A$  breaks hypothesis 3 is defined as  $Adv3_{\Psi,A}(\lambda) := |\Pr[A(W, T_1) = 1] - \Pr[A(W, T_2) = 1]|$ .

According to the research [6], it is said that the algorithm  $\Psi$  satisfies hypothesis 3, if the advantage  $Adv3_{\Psi,A}(\lambda)$  obtained by any probability polynomial adversary is negligible.

### B. Binary Extractor

This statistical distance about two random variables  $P$  and  $Q$  is defined as:

$$STDS = \frac{1}{2} \sum_{\theta \in \Xi} |\Pr(P = \theta) - \Pr(Q = \theta)| \quad . \quad \text{This}$$

minimum entropy for a random variable  $P$  is defined as:  $H_\infty(P) = -\text{Log}(\max_p \Pr(P = p))$ .

The extractor [39]. We call a function  $\text{Ext}: \{0, 1\}^n \times \{0, 1\}^r \rightarrow \{0, 1\}^m$  as  $(k, \varepsilon)$  strong extractor as long as it meets the conditions. Suppose that  $U$  is the uniform distribution over  $\{0, 1\}^m$  and  $V$  is the uniform distribution over  $\{0, 1\}^r$ . If  $A \in \{0, 1\}^n$  and  $H_\infty(A) > k$ , we can get that  $STDS((\text{Ext}(A, V), V), (U, V)) \leq \varepsilon$ , where  $\varepsilon$  is a negligible value.

**Conclusion 1** [40]. If  $P$ ,  $Q$  and  $R$  are three random variables, and  $Q$  contains  $2^\xi$  value where  $\xi$  is an integer which is used to express the upper bound of leakage, we get  $\tilde{H}_\infty(P | (Q, R)) \geq \tilde{H}_\infty(P | R) - \xi$ .

### C. Hierarchical Identity-Based Hash Proof System

Inspired by the literature [40, 41, 42], we constructed a hierarchical identity-based hash proof system (HIB-HPS). The HIB-HPS includes the following algorithms: Setup, KeyG, Delegate, Encap, Encap\*, and Decap.

**Setup.** This algorithm inputs a security parameter  $\lambda$ . It generates the public key parameter  $PK$  and the master private key  $MK$ .  $\text{Setup}(\lambda) \rightarrow PK, MK$ .

**KeyG.** This algorithm inputs  $MK$  and an identity vector  $\vec{I}$ . It gives the private key  $SK_{\vec{I}}$ .  $\text{KeyG}(MK, \vec{I}) \rightarrow SK_{\vec{I}}$ .

**Delegate.** This algorithm takes an identity vector  $\vec{I}$  with depth  $i$  and an identity  $ID_{i+1}$  as the input. It produces the private key  $SK_{\vec{I}:ID_{i+1}}$  for this identity vector  $\vec{I}:ID_{i+1}$  with depth  $i+1$ .  $\text{Delegate}(PK, SK_{\vec{I}}, ID_{i+1}) \rightarrow SK_{\vec{I}:ID_{i+1}}$ .

**Encap.** This algorithm inputs  $PK$  and  $\vec{I}$ . It generates  $(C, k)$ .  $C$  expresses a correct ciphertext.  $k$  expresses an encapsulated key.  $\text{Encap}(PK, \vec{I}) \rightarrow (C, k)$ .

**Encap\*.** This algorithm inputs  $PK$  and  $\vec{I}$ . It obtains an invalid ciphertext  $C$ . This algorithm is only used for the security proof.  $\text{Encap}^*(PK, \vec{I}) \rightarrow C$ .

**Decap.** The algorithm inputs  $PK$ ,  $C$  and a private key  $SK_{\vec{I}}$ . It produces an encapsulated key  $k$ .  $\text{Decap}(PK, SK_{\vec{I}}, C) \rightarrow k$ .

HIB-HPS has the three characteristics as follows.

1) Correctness

$$\begin{aligned} \Pr[k \neq k' | \text{Encap}(PK, \vec{I}) \rightarrow (C, k), \\ \text{Decap}(PK, SK_{\vec{I}}, C) \rightarrow k'] < \varepsilon, \end{aligned}$$

which means that the decapsulation algorithm are almost always right to obtain the encapsulation key. That is, if the encapsulation algorithm is used to obtain ciphertext  $C$  and the encapsulated key  $k$ , then the probability of the encapsulated key  $k$  obtained by the de encapsulation algorithm is  $1 - \varepsilon$  ( $\varepsilon$  is a negligible value).

2) Indistinguishability between the valid and invalid ciphertext.

Given a private key  $SK_{\vec{I}}$ , the ciphertext gained by the **Encap** algorithm is indistinguishable from the ciphertext generated by an invalid **Encap\*** algorithm.

The indistinguishability is reflected by the next game which is played by an attacker  $A$  and a challenger  $C$ .

### Game<sub>Real</sub>

**Initialize.**  $C$  revokes the algorithm **Setup** to gain the public parameter  $PK$ . Let  $S$  denote the private key created by the challenger but not given to the attacker. The  $S$  is null at the beginning, i.e.  $S = \phi$ .

**Phase 1.**  $\mathcal{A}$  carries on the private key creation inquiry ( $\square - Create$ ), private key delegation inquiry ( $\square - Delegate$ ), and private key inquiry ( $\square - SK$ ).

$\square - Create$ .  $\mathcal{A}$  gives one identity vector  $\vec{I}$ .  $\mathcal{C}$  calls the **KeyG** algorithm to obtain a private key and adds it in  $\mathcal{S}$ .  $\mathcal{C}$  only sends  $\mathcal{A}$  a reference about the private key, not this private key itself.

$\square - Delegate$ .  $\mathcal{A}$  gives a private key  $SK_{\vec{I}}$  in  $\mathcal{S}$  and an identity  $ID$ .  $\mathcal{C}$  connects  $ID$  and  $\vec{I}$  to obtain  $\vec{I} : ID$ . Then,  $\mathcal{C}$  generates a corresponding private key by calling the private key delegation algorithm.  $\mathcal{C}$  only sends  $\mathcal{A}$  a reference about the private key, not this private key itself.

$\square - SK$ .  $\mathcal{A}$  selects a specific element in  $\mathcal{S}$ .  $\mathcal{C}$  sends the private key to  $\mathcal{A}$ . Then,  $\mathcal{C}$  deletes it out of  $\mathcal{S}$ . As for the private key,  $\mathcal{A}$  will no longer do the query  $\square - Delegate$ .

**Challenge.**  $\mathcal{A}$  gives  $\mathcal{C}$  a challenge identity vector  $\vec{I}^*$ . The restriction is that none of its prefix vectors has been inquired in phase 1.  $\mathcal{C}$  randomly selects  $\nu \in \{0, 1\}$ .

If  $\nu = 0$ , the challenger calculates  $Encap(PK, \vec{I}) \rightarrow (C, k)$ .

If  $\nu = 1$ , the challenger calculates  $Encap^*(PK, \vec{I}) \rightarrow C$ .

The challenger sends the ciphertext  $C$  to the adversary.

**Phase 2.** It is similar with phase 1. The basic limitation is that any inquired identity vector cannot be a prefix of  $\vec{I}^*$ .

**Guess.** This adversary outputs a guess  $\nu'$  about  $\nu$ . If  $\nu = \nu'$ ,  $\mathcal{A}$  wins the game. This adversary's advantages are defined as  $Game_{Real}Adv_A(\lambda) = |\Pr[\mathcal{A} \text{ wins}] - \frac{1}{2}|$ . We

have  $Game_{Real}Adv_A(\lambda) \leq \epsilon$ .

3) Smoothness

If  $C \leftarrow Encap^*(PK, \vec{I})$ ,  $k \leftarrow Decap(PK, SK_{\vec{I}}, C)$  and  $k' \leftarrow U$  ( $U$  is a uniform distribution), it can be get that  $STDS((C, k), (C, k')) \leq \epsilon$ .

#### IV. THE PROPOSED LR-HIBE SCHEME

A leakage-resistant and hierarchical identity-based encryption (LR-HIBE) scheme is given in this paper. The ciphertext is compressed to constant group elements and the private key can be re randomized by completely depending on the private key delegation algorithm. By BG-CO, we designs our the scheme. This private key is randomized by  $G_{v_3} \cdot G_{v_2}$

is not used for the real system, but only as a semi-functional form.

**Setup.** This algorithm chooses a BG-CO  $G_1$  and  $N = v_1 v_2 v_3$ , where  $v_1, v_2$  and  $v_3$  are different primes with the equal length. Let  $\ell$  indicate the maximum depth for LR-HIBE. It randomly selects  $g_1, h_1, u_1 \in G_{v_1}, X_3 \in G_{v_3}$  and  $\alpha, \beta \in Z_N$ . This public parameter is  $PK = \{g_1, h_1, u_1, X_3, e(g_1, g_1)^\alpha, e(g_1, g_1)^\beta\}$ . The master key is  $MK = (g_1^\alpha, g_1^\beta)$ .

**KeyG.** It randomly selects  $r, t \in Z_N$  and  $R_3, R'_3, R''_3 \in G_{v_3}$ . It takes the public parameter and one identity vector  $(ID_1, \dots, ID_j)$  as input. It sets the private key:  $K_1 = g_1^r R_3, K_2 = g_1^\alpha g_1^{-\beta t} (u_1^{ID_1 + \dots + ID_j} h_1)^r R'_3, K_3 = t, E = u_1^r R''_3$ .

**Delegate.** Given this private key  $K'_1, K'_2, E'$  for an identity vector  $(ID_1, \dots, ID_j)$  and an identity  $ID_{j+1}$ , this algorithm generates one private key based on this identity vector  $(ID_1, \dots, ID_j, ID_{j+1})$ . It randomly selects  $r', t' \in Z_N$  and  $\tilde{R}_3, \tilde{R}'_3, \tilde{R}''_3 \in G_{p_3}$  and gives the private key:

$$K_1 = K'_1 g_1^{r'} \tilde{R}_3,$$

$$K_2 = K'_2 g_1^{-\beta t'} (u_1^{ID_1 + \dots + ID_j} h_1)^{r'} (E')^{ID_{j+1}} u_1^{r' ID_{j+1}} \tilde{R}'_3,$$

$$K_3 = t', E = E' u_1^{r'} \tilde{R}''_3.$$

The new private key is completely randomized.

**Encrypt.** Given one message  $M$  and an identity vector  $(ID_1, \dots, ID_j)$ , this algorithm randomly selects  $s, d \in Z_N$ . It computes the ciphertext:

$$C_0 = M \cdot Ext(e(g_1, g_1)^{\alpha s}, d), C_1 = (u_1^{ID_1 + \dots + ID_j} h_1)^s,$$

$$C_2 = g_1^s, C_3 = e(g_1, g_1)^{\beta s}, C_4 = d$$

**Decrypt.** If one identity vector corresponding to a private key is just a prefix of  $(ID_1, \dots, ID_j)$ , this algorithm runs the delegation algorithm to generate an identity vector corresponding to the ciphertext. Otherwise, when the private key and ciphertext for the identity vector  $(ID_1, \dots, ID_j)$ , this algorithm gets the message as follows.

$$\begin{aligned} \frac{e(K_2, C_2)}{e(K_1, C_1)} C_3^{K_3} &= \frac{e(g_1^\alpha g_1^{-\beta t} (u_1^{ID_1+\dots+ID_j} h_1)^r R_3', g_1^s)}{e(g_1^r R_3, (u_1^{ID_1+\dots+ID_j} h_1)^s)} e(g_1, g_1)^{\beta s t} \\ &= \frac{e(g_1, g_1)^{\alpha s} e(u_1^{ID_1+\dots+ID_j} h_1, g_1)^{rs}}{e(g_1, u_1^{ID_1+\dots+ID_j} h_1)^{rs}} \\ &= e(g_1, g_1)^{\alpha s} \end{aligned}$$

$$\begin{aligned} C_0 \oplus Ext(e(g_1, g_1)^{\alpha s}, C_4) \\ = M \oplus Ext(e(g_1, g_1)^{\alpha s}, d) \oplus Ext(e(g_1, g_1)^{\alpha s}, d) = M \end{aligned}$$

The security of our scheme can be obtained through the next game  $\text{Game}_{Real}$  which is played by the attacker and the challenger.

$\text{Game}_{Real}$ .

**Initialize.** The challenger  $C$  runs the algorithm **Setup** to generate the public parameter  $PK$  for the attacker  $A$ . Let  $S$  denote the private key created by the challenger but not given to the attacker. The  $S$  is null at the beginning, i.e.,  $S = \phi$ .

**Phase 1.**  $A$  can ask these oracles  $\square - Create$ ,  $\square - Delegate$ ,  $\square - SK$ , and leakage query ( $\square - LK$ ).

$\square - Create$ .  $A$  gives one identity vector  $\vec{I}$ .  $C$  calls the **KeyG** algorithm to obtain a private key and adds it in  $S$ .  $C$  only sends  $A$  a reference about the private key, not this private key itself.

$\square - Delegate$ .  $A$  gives a private key  $SK_{\vec{I}}$  in  $S$  and an identity  $ID$ .  $C$  connects  $ID$  and  $\vec{I}$  to obtain  $\vec{I} : ID$ . Then,  $C$  generates a corresponding private key by calling the private key delegation algorithm.  $C$  only sends  $A$  a reference about the private key, not this private key itself.

$\square - SK$ .  $A$  selects a specific element in  $S$ .  $C$  sends the private key to  $A$ . Then,  $C$  deletes it out of  $S$ . As for the private,  $A$  will no longer do the query  $\square - Delegate$ .

$\square - LK$ . Given a private key  $SK_{\vec{I}}$  for one identity vector  $\vec{I}$ ,  $A$  can adaptively select the leakage function  $f(\cdot)$ .  $C$  returns  $f(SK_{\vec{I}})$  to  $A$ . This output length for  $f(SK_{\vec{I}})$  is recorded as  $\xi$ .

**Challenge.** The adversary gives  $C$  two challenge messages  $M_0$  and  $M_1$ , and one identity vector  $\vec{I}^*$ . This identity vector must meet the condition that none of its prefix

vectors is queried at phase 1.  $C$  randomly selects  $\nu \in \{0, 1\}$ , calculates the ciphertext  $M_\nu$  and sends it to  $A$ .

**Phase 2.** It is similar to phase 1. The extra constraint is that any inquired identity vector cannot be a prefix about  $\vec{I}^*$ .

**Guess.**  $A$  outputs a guess  $\nu'$  about  $\nu$ . If  $\nu = \nu'$ ,  $A$  wins.

If any probability polynomial time adversary can only achieve negligible advantages in the game  $\text{Game}_{Real}$ , the given **LR-HIBE** is secure.

This proposed scheme is divided into two aspects. The first aspect is the proof of security. The second aspect is the analysis of leakage resilience. The details are given in the next section.

## V. SAFETY PROOF AND LEAKAGE RESILIENCE ANALYSIS

In general, the system presented in this study can be constructed through two steps. The first step is a key encapsulation algorithm (KEA), and the second step is to combine the extractor with the key encapsulation algorithm to construct our scheme. First, we prove that this KEA can constitute a hash proof system, which proves the security of our scheme. Then, by combining this obtained hash proof system with the extractor we get the proposed scheme. Thus, the leakage resilience performance can be analyzed according to the characteristics of the extractor.

### A. Safety Proof

The presented LR-HIBE includes a key encapsulation algorithm. This key encapsulation algorithm is as follows.

**Setup.** This algorithm is identical with **Setup** algorithm of LR-HIBE.

**KeyG.** This algorithm is identical with **KeyG** algorithm of LR-HIBE.

**Delegate.** It is identical with **Delegate** algorithm of LR-HIBE.

**Encap.**  $Encap(PK, \vec{I}) \rightarrow (C, k)$ . This algorithm inputs this public parameter  $PK$  and one identity vector  $\vec{I} = (ID_1, \dots, ID_j)$ , and randomly selects  $s \in Z_N$ . It outputs an invalid ciphertext  $C = (C_1, C_2, C_3) = ((u_1^{ID_1+\dots+ID_j} h_1)^s, g_1^s, e(g_1, g_1)^{\beta s})$ .

The encapsulated key is  $k = e(g_1, g_1)^{\alpha s}$ .

**Encap\*.**  $Encap^*(PK, \vec{I}) \rightarrow C$ . It inputs  $PK$  and one identity vector  $\vec{I}$  and randomly selects  $s, s' \in Z_N$ . It outputs an invalid ciphertext.

$$C = (C_1, C_2, C_3) = ((u_1^{ID_1+\dots+ID_j} h_1)^s, g_1^s, e(g_1, g_1)^{\beta s'})$$

This algorithm is only used for the security proof.

**Decap.**  $Decap(PK, SK_{\bar{T}}, C) \rightarrow k$ . The algorithm inputs the ciphertext  $C$  and one private key  $SK_{\bar{T}}$ . It generates the encapsulated key  $k = \frac{e(K_2, C_2)}{e(K_1, C_1)} C_3^{K_3}$ .

We will prove that the key encapsulation algorithm is an HIB-HPS.

Proof.

1) *Correctness*: The decapsulation of a valid ciphertext is as follows.

$$\begin{aligned} \frac{e(K_2, C_2)}{e(K_1, C_1)} C_3^{K_3} &= \frac{e(g_1^\alpha g_1^{-\beta t} (u_1^{ID_1+\dots+ID_j} h_1)^r R_3^s, g_1^s)}{e(g_1^r R_3, (u_1^{ID_1+\dots+ID_j} h_1)^s)} e(g_1, g_1)^{\beta s t} \\ &= \frac{e(g_1, g_1)^{\alpha s} e(u_1^{ID_1+\dots+ID_j} h_1, g_1)^{rs}}{e(g_1, u_1^{ID_1+\dots+ID_j} h_1)^{rs}} \\ &= e(g_1, g_1)^{\alpha s} \end{aligned}$$

So the correctness is established.

2) *Smoothness*: The decapsulation of an invalid ciphertext is as follows.

$$\begin{aligned} \frac{e(K_2, C_2)}{e(K_1, C_1)} C_3^{K_3} &= \frac{e(g_1^\alpha g_1^{-\beta t} (u_1^{ID_1+\dots+ID_j} h_1)^r R_3^s, g_1^s)}{e(g_1^r R_3, (u_1^{ID_1+\dots+ID_j} h_1)^s)} e(g_1, g_1)^{\beta s' t} \\ &= \frac{e(g_1, g_1)^{\alpha s} e(u_1^{ID_1+\dots+ID_j} h_1, g_1)^{rs}}{e(g_1, u_1^{ID_1+\dots+ID_j} h_1)^{rs}} e(g_1, g_1)^{\beta(s'-s)t} \\ &= e(g_1, g_1)^{\alpha s} e(g_1, g_1)^{\beta(s'-s)t} \end{aligned}$$

Because  $s$  and  $s'$  are randomly selected,  $e(g, g)^{\alpha s} e(g, g)^{\beta(s'-s)t}$  is evenly distributed in  $G_T$ . Thus, the smoothness is proved.

3) *The indistinguishability between the valid and invalid ciphertext*: First, we give the semi functional (SF) ciphertext and SF private key. They only play a role in proof.

**SF ciphertext.** Suppose that  $g_2$  is a generator for  $G_{v_2}$ . Given the normal ciphertext  $C_1, C_2, C_3$ , this algorithm randomly selects  $x, z_c \in \mathbb{Z}_N$  and sets semi functional ciphertext  $C_1' = C_1 g_2^{xz_c}, C_2' = C_2 g_2^x, C_3' = C_3$ .

**SF private key.** First, this algorithm gains one normal private key  $K_1, K_2, K_3, E$ . Then, it randomly selects  $\gamma, z_k, z \in \mathbb{Z}_N$ . It computes SF private key  $K_1' = K_1 g_2^\gamma, K_2' = K_2 g_2^{\gamma z_k}, K_3' = K_3, E' = E g_2^{\gamma z}$ .

When an SF private key decrypts an SF ciphertext, we have

$$\begin{aligned} \frac{e(K_2', C_2')}{e(K_1', C_1')} C_3^{K_3'} &= \frac{e(K_2 g_2^{\gamma z_k}, C_2 g_2^x)}{e(K_1 g_2^\gamma, C_1 g_2^{xz_c})} C_3^{K_3} \\ &= \frac{e(K_2, C_2)}{e(K_1, C_1)} C_3^{K_3} \frac{e(g_2^{\gamma z_k}, g_2^x)}{e(g_2^\gamma, g_2^{xz_c})} \\ &= e(g_1, g_1)^{\alpha s} \frac{e(g_2^{\gamma z_k}, g_2^x)}{e(g_2^\gamma, g_2^{xz_c})} = e(g_1, g_1)^{\alpha s} e(g_2, g_2)^{xy(z_k - z_c)} \end{aligned}$$

It has an extra item  $e(g_2, g_2)^{xy(z_k - z_c)}$ . When  $z_c = z_k$ , the decryption is correct. We call the semi functional private key a nominal SF private key.

This indiscernibility between the valid and invalid ciphertext can be achieved by constructing these games.  $\text{Game}_{Real}$  is a real security game. The ciphertext is generated by a valid encapsulation algorithm and is normal.  $\text{Game}_{Real'}$  is similar to  $\text{Game}_{Real}$ , but for all private key queries it generates the private key by calling the **KeyG** algorithm instead of using a delegation algorithm.  $\text{Game}_{Restricted}$  is similar to  $\text{Game}_{Real'}$ , but an attacker cannot ask for such one identity that is the prefix for a challenge identity mode  $p_2$ . Similar restrictions are set forth below. Let  $q$  indicate this number about inquiries.

$\text{Game}_i (i \in [0, q])$ . It is similar to  $\text{Game}_{Restricted}$ . The difference is that this ciphertext sent to an adversary is one SF ciphertext. These forward  $i$  private keys are SF ones. These rearward private keys are normal ones. In  $\text{Game}_0$ , only this ciphertext is SF form. In  $\text{Game}_q$ , this challenge ciphertext is SF one and every private key is SF one.

$\text{Game}_{Semi}$ . It is similar to  $\text{Game}_q$ . The difference is that this challenge ciphertext is an SF invalid one which is generated by an invalid encapsulation algorithm.

$\text{Game}'_i (i \in [0, q])$ . This game and  $\text{Game}_i$  are similar. The difference is that this ciphertext is generated by **Encap\*** algorithm. For  $\text{Game}'_0$ , every private key is normal, and this ciphertext is SF and invalid. For  $\text{Game}'_q$ , all private keys except the first  $i$  queries are semi functional. This ciphertext is also SF and invalid.

$\text{Game}_{Final}$ . This game and  $\text{Game}_{Real}$  are similar. The only difference is  $C$  chooses one normal and invalid ciphertext to  $A$ , i.e. he selects  $\nu = 1$ .

The following 7 lemmas prove the indiscernibility of this series of games.

**Lemma 1.** For every  $A$ ,  $\text{Game}_{\text{Real}} \text{Adv}_A = \text{Game}_{\text{Real}} \text{Adv}_A$ .

**Proof.** No matter a private key is generated by this private key delegation algorithm or by this private key generation algorithm, their distributions are identical. In the view of the adversary, they are not fundamentally different.

**Lemma 2.** If there is an adversary  $A$  that makes  $\text{Game}_{\text{Real}} \text{Adv}_A - \text{Game}_{\text{Restricted}} \text{Adv}_A = \varepsilon$ , we may construct an algorithm  $C$  to destroy hypothesis 2 with more than  $\frac{\varepsilon}{2}$  advantages.

**Proof.** Given  $g_1, X_1, X_2, X_3, Y_2, Y_3$ ,  $C$  and  $A$  simulate  $\text{Game}_{\text{Real}}$ .  $A$  can generate identity vector  $ID$  and  $ID^*$  over  $\varepsilon$  probability under the conditions that  $ID \neq ID^* \pmod N$  and  $(ID - ID^*)$  is divided by  $v_2$ .  $C$  obtains one nontrivial factor for  $N$  by calculating  $x = \text{gcd}(ID - ID^*, N)$ . Let  $y = \frac{N}{x}$ . Because  $x$  is divided by  $v_2$  and  $N = xy = v_1 v_2 v_3$ . There are three cases.

- (1)  $x$  or  $y$  is  $v_1$ . Another one is  $v_2 v_3$ .
- (2)  $x$  or  $y$  is  $v_2$ . Another one is  $v_1 v_3$ .
- (3)  $x$  or  $y$  is  $v_3$ . Another one is  $v_1 v_2$ .

For case 1,  $C$  determines which of  $x$  and  $y$  is the identity element through judging which of  $(Y_2 Y_3)^x$  and  $(Y_2 Y_3)^y$  is the identity element. In general, it can be assumed that  $x = v_1$  and  $y = v_2 v_3$ .  $C$  determines whether  $T$  contains  $G_{v_2}$  part through testing whether  $e(T^x, X_1 X_2)$  is an identity element. If not,  $T$  has the  $G_{v_2}$  composition.

For case 2,  $C$  tests which of  $(X_1 X_2)^x$  and  $(X_1 X_2)^y$  is the identity element. If none of them is the identity element and it is not case 1, it is case 2.  $C$  determines which of  $x$  and  $y$  is  $v_1 v_3$  through testing which of  $g_1^x$  and  $g_1^y$  is an identity element. In general, it can be assumed that  $x = v_2$  and  $y = v_1 v_3$ .  $C$  determines whether  $T$  contains  $G_{v_2}$  part through testing whether  $T^y$  is an identity element. If  $T^y$  is an identity element,  $T \in G_{v_1 v_3}$ . If not,  $T$  has the  $G_{v_2}$  composition ( $T \in G_1$ ).

If case 1 and case 2 do not hold, case 3 holds. By detecting which of  $X_3^x$  and  $X_3^y$  is the identity element,  $C$  determines which of  $x$  and  $y$  is  $v_3$ . Without losing generality, it can be assumed that  $x = v_3$ .  $C$  determines whether  $T$  contains  $G_{v_2}$  part through judging whether  $e(T^x, Y_2 Y_3)$  is an identity element. If not,  $T$  contains  $G_{v_2}$  composition. Thus, the algorithm  $B$  destroys hypothesis 2 with more than  $\frac{\varepsilon}{2}$  advantages.

**Lemma 3.** If there exists an algorithm  $A$  who makes  $\text{Game}_{\text{Restricted}} \text{Adv}_A - \text{Game}_0 \text{Adv}_A = \varepsilon$ . We may construct an algorithm  $C$  to destroy hypothesis 1 with more than  $\frac{\varepsilon}{2}$  advantages.

**Proof.** Given  $g_1, X_3, T$ ,  $C$  simulates the  $\text{Game}_{\text{Restricted}}$  or  $\text{Game}_0$  with  $A$ .  $C$  randomly selects  $\alpha, a, b \in \mathbb{Z}_N$ , and sets  $u_1 = g_1^a$  and  $h_1 = g_1^b$ .  $C$  sends the public parameter  $\{N, g_1, h_1, u_1, e(g_1, g_1)^\alpha\}$  to  $A$ . When  $C$  is requested to provide a private key corresponding to the identity vector  $\vec{I}_j = (ID_1, \dots, ID_j)$ , he randomly selects  $r, t, t', w, v \in \mathbb{Z}_N$ , and calculates:  $K_1 = g_1^r X_3^t, K_2 = g_1^\alpha (u_1^{ID_1 + \dots + ID_j} h_1)^r X_3^w, K_3 = t', E = u_1^r X_3^v$ .  $C$  generates the normal ciphertext  $C = (C_1, C_2, C_3) = (T^{a(ID_1^* + \dots + ID_j^*) + b}, T, e(T, g_1)^\beta)$ .

This implies that  $g_1^s$  is a part for  $T$ . If  $T \in G_{v_1 v_2}$ , this is an SF ciphertext, where  $z_c = a(ID_1^* + \dots + ID_j^*) + b$ .  $A$  simulates  $\text{Game}_0$ . If  $T \in G_{v_1}$ , this is a normal ciphertext.  $A$  simulates  $\text{Game}_{\text{Restricted}}$ . Thus, the algorithm  $C$  destroys hypothesis 1 with more than  $\frac{\varepsilon}{2}$  advantages.

**Lemma 4.** If there exists an algorithm  $A$  who makes  $\text{Game}_{i-1} \text{Adv}_A - \text{Game}_i \text{Adv}_A = \varepsilon$ . We may construct an algorithm  $C$  to destroy hypothesis 2 with more than  $\frac{\varepsilon}{q}$  advantages.

**Proof.** The algorithm  $C$  needs to select an identity vector to create an SF private key.  $C$  does not know the challenge identity vector before the challenge phase, so  $C$  randomly



selects one as the challenge identity vector. The probability of success is  $\frac{1}{q}$ . Given  $g_1, X_1X_2, X_3, Y_2Y_3$  and  $T$ ,  $C$  randomly selects  $\alpha, a, b \in Z_N$ .  $C$  obtains the public parameters  $u_1 = g_1^a, h_1 = g_1^b, e(g_1, g_1)^\alpha$  and sends them to  $A$ . When  $A$  queries a private key of the  $p^{th}$  ( $p < i$ ) identity vector  $(ID_1, \dots, ID_j)$ ,  $C$  generates an SF private key.  $C$  randomly selects  $r, z, t, t', v \in Z_N$ .  $C$  computes  $K_1 = g_1^r (Y_2Y_3)^t, K_2 = g_1^\alpha (u_1^{ID_1+\dots+ID_j} h_1)^r (Y_2Y_3)^z, K_3 = t', E = u_1^r (Y_2Y_3)^v$ . This is an SF private key, where  $g_2^z = Y_2^t$ .

When  $p > i$ ,  $C$  calls the normal **KeyG** generation algorithm to achieve a normal private key.

In order to generate the private key of the  $p^{th}$  identity vector  $(ID_1, \dots, ID_j)$ ,  $C$  sets  $z_c = a(ID_1^* + \dots + ID_j^*) + b$ .  $C$  randomly selects  $w_k, w \in Z_N$ , and calculates  $K_1 = T, K_2 = g_1^\alpha T^{z_c} X_3^{w_k}, K_3 = t', E = T^a X_3^w$ .

Supposing that  $T \in G_{v_1v_3}$ , this private key is normal, where  $g_1^r$  is equal to this  $G_{v_1}$  part about  $T$ . If  $T \in G_1$ , this is an SF private key.

**Challenge.**  $A$  selects an identity vector  $ID^* = (ID_1^*, \dots, ID_j^*)$  and gives it to  $C$ .  $C$  terminates if  $C$  cannot guess the private key correctly. Otherwise,  $C$  calculates the ciphertext as follows:  $(C_1, C_2, C_3) = ((X_1X_2)^{a(ID_1^*+\dots+ID_j^*)+b}, X_1X_2, e(X_1X_2, g_1)^\beta)$ , where  $g_1^s = X_1$  and  $z_k = a(ID_1^* + \dots + ID_j^*) + b$ . Since the  $i^{th}$  identity is not the prefix about  $ID^*$  modulo  $v_2$ ,  $z_c$  and  $z_k$  are randomly distributed in  $A$ 's view. This relationship of  $z_c$  and  $z_k$  is crucial. When  $C$  tests whether the  $i^{th}$  private key is semi functional, he creates an SF ciphertext about  $ID^*$ , and decrypts it. Regardless of whether this  $i^{th}$  private key is semi functional, decryption can always succeed for  $z_c = z_k$ . In fact, this is equivalent to creating a nominal semi functional private key.

If  $T \in G_{v_1v_3}$ ,  $C$  simulates  $Game_{i-1}$  correctly. If  $T \in G_1$ ,  $C$  simulates  $Game_i$  correctly. Thus,  $C$  destroys hypothesis

2 with more than  $\frac{\epsilon}{q}$  advantages.

**Lemma 5.** Supposing that there exists an algorithm  $A$  that makes  $Game_q Adv_A - Game_{Semi} Adv_A = \epsilon$ . We may construct one algorithm  $C$  to destroy hypothesis 3 with more than  $\frac{\epsilon}{q}$  advantages.

**Proof.** Given  $g_1, g_1^\beta X_2, X_3, g_1^s Y_2, Z_2, T$ ,  $C$  randomly selects  $\alpha, a, b, t^*, \tilde{\alpha} \in Z_N$  such that  $\alpha = t^* \beta + \tilde{\alpha}$  and sets the public parameters

$$u_1 = g_1^a, h_1 = g_1^b, e(g_1, g_1)^\beta = e(g_1 X_2, g_1)^\beta, \\ e(g_1, g_1)^\alpha = (e(g_1, g_1)^\beta)^{t^*} e(g_1, g_1)^{\tilde{\alpha}},$$

and sends them to  $A$ .

When  $A$  queries the private key of the identity vector  $(ID_1, \dots, ID_j)$ ,  $C$  randomly selects one to generate an SF private key for  $C$  is not aware of the challenge identity vector. The probability of success is  $\frac{1}{q}$ .  $C$  selects

$c, r, t, z, z', w, w' \in Z_N$  at random and computes

$$K_1 = g_1^r Z_2^z X_3^t, K_2 = (g_1^\beta X_2)^i g_1^{\tilde{\alpha}} (u_1^{ID_1+\dots+ID_j} h_1)^r X_3^w Z_2^c, \\ K_3 = t^* - \tilde{t}, E = u_1^r Z_2^{z'} X_3^{w'}.$$

It is a properly distributed SF private key, where  $(g_1^\beta)^i g_1^{\tilde{\alpha}} = g_1^\alpha g_1^{-\beta K_3}$ .

$A$  selects the challenge identity vector  $ID^* = (ID_1^*, \dots, ID_j^*)$  and gives it to  $C$ .  $C$  selects  $r, t, w, z, w' \in Z_N$  at random and generates a properly distributed normal private key

$$K_1^* = g_1^r X_3^t, K_2^* = g_1^{\tilde{\alpha}} (u_1^{(ID_1^*+\dots+ID_j^*)} h_1)^r X_3^w, \\ K_3^* = t^*, E = u_1^r Z_2^{z'} X_3^{w'}.$$

$A$  gives  $C$   $ID^* = (ID_1^*, \dots, ID_j^*)$ .  $C$  gives the ciphertext  $(C_1, C_2, C_3) = ((g_1^s Y_2)^{a(ID_1^*+\dots+ID_j^*)+b}, g_1^s Y_2, T)$  to  $A$ , Let  $z_c = a(ID_1^* + \dots + ID_j^*) + b$ .  $z_c$  is modulo  $v_2$  and  $u_1 = g_1^a$  and  $h_1 = g_1^b$  are some elements of  $G_{v_1}$ . If  $\alpha, a, b \in Z_N$  are selected randomly,  $\alpha, a, b \in Z_N$  modulo  $N$  is not related to  $z_c = a(ID_1^* + \dots + ID_j^*) + b$  modulo  $v_2$ .

In the event that  $T = e(g_1, g_1)^{as}$ , this ciphertext is a properly distributed SF ciphertext. In the event that  $T \in G_2$ , this is an SF ciphertext about one random message. So, the algorithm C destroys hypothesis 3 with more than  $\frac{\epsilon}{q}$  advantages.

**Lemma 6.** Supposing that there exists an algorithm A that makes  $\text{Game}_i' \text{Adv}_A - \text{Game}_{i-1}' \text{Adv}_A = \epsilon$ . We may construct one algorithm C to destroy hypothesis 2 with more than  $\frac{\epsilon}{2}$  advantages.

**Proof.** This process of proof is similar to that of Lemma 4.

**Lemma 7.** Supposing that there exists an algorithm A that makes  $\text{Game}_1' \text{Adv}_A - \text{Game}_{Final} \text{Adv}_A = \epsilon$ . We may construct one algorithm C to destroy hypothesis 3 with more than  $\frac{\epsilon}{2}$  advantages.

**Proof.** This process of proof is similar to that of Lemma 5.

**Theorem 1.** If hypothesis 1, hypothesis 2 and hypothesis 3 are true, the valid ciphertext and invalid ciphertext are indistinguishable.

**Proof.** The maximum advantages obtained by the adversary in hypothesis 1, hypothesis 2 and hypothesis 3 are respectively denoted by  $\epsilon_1, \epsilon_2$  and  $\epsilon_3$ .

According to the above 7 lemmas, the difference between the advantages of adversary A in the above different games are:

$$\text{Game}_{\text{Real}} \text{Adv}_A - \text{Game}_{\text{Restricted}} \text{Adv}_A \leq \epsilon_2,$$

$$\text{Game}_{\text{Restricted}} \text{Adv}_A - \text{Game}_0 \text{Adv}_A \leq \epsilon_1,$$

$$\text{Game}_{i-1} \text{Adv}_A - \text{Game}_i \text{Adv}_A \leq q\epsilon_2,$$

$$\text{Game}_q \text{Adv}_A - \text{Game}_{\text{Semi}} \text{Adv}_A \leq q\epsilon_3,$$

$$\text{Game}_i' \text{Adv}_A - \text{Game}_{i-1}' \text{Adv}_A \leq q\epsilon_2,$$

$$\text{Game}_1' \text{Adv}_A - \text{Game}_{\text{Final}} \text{Adv}_A \leq q\epsilon_3,$$

From the above inequality, we can get.

$$\begin{aligned} & \text{Game}_{\text{Real}} \text{Adv}_A - \text{Game}_{\text{Final}} \text{Adv}_A \\ & \leq \epsilon_2 + \epsilon_1 + 2q(q-1)\epsilon_2 + 2q\epsilon_3 \end{aligned}$$

Because the above equation is a polynomial about  $q$ , any adversary's advantage can be ignored.

### B. Performance Analysis about Leakage Resilience

Based on the key encapsulation algorithms: Setup, KeyG, Delegate, Encap, Encap\*, and Decap, our LR-HIBE scheme is constructed. The encapsulated key space has  $\text{Log}(p_1)$  elements. We use a  $(\text{Log}(p_1) - \text{Leak}, \epsilon)$  strong extractor  $\text{Ext} : \{0, 1\}^{\text{Log}(p_1) - \text{Leak}} \times \{0, 1\}^r \rightarrow \{0, 1\}^{\text{Log}(p_1)}$ . The obtained LR-HIBE has the same algorithm as the key encapsulation algorithms: Setup, KeyG, Delegate. The encryption and decryption algorithms are as follows.

**Encrypt:**  $\text{Encrypt}(PK, M, \vec{I}) \rightarrow CT$ . This algorithm calls  $\text{Encap}(PK, \vec{I}) \rightarrow (C, k)$ , randomly selects a seed  $s^*$  of the extractor and sets  $C_0 = \text{Ext}(k, s^*) \oplus M$ . This algorithm generates a ciphertext  $CT = (C_0, s^*, C)$ , where  $C = (C_1, C_2, C_3)$ .

**Decrypt:**  $\text{Decrypt}(PK, CT, SK_{\vec{I}}) \rightarrow M$ . It takes  $PK$ ,  $CT$  and  $SK_{\vec{I}}$  as the input, where  $CT = (C_0, s^*, C)$  and  $k = \text{Decap}(C, SK_{\vec{I}})$ . It outputs the message  $M = \text{Ext}(k, s^*) \oplus C_0$ . The decryption can succeed as long as the identity vector used in decryption is the same as the identity vector used by this encryption.

**Theorem 2.** If there is a key encapsulation algorithm as defined in section 4.1. By the above transformation we can get LR-HIBE (that is, the scheme given in this paper). This relative leakage ratio about the encapsulated key of this given LR-HIBE is close to 1.

**Proof.** Let  $\text{View}$  represent the view (all random variables) that A sees when there is no leakage, we have  $\tilde{H}_{\infty}(A|\text{View}) = \text{Log}N$ . The encapsulated key length is  $\text{Log}N$ . When there is a leakage query, adversary A can obtain  $\xi$  bits information which is regarded as  $\text{Leak}$ , that is,  $\text{Leak}$  has  $2^{\xi}$  values. According to conclusion 1 we get  $\tilde{H}_{\infty}(A|\text{Leak}, \text{View}) \geq \tilde{H}_{\infty}(A|\text{View}) - \xi = \text{Log}N - \xi$ . Therefore, as long as the extractor is  $(\text{Log}N - \xi, \epsilon)$  strong,  $\text{SD}((\text{Ext}(k, s^*), s^*, \text{Leak}, \text{View}), (U, s^*, \text{Leak}, \text{View})) \leq \epsilon$ , where U is uniformly distributed. As long as the performance of the extractor is good enough, this leakage amount  $\xi$  for an encapsulated key is close to  $\text{Log}N$ . So the distance of  $C_0 = \text{Ext}(k, s^*) \oplus M$  and the uniform distribution is  $\epsilon$ . Thus, this statistical distance about two ciphertexts is no more than  $2\epsilon$ . Consequently, no PPT adversary may make a distinction between two challenge ciphertexts over more than  $2\epsilon$  advantage. This relative leakage ratio is  $\rho = \text{Leak} / \text{Log}N \approx \text{Log}N / \text{Log}N = 1$ .

Theorem 2 is proved.

## VI. PERFORMANCE COMPARISONS AND EXPERIMENTAL SIMULATION

Some comparisons between this study and several related researches [6, 8] are given in Table I. LR stands for leakage resilience.  $|G_{v_1}|$  and  $|G_{v_3}|$  represent the element length of the subgroup  $G_{p_1}$  and  $G_{p_3}$ , respectively. E indicates exponential operation in the group.

We make some comparisons about leakage resilience, public key length, private key generation and encryption cost. Our scheme has the same public key length, private key generation, private key delegation, and encryption costs as [8]. This public key in our scheme is much smaller than that given in [6], which greatly reduces the network communication burden. Since the number of system layers in a hierarchy can generally reach ten or more, the computation cost of our scheme for private key generation and private key delegation is much lower than that of the scheme [6]. When the number of layers is little, the encryption cost of our scheme is basically the same as theirs, but when the number of layers gradually increases, our encryption calculation operation is obviously better than that given in [6].

TABLE I. SOME COMPARISONS BETWEEN OUR SCHEME AND SEVERAL RELATED SCHEMES [6, 8]

	[8]	[6]	Ours
LR	No	No	Yes
Public Key Size	$3 G_{v_1}  +  G_{v_3} $	$(l+2) G_{v_1}  +  G_{v_3} $	$3 G_{v_1}  +  G_{v_3} $
Private Key Generation	$5E$	$(l+3)E$	$5E$
Private Key Delegation	$6E$	$(l+3)E$	$6E$
Encryption	$4E$	$(j+3)E$	$4E$

In addition to the performance comparisons, we also give the experimental simulation.

The experimental platform is a PC with 64 bit operating system Windows 10, 3.40 GHz main frequency, 8.00G RAM and Intel (R) Core (TM) i7-6700 CPU. Based on Java Pairing Based Cryptography Library 2.0.0 [43], we use Eclipse 4.4.1 for simulation software. A 160 bit composite order elliptic curve  $y^2 = x^3 + x$  is selected for our experiment. The private key generation time is 0.125 seconds, the private key delegation time is 0.150 seconds, and the encryption time is 0.100 seconds.

## VII. CONCLUSIONS

We propose a hierarchal and efficient identity-based encryption scheme. This given scheme may resist the bounded leakage for this encapsulated key. By using dual system encryption combined with hash proof system, the security proof can be achieved. The leakage resilient function is realized by using extractor technology. The relative leakage ratio of the encapsulated key is close to 1.

The features of this scheme are as follows.

- 1) There is no limit to the hierarchy depth of the system, and only the maximum hierarchy length is required to be given when the system is initialized.
- 2) The system has the performance of resisting the leakage of encapsulated symmetric keys, and the relative leakage rate of encapsulated symmetric keys can almost reach 1.
- 3) The system is efficient, because unnecessary parameters are appropriately reduced.

The scheme in this study is constructed in composite order groups, and the computational cost may be slightly higher than that is constructed in prime order groups. In the future, we will start to consider how to construct an LR encryption scheme in prime order groups.

Attribute based encryption is a generalization of identity based encryption and has good applications. How to construct efficient and leakage resilient attribute based encryption is worth further study.

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# Image Specular Highlight Removal using Generative Adversarial Network and Enhanced Grey Wolf Optimization Technique

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**Abstract**—Image highlight plays a major role in different interactive media and computer vision technology such as image fragmentation, recognition and matching. The original data will be unclear if the image contains highlights. Moreover, it may reduce the robustness in non-transparent as well as glassy objects and also it reduces accuracy. Hence, the removal of highlights is an extremely crucial thing in the dome of digital image enhancement. This is to develop the enhancement of the texture in imageries, and video analytics. Several state-of-art methods are used for removing highlights; but they face some difficulties like insufficient efficacy, accuracy and producing less datasets. To overcome this issue, this paper proposes an optimized GAN technology. The Enhanced Grey Wolf Optimization (EGWO) technique is employed for feature selection process. Generative Adversarial Network is a machine learning (ML) algorithm. Here, two neural networks that will compete among themselves to produce better calculations. The algorithm generates realistic data, especially images, with great practical results. The investigational outcome reveals that the future algorithm has the ability to verify and eliminate the illumination spotlight in the image so that real details can be obtained from the image. The effectiveness of the proposed work can be proved by comparing the proposed optimized GAN with other existing models in highlight removal task. The comparison outcome gives better accuracy with 99.91% compared to previous existing methods.

**Keywords**—*Highlight detection; optimization; specular highlight detection; GAN*

## I. INTRODUCTION

Image spotlight is a mutual factor in this physical biosphere, frequently an illumination is produced when the light contacts the material surface [1]. The highlights can easily damage the quality of the target image owing to the combined effect of the sunlight and the target's surface's physical characteristics. The flow and strength of the illumination will be determined by objective's category and

dye, and also the reservation among the external area and the source of light [2]. Due to these highlights, the brightness of the image will be reduced in a sliding window and it frequently causes some unwanted discontinuities in the diffused part of the object [3]. Moreover, it will not provide true details of the image. To overcome this difficulty, a highlight removal method is introduced. The elimination of image spotlight is a major difficulty in supercomputer illustrations, computer visualization, and so on. Meanwhile, it delivers valuable info for some solicitations [4]. Because of two motivations. Firstly, it is necessary to find out the direction from where the light will be reflected. Secondly, eliminating the consequence from high spot will have the ability to improve the execution of various visualization tasks, like object recognition, essential image disintegration, and tracing.

Nevertheless, various methods have been recommended to find and repair specular reflection affected areas that rely on the evaluation of fixed images [5]. Due to this, the specular highlight may use high-level contextual cues to reduce uncertainty in areas with transformer module, thereafter the detection and correction of specular highlights from transmissive materials are more challenging and not forthright, especially when the geometry of the object is unknown. Therefore, the highlighted extracted method includes multi-scale data to identify regions with various level of highlight intensity. The estimated intensity ratio of the previous highlight removal method is used to relate the modifications among the diffused and specular replication modules then it enables the elimination of spotlights from a sole image. Hence, the standardized weighting mechanism is used to reinstate the fringe pattern in the illuminated zone whereas the highlight removal cannot be consistent between images from different viewpoints [6].

The occurrence of high spot drives a thoughtful influence on numerous features of invention. The furthestmost mutual influence is that the spotlight will convey sound and intrusion to the new image, thus the specularly on all images will be reduced, and it creates a new region with an aware of highlight image creation model [7]. Once associated with the translation tasks of additional image, the image that containing the spotlight and the dispersed image will display a heavy amount of resemblance. These resemblances in them are equal, and are different only in rare emphasized zones and gives unfortunate outcomes in argumentative workout. Hence, to carry out the issue occurred by the resemblance, an autoencoder is placed in front of the attention component, where the replication intensity of each pixel in the highlighted images is predicted by highlighted concentration cover [8].

The active rank of an image can be obtained from various ideas of image detector and the active rank is defined as the proportion among the minimum and major value that are recorded or depicted on the display [9]. Capturing image sequences with different exposure periods, provides a well-exposure all through the object surface to deal with the issue of consequent saturation. Thus, certain circumstances or expectations have the capability of enabling content analysis-based solutions. The picture element analysis based on later methods can be considered as the shiniest pixels as the high spot, that disposed to untrue recognition of spotlight and the regions with unclear white regions are developed under chromaticity analysis. Hence, the solicitation of vigorous detecting approaches cannot safe the renovated info in the current highlighted regions as the bright illumination is returned in the reflective path instead of sprinkling towards the instrument.

Projecting uniformity image patterns onto the surface underlying featureless objects has traditionally been used as a reconstruction technique to get remote sensing data. But specular reflection creates highlights, projection over these areas could result in saturation of the image through overuse [10]. The features of the estimated design continue to pose multiple problems, which have been discovered to influence the outcomes of the reconstruction. Under photometric calculations, the connection amongst the image illumination and exterior depth are used to enable this renovation. Even so, it is an under-confined difficulty; expectations are computed stronger for the features of the dispersed replications. To handle specular surfaces, a reflectance model is introduced. It describes the bond among the replicated brightness and exterior depth under an orthographic camera estimation hypothesis.

In the field of image synthesis, the Generative Adversarial Network(GAN) already has tremendous success [11]. The GAN's aim is to evaluate a set of training examples to discover the probability distribution. Generative Adversarial Network has the capability to create new examples from the estimated probability distribution. To eliminate the highlights, this paper offers a novel based GAN method for dealing with problems. In other words, the removal of specular highlights is an image-to-image transformation among the diffuse area and the highlighted area.

The key contribution of the paper is briefed as follows:

- At first, images with heavy quantity of highlights are collected and handled in this process.
- Moreover, the impulsive noise that exists in the grey scale image can be filtered by the Wavelet Decomposition Anisotropic Filter (WDAF).
- The segmentation process employed in this paper is K-means clustering and is utilized to find the groups in the unlabelled data.
- The feature selection process is carried out by the Enhanced Grey Wolf Optimization (EGWO) process to improve the hunting strategy of the wolves.
- Feature extraction process is done by Gray-Level Co-Occurrence Matrix (GLCM) algorithm; this will reduce the unwanted data from the dataset.
- The Generative Adversarial Networks (GAN) is used to notice the emphasized area from the image.
- Finally, the highlights in the image can be eliminated by Structure texture layering Algorithm
- The concluded method's success has been recognized and contrasted to other approaches to prove its better in accuracy and efficacy.

The remaining of this study is divided into the resulting sections as follows: Section II exposes the relevant works are done from a thorough analysis. Problem statement is discussed in Section III. The particulars of EGWO-GAN explored in Section IV. Under Section V, the outcomes of the experiment are reviewed and provided exactly. Section VI is the conclusion of the paper.

## II. RELATED WORKS

Su et al. [6] discussed that the Lightweight optimization technique is employed for eliminating the issues in multi-view digital image. The highlights can be removed by assumptioning the estimation of illumination chromaticity, and it carries out the orthogonal subspace projection. The method provides a practical feature which doesn't requires image reflectance priors. A Ground truth dataset is employed to establish the demonstration of the process. The paper reveals that the accuracy and robustness is more effective when compared to the existing method. The paper doesn't explain that how a single phased image could be taken from multi view facial images.

The removal of specular spotlight in colour images play a title role to enable numerous hypermedia and supercomputer visualization tasks revealed by Wu et al. (2022). Here the details of the Ground truth illuminated images are furnished and the images that photographed are real world objects. The dataset used here is Paired Specular Diffuse (PSD) dataset. Here an organic lattice is used to deteriorate the illumination in the assumed sole image and it uses GAN network Without requiring an explicit assessment the network functions the consideration mechanism to represent the mapping relationship among the diffused area and the illuminated area.



The detection result of the specular highlight will be lesser. High specular and specular on metal materials are not explained in this paper.

Under computer vision technology the Non-destructive surveying mechanism strictly improved the investigation of fresh fruit quality revealed by Hao, Zhao, and Peng [12]. During image acquisition specular highlight easily affects the fruit that has soft surface and small texture. The illuminated highlight that appears on the body of fruit will strongly affect the standard inspection. To solve this issue, a specular spotlight removing mechanism is used and it's founded on the basis of multi-band polarization imaging technique. The image at real time is realized first by developing a new multiband polarization imager. Secondly, a combined multi-band-polarization habitual vector is utilized to check whether the illuminated highlight was removed. Then the illuminated highlight was removed by separating ergodic least-squares combined with a Max-Min multi-band-polarization strategy. At last, the missed particulars are retrieved by chromaticity consistency. The suggested method will eliminate the spotlight strongly and gives an improved exchange among precision and complexity when compared to the existing method. The paper doesn't give a brief explanation about strong picture quality and unbiased estimation indexes.

Fu et al. [1] states that the highlight detection is the basic and difficult task in today's image processing field. Recent method provides a clear result by practicing two processes on artificial training facts in a controlled mode for detecting and removing highlights. A novel network is used to remove the illumination spotlight. Then a dataset with 16K real image is introduced first to reject the domain area among artificial preparation prototypes and actual investigation images and also for helping the learning-based methods. Investigation result declares that the future work is faraway enhanced than the previous technique. The study does not explain about the highlight colour evaluation model. ElMasry, Gou, and Al-Rejaie [13] disclosed that the illumination or highlight trouble arose in radiometric images, the reflecting variation will be obtained from its real value, and it hides severe problems in food products or detect heavy negative issues may cause breakdown in the investigation and verification processed. According to a non-repetitive model, the multicolour dispersion type and Principal Component Analysis (PCA) were identified and removed by specular highlight objects. The method gives effective results on hyperspectral and multispectral images; it strongly reduces the oddity and effectively increases the excellency in the illuminated data. The investigational outcomes give that the suggested technique along with PSNR will give better results. The robustness is not explained briefly here.

The specular highlight spotting and elimination are the main difficulties in computer vision technology and image visualization said by Wu et al. [14]. Deep learning model is used as the proposed method here to find and deteriorate the specular spotlight in a sole image. The specular highlight is verified using encoder and decoder web. Unet-Transformer network is used to remove highlights. Spotlight investigation pattern is used as a cloak to train the rejected work. Both the networks can be guided in a powerful mode. The feature

texture is poor here. The result should become more effective in public benchmark and real-world images when compared with previous method. The study about dataset is not discussed here. Huang, Hu, and Wang [15] disclosed that a novel uniformity framework method is introduced here to detect and remove highlights in pretended images, facial images, verbal images and organic images. Three main components are used. They are spotlighting characteristic ejected component, spotlight coarse rejected component, and spotlight filter rejection component. The spotlighting characteristic ejected component will divide the highlighted and non-highlighted image from the real image. Then the removed spotlighted image is re-obtained from spotlight coarse rejected component and the spotlight filter rejection component is gained by contextual spotlight attention mechanisms. The proposed work will gain better visual effects. The facts about real textures are not explained clearly here.

The organized bright prediction is broadly employed in 3D outline dimension revealed by [16]. Here the fringe surface is covered completely and huge reflective surfaces are affected by uneven spotlights. A polarization-based algorithm, is introduced to solve uneven illumination. By using this algorithm, the SNR of the polarized image is developed and the spotlights are removed. The centralized weighting algorithm is used to resave the surface knowledge in highlighted domain. The project result proves that the SNR of polarization figure is developed with the help of the proposed algorithm. The result proves that the fringe module is restored. The study does not explain about the saturated components. Modern high spot elimination procedures couldn't semantically distinguish among all-white or near-white resources on the external face of smooth liquor bottles discussed by Guo et al. [17]. The latest spotlight elimination processes grounded under deep learning process and it will deficit resistance in system design, ensure issues with complex training, and have inadequate objective relevance. They consequently do some jobs with less efficiency because they are unable to find and delete highlights in some tiny sample highlighted datasets. Hence, this study suggests a quick highlight removal technique that combines U2-Net and LaMa. The U2-Net is applied in the beginning of the process to detect problems. Lama is used as the core. The model is easy, efficient and simple to carry out. This proposed work provides good results than the previous method. The study about flexibility is not explained here.

Xia et al.[18] state that the specular highlights caused by laparoscopes may produces wrong visual observations, audio restoration and image fragmentation in medical and normal images. The removal of illumination from a sole image is more essential because both the normal and medical images are located in amorphous regions. Therefore, a global optimization technique grounded on a dichromatic reflection model is suggested towards controlling these issues from a sole image. The future work comprises two methods for the removal of spotlights from the image. One is for calculating the spreading of pigmentation to precise the shade and congestion in the illuminated areas and the other one uses complex optimization with double generalisation to compute

diffused and specular replication coefficients. According to the experimental findings the suggested method eliminates the illuminations from the natural and endoscopic images. A stereo reconstruction application that uses a dataset presents that the highlight reduction method may removes the RMSD of the exterior renovation truthfulness from 1.10mm to 0.69mm.

The highlight removal methods calculate and group the illuminated chromaticity value to extract diffused and specular replication constituents on or after a solitary image established under the dichromatic reproduction model said by Souza et al. in [19]. Whereas these methods can produce results that are visually appealing, their clustering algorithms either have poor setup and are too costly to perform in actual time. In this study, a high-grade of pixel grouping algorithm is proposed to eradicate the high spot from the sole image. In existing methodology, the max and min values of all the pixels are calculated. In order to suggest a successful pixel clustering method, the dissemination arrangement of those standards in a max-min chromaticity universe is examined by pseudo specular free image. In order to differentiate among diffuse and specular components, the intensity ratio is estimated for each cluster. To apply the method on CPU and GPU frameworks an optimization technique is suggested. When using only the CPU, the investigational outcomes shows that the proposed method is not only faster than the state-of-the-art method but also more accurate. Therefore, the existing previous technique can eliminate specular highpoints from a 4K image with a resolution of 3840 by 2160 in just 24 milliseconds when using the GPU.

One of the supreme essential study questions in supercomputer visualization and computer graphics is how to eliminate specular highlights from an image discussed by Fu et al. in [20]. Several techniques have been established but they generally won't operate fit for actual images because of the attendance of composite resources, solid shades, rich textures, constrictions, and hue enlightenment, among other factors. This paper introduces an original spotlight reduction mechanism to eliminate the highlights. The technique is constructed on two findings: (i) the specular highlights are frequently small and thin in dissemination; and (ii) the enduring turgid images can be characterized by an undeviating amalgamation. An optimization framework is created for the observation of the turgid and illuminated images from a sole image. The diffusion mechanisms are restored by boosting the sparseness of the encrypting factors via the L0 norm. According to the illumination definition, the additive colour mixing theory, the encrypting factors and the illumination that focuses to non-negativity. Extensive researches on a variety of images have proven the efficacy of the future work and its advantage above the earlier approaches.

Facemask spotlight elimination methods object to increase image eminence and simplify responsibilities like surface reconstruction and verification by removing the specular highlight from facial images said by Z. Wang et al [21]. However, earlier learning-based methods frequently fails when applied to images from the real world because their simulations are frequently qualified on combined artificial or test site images owing to the necessity of combined

preparation information. As an alternative to these techniques, the spotlight elimination system is suggested, which is performed on an artificial dataset then finetuned on the unpaired rough imageries. To accomplish this, a spotlight cover supervision training method is proposed that allows Generative Adversarial Networks (GANs) to train a highlight removal network utilising real-world image. In spite of the fact, nearly every image is taken in the rough embrace under certain areas, have found that even small areas without highlights can deliver valuable info for the process of removing illumination. This stimulates to create a region-based discriminator that can differentiate between the highs and lows in a facemask image and habit it to improve the originator. According to the experimentations, the approach yields result that are of a higher calibre than those produced by contemporary highlight removal methods.

### III. PROBLEM STATEMENT

Lightweight Optimization (LWO) based on machine learning technique that clears the problems in the earlier studies and it is used for identifying and graphing the highlights in the image [6]. It will not provide correct data because the computational complexity is poor here and this will affect the image quality. It will reduce the network parameters and computational complexity. Therefore, for achieving clear and good results machine learning (ML) based Generative Adversarial Network (GAN) is used. For removing the highlights from the image and to provide higher accuracy and better complexity, an Enhanced Grey Wolf Optimization (EGWO) method is utilized here and it will also reproduce the behaviour of grey wolves in a helpful way.

### IV. METHODOLOGY

The planned technique is charted in Fig. 1. Enhanced Grey Wolf Optimization based Generative Adversarial Networks is utilized for this process. There are many datasets presented and they are used for training and testing purpose and this process uses Kaggle dataset to discuss about the data and to find the accurate coding for the data etc., The images that contain highlights are exposed to pre-processing technique to reduce the noise in the image. Similarly, the recognized EGWO-GAN method is utilized to label the image high spot and its classifications. Moreover, it is utilized to achieve a greater accuracy worth. Henceforth the accepted method considers and then it labels the highlights in the image.

#### A. Data Collection

The dataset used for the testing and training process is Kaggle dataset. Approximately 10,000 dataset imageries with high spots have remained together and castoff in this research. From that image 50% (5000) of imageries were selected for training data and 50% (5000) of imageries were selected for testing data [22]. It holds 48-by-48-pixel grayscale images. The pixel section comprises a string in each picture. The training group covers 28,709 representations. The test group covers 3,589 representations.

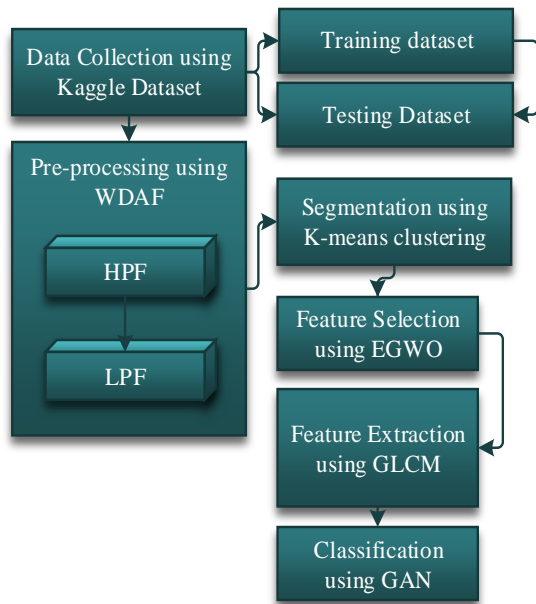


Fig. 1. Proposed EGWO-GAN technique

### B. Pre-processing

Lately, filtering by image reinforcements has increased the importance for noise elimination [23]. Though, to verify the reflected region in the image, a pre-processing technique has been introduced. Pre-processing will reduce the noise in the image. Some appearance of accidental symbols and unevenness in radiance and hue of the appearance is titled as noise. It is very important to remove the noise because the noise in the image will affect the quality of the image. So many filters are used to remove noise. Under this study, Wavelet Decomposition Anisotropic Filter (WDAF) is used for decreasing or eliminating the impulsive noise from the grey scale images. The filter is very effective in identifying peak noises from the image. The functionality, time complexity, and relative performance of these filters are compared for better performance. Henceforth, the attained noiseless images are applied in the EGWO-GAN model to eliminate the high spot from the image.

The difficulty in discrete time is given in Eqn. (1),

$$m[k] \times n[k] = \sum_{y=-\infty}^{\infty} m[y]n[k - y] \quad (1)$$

where,  $m[k]$  and  $n[y]$  are denoted as the illustrations of the intake image, while  $n[k]$  and  $n[k - y]$  is denoted as the illustrations of compulsion reaction.

Alteration of wavelet breakdown to high and low pass indications is assumed in Eqn. (2) and Eqn. (3),

$$jhigh[y] = \sum_k m[k] h[2y - k] \quad (2)$$

$$jlow[y] = \sum_k m[k] n[2y - k] \quad (3)$$

where,  $jhigh[y]$  and  $jlow[y]$  are the illustrations of the outlet gestures,  $h$  is represented as the half band high pass filter and  $n$  is represented as the half band low pass filter.

The divergence function is given in Eqn. (4) and the anisotropic function is given in Eqn. (5),

$$\partial gi(x, y; k) \partial h = div[f(x, y; k) \nabla gi(x, y; k), \quad (4)$$

$$n(k) = \frac{1}{1+(f/\lambda)^2}, \quad (5)$$

$div$  is denoted as the divergence operator,  $gi$  is represented as the diffusion coefficient,  $g(x, y)$  is noted as the image with coordinates  $(x, y)$  at period  $k$ ,  $\nabla$  is a inclined operator,  $k = |\nabla g|$  and  $\lambda$  is the inception of inclination magnitude.

The conservative anisotropic filter presents a stairway result to strained images, so, the dispersion constant to the conservative anisotropic dissemination filter has been introduced in Eqn. (6),

$$EAD = div[f(x, y; k) \nabla gi(x, y; k) \times \left[ 1 - \frac{1}{1+exp(-g(p^2 * p_0^2) - \alpha(\frac{p_0^2}{p^2}))} \right] \quad (6)$$

Finally, WDAF is given in Eqn. (7),

$$W_{WDAF} = jhigh[y] + jlow[y] + EAD \quad (7)$$

### C. Segmentation using K-means Clustering

A segmentation mask is formed for all samples, it structures the similar ellipse with white colour on a black background [24]. Numerous investigation instructions consume advanced segmentation methods under the basis of grey scale image. The present work will utilize the potential of colour image segmentation approach using K-means (KMC) clustering algorithm. This procedure is used for removing the entirely highlight affected areas.

The process of converting unidentified dataset information into various cluster particles is the main aim of the K-means clustering procedure [25]. This will solve the problems that coming under clustering or data science. The main importance of this clustering is that it will give a guarantee to convergence. It will give a smooth starting to the directions of the centroids. This algorithm figures the centroids and repeats till finding the correct centroid. It will simplify the clusters with different shapes and sizes.

The highlighted image that contains the spatial coordinates to resolve  $i*j$ , then the images should be assembled to form the  $k$ -clusters. Consider  $h(i, j)$  as the information pixel and  $P_k$  is specified as the function that focuses the group of the  $k$ -cluster. The K-means clustering algorithm has some of the following procedures and are given step by step [26],

Step 1: The centre and the cluster  $K$  must be determined.

Step 2: The Euclidean distance  $E_d$  is specified for every pixel and is expressed in the Eqn. (8).

$$E_d = ||h(i, j) - P_k|| \quad (8)$$

Step 3: All the pixels are allocated to the centre point under the basis of  $E_d$ .

Step 4: By ensuing the task assigned to all the pixels, the new centre positions are re-computed by Eqn. (9)

$$Pk = \frac{1}{k} \sum_{j \in Pk} \sum_{i \in Pk} h(i, j) \quad (9)$$

Step 5: Repeat the procedure till the condition met.

This algorithm possesses some difficulties because it has several more characteristic processes. The voluntary option for the initial centroid is more important for the clustering process. When the necessary centroid is psyche-assuredly selected, some different outcomes are produced for the centres that are necessary for the clustering. To achieve the wanted separation, important centres should be chosen exactly. When using K-means clustering, the computational complex eminence must be taken into attention whether it has infinite quantity of data parts, numerous groups and quantity of sequences. The usage of K-means clustering algorithm for the separation of image frequently comes under the basis of topographies. The outcome of the process of removing highlight is secluded into K-numbers that is used by the soul. The major difficulty of this method is if the dimension of K grows, the method will slog against us. As a consequence, if the sections grow bigger, it is more difficult to discover the affected parts. If the valuation of K reduces, it will speed the mixture of some regions that have undesirable influence on the exactness of image parting.

#### D. Feature Extraction using GLCM

The procedure of converting initial facts obsessed by arithmetical characteristics may be treated although maintaining the evidence in the unique form is recognized as feature extraction. Features are elements of information that are pertinent for dealing with particular applications and for illustrating important aspects of pictures [27]. When compared to machine learning, it produces superior results. Feature extraction helps in reducing the redundant data from the dataset. This paper uses a Gray-Level Co-Occurrence Matrix (GLCM) for the feature extraction process.

Under feature extraction, the foundation data is transformed into arithmetical topographies deprived of constructing any changes in the odd datasets and its characteristics is based on its pixel. For eliminating the statistical texture feature from the image, it uses some functions like correlation, energy, homogeneity, contrast, entropy, etc. are estimated as second-order image individualities.

1) *Correlation*: Correlation value designates the resemblance of texture of the image in two orthogonal directions specifically the horizontal and vertical directions. It is given in Eqn. (10),

$$C_{\text{correlation}} = \sum_{x,y=0}^{K-1} M_{xy} \frac{(x-\mu)(y-\mu)}{\sigma^2} \quad (10)$$

2) *Energy*: Energy is well-defined as the summation of squares with grayscale standards that are frequently higher and require unreliable concentrated values in images. It is given in Eqn. (11),

$$\text{Energy} = \sum_{x,y=0}^{K-1} (M_{xy})^2 \quad (11)$$

3) *Homogeneity*: It defines the likeness of pixels. The value of GLCM medium of consistent copy is given as 1. The

GLCM medium should be very stumpy to get least altered image texture. The homogeneity is given in Eqn. (12),

$$\text{Homogeneity} = \sum_{x,y=0}^{K-1} \frac{M_{xy}}{1+(x-y)^2} \quad (12)$$

4) *Contrast*: Features are hand-me-down to extent the resident dissimilarity of an image, and it is forecasted to be small in the even concentrated values. The creative image's entire grayscale content is then estimated in Eqn. (13),

$$\text{Contrast} = \sum_{x,y=0}^{K-1} M_{xy} (x-y)^2 \quad (13)$$

5) *Entropy*: The randomness of the image will be calculated by entropy and it will produce lower entropy values. It is given in Eqn. (14)

$$\text{Entropy} = \sum_{x,y=0}^{K-1} -\ln(M_{xy}) M_{xy} \quad (14)$$

#### E. Feature Selection using Grey Wolf Optimization

While emerging an analytical model the input variables are reduced by feature selection process. The number of input variables is lowered by this process while creating an analytical model. In certain cases, while dropping the computational cost and contribution variable of the model, the execution process will be improved. The recognition of highlights in the image has been executed by a method known as Enhanced Grey Wolf Optimization (EGWO). Its standard is to make a replica of the behaviour of grey wolves to quest in a supportive method. The EGWO will improve efficiency and accuracy. EGWO is dissimilar as of others in conditions of traditional arrangement [28]. The most informative features are chosen using the EGWO. The EGWO is meant for resolving universal enhancement and engineering design complications. Thus, the method undergoes two major changes to the EGWO. Firstly, the intelligent initialization phase, which creates the population by using the data since the filter-based method. Secondly, the implementation of the Extreme Learning Machine is used as the vile sorter to deal with the greater difficulty [29].

GWO is scalable, adaptable and simple to use. In the framework of search process, the algorithm gains a balance between utilization and investigation that generates an outstanding resolution [30]. Engineers and scientists who work in a variety of disciplines have consequently grown fascinated towards the GWO. When compared to other optimization techniques GWO is the strongest and fastest algorithm.

The GWO algorithm follows the grey wolf's group dynamics and hunting tactics. The four wolf varieties that make up the leadership sequence are  $\alpha$  (the acceptable),  $\beta$  (the second-fittest),  $\delta$  (the third-fittest), and  $\Omega$  (the left particulars of the aspirant resolutions). The procedure additionally includes three primary killing techniques of pursuing, encircling, and hitting targets.

Grey wolves enclose their prey and trudge during hunting; this is identified in the following Eqn. (15),

$$\vec{A} = |\vec{F} \cdot \vec{Y}_k(u) - Y(u)|$$

$$Y^{\rightarrow}(u + 1) = (Y_k)^{\rightarrow}(u) - C^{\rightarrow} \cdot A^{\rightarrow} \quad (15)$$

The subsequent connections are used to alter the geographical positions of different wolves that search using data from alpha, beta, and delta under Eqns. (16), (17) and (18),

$$\left. \begin{aligned} \vec{A}_\alpha &= |\vec{F}1 \cdot \vec{Y}_\alpha - \vec{Y}| \\ \vec{A}_\beta &= |\vec{F}2 \cdot \vec{Y}_\beta - \vec{Y}| \\ \vec{A}_\delta &= |\vec{F}3 \cdot \vec{Y}_\delta - \vec{Y}| \end{aligned} \right\} \quad (16)$$

$$\left. \begin{aligned} \vec{Y}_1 &= \vec{Y}_\alpha - \vec{C}_1 \cdot \vec{A}_\alpha \\ \vec{Y}_2 &= \vec{Y}_\beta - \vec{C}_2 \cdot \vec{A}_\beta \\ \vec{Y}_3 &= \vec{Y}_\delta - \vec{C}_3 \cdot \vec{A}_\delta \end{aligned} \right\} \quad (17)$$

$$\vec{Y}(u + 1) = \frac{\vec{Y}_1 + \vec{Y}_2 + \vec{Y}_3}{3} \quad (18)$$

Where,

u signifies the present repetition.

$\vec{A}$  displays the moment path.

$\vec{Y}_k$  designates prey's spot path.

$\vec{C}$  and  $\vec{F}$  are represented as the co-efficient vectors.

$\vec{Y}$  denotes the grey wolf's spot path.

The subscripts  $\alpha, \beta, \delta$  denote the alpha, beta and delta wolves. Therefore, to finish the quest with ending attack. The last violence is demonstrated by lowering the  $\vec{a}$  standards since 2 to zero.  $\vec{A}$  is an arbitrary value in the series of  $-2\vec{a}$  and  $2\vec{a}$ . Decreasing  $\vec{a}$  would also reduce  $\vec{A}$ . The wolves get closer to the prey if  $|\vec{A}| < 1$ . The grey wolves will keep an eye on the leader wolf and they will separate individually to find and attack their prey.

Number of Wolves (NW) and the Generation Number (NG) are the two most important factors assigned by the GWO technique. Where NW actually characterizes the purpose assessments in all group, and every group characterizes the conclusion movement of a wolf. The sum of Objective Function Evaluations (OFEs) will be equal to NG increased by NW. The determination of OFEs is indicated in Eqn. (19),

$$OFEs = N_W \times N_G \quad (19)$$

#### F. Detection of Highlights using GAN

Generative Adversarial Networks (GANs) ensured realized outcomes in image handling, and they are more prevalent in commercial and also in intellectual worlds [31]. GAN is a useful tool to instruct a particular reproductive prototype, thus the confrontational exercise among the originator and differentiator has the capability of generating realistic images. One essential presentation of GANs is model-to-model transformation. It may be implemented to a vast number of responsibilities, especially design transmission and image resolution. Further highlight removal method is included to demonstrate the legitimacy of the method. Deep illustrations can be learned without training material using generative adversarial networks (GANs). The co-existence of a generator and a discriminator that work against every adversarial process is the basic tenet of GAN. The generator intends for the distribution of the instances it produces to match that of the training set. By examining such examples and determining whether they are genuine or artificial, the discriminator learns using conventional supervised learning techniques. The originator needs to absorb how the models are taken from similar dissemination data in order to produce synthetic data that can't be distinguished from actual data [32].

An unsystematic illustration is taken from hidden place x that acts as the generator's input. The differentiator reorganizes the originator's output G(x) using a model of actual distribution. Even though the differentiator gives the importance of supplemental commitments, it will verify that the given principles are fake or genuine. In order to reduce the utility of  $\log(1 - D(G(x)))$ , the generator is trained. This instructs the generator to create pictures as the discriminator can't verify the fake in it (i.e.,  $D(G(x)) \approx 1$ ). To increase the likelihood that it will correctly distinguish between the real models ( $D(y)$ ) and the made-up models ( $D(G(x))$ ), the differentiator is additionally taught how to create the function  $\log(D(y)) + \log(1 - D(G(x)))$ . The above image explains about the architecture of Generative Adversarial Network. Various datasets are given as the input image here. After some predictions the highlights in the images will be removed. Fig. 2 shows the Architectural diagram of the Generative Adversarial Network.

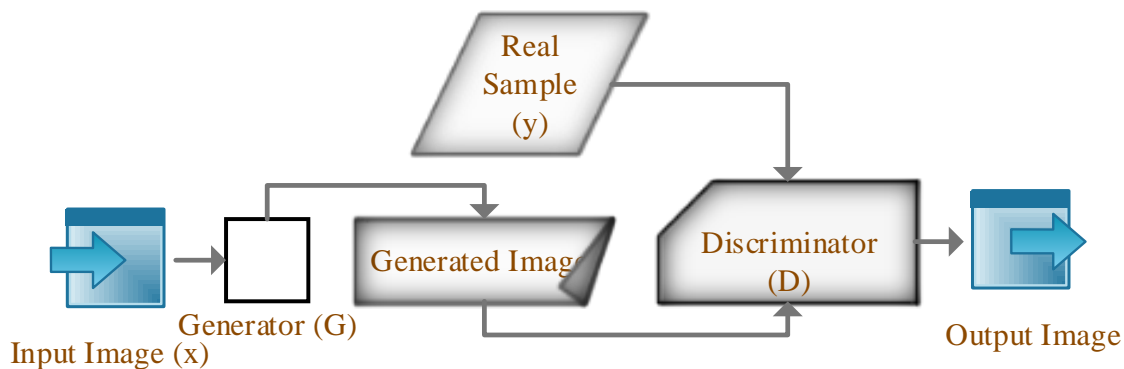


Fig. 2. Architectural diagram of generative adversarial network.

1) *Creation of artificial data using GAN*: The generator and discriminator are designed as multiple perceptions with layers in the initial GAN structure. The procedure continues by picking a fixed-length vector at random from the Gaussian distribution. The generator then receives vector as input, and it acts as an arbitrary seed for the generative process. A data distribution has been projected into the vector space, also known as the tucked space. The GAN will enable the originator to investigate how a quantified inactive galaxy allocates consequence to fundamentals, how to allow it to accept new concepts from the inactive space for the contribution, and how it creates new output from the input that is already available. The Contribution blast is also auxiliary to the originator because it enables the GAN to produce an extensive range of samples commencing various locations within the target distributions and the algorithm permits the GAN to produce a broad range of data. The discriminator functions as a classifier and forecasts as a binary class label for an unidentified model from either the originator or actual preparation data. The training module is determined as follows in Eqn. (20),

$$\min_G \max_D K(D, G) = E_{y \sim Q_{data}(y)} [\log(D(y))] + E_{x \sim Q_x(x)} [\log(1 - D(G(x)))] \quad (20)$$

Here,

x is denoted as the input of the image.

D is the represented as the Discriminator.

G is the generator.

E is the Expectation operator.

y is denoted as the real samples.

#### G. Elimination of Highlight using Structure Texture Layering Algorithm

After the detection of highlights, it can be removed using a highlight removing technique. This paper uses Structure texture layering algorithm to eradicate the high spot from a sole image [33]. An integrated mechanism is conveyed simultaneously to tackle the removal of reflection and artifact destruction. Here, the unique input image is divided into two strata, namely, the structure and the texture layer. Any image can be considered as contrasted and nested collection of dark and light objects it only appears in a particular range of resolution is defined as the structure. Whereas, the brightness intensity of the pixels spatial fluctuation is used to determine the texture. The modification amongst the input image and the x and its structured layer  $x_S$  is calculated using the Eqn. (21). The formulation used for the total variant image restoration is based on the relative total dissimilarity measurements and a soul object generates the illusion of eradicating the texture stratum from the image is given in Eqn. (22)

$$x_T = x - x_S \quad (21)$$

$$\min_S \sum_k ||S_k - x_k||^2 + \lambda \left( \frac{\sigma_i(k)}{\delta_i(k) + \epsilon} + \frac{\sigma_j(k)}{\delta_j(k) + \epsilon} \right) \quad (22)$$

Where,

x is the input image.

$x_T$  is the texture layer.

$x_S$  is the structure layer.

S is the structure image.

K is the 2D pixel.

$(S_k - x_k)^2$  is used to define the structure that is comparable to those of the input image.

$\sigma_{i(k)}$  and  $\sigma_{j(k)}$  is strong-minded as the windowed total variation in i and j direction from the pixel k

$\delta_{i(k)}$  and  $\delta_{j(k)}$  is determined as the windowed inherent variations

$\lambda$  is denoted as the weight

The algorithm of EGWO-GAN is given below and followed by that the flow diagram of the proposed EGWO-GAN is shown in Fig. 3.

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#### Algorithm for EGWO-GAN

---

**Input:** Image containing highlight

**Output:** Highlight detection in hyperspectral images

Load data for provided images

$X = \{X_1, X_2, X_3, \dots\}$

//Data Acquisition

Image Pre-processing

//Wavelet Decomposition Anisotropic Filter

$W_{WDAF}$  is given in Eqn. (7)

Image Segmentation

//K-means clustering

Identify the number of K clusters for assigning

Specify Euclidean distance  $E_d$  for each pixel using Eqn. (8)

Allocate all the pixel to the centre point under  $E_d$

After assigning the tasks, new centroid points are re-computed using Eqn. (9)

Do the process till it reaches the correct criteria

Feature Extraction

// Grey-Level Co-Occurrence Matrix

Feature Selection

//Grey Wolf Optimization

Feature Selection is given in Eqn. (19)

Encircling prey

Knowledge of alpha, beta, delta wolfs

Getting closer to the prey

Seeking and attacking the prey

Setting parameters for representing NW and NG //

Objective Function Evaluation (OFE)

Detecting image highlights

//Generative Adversarial Network

The highlights in the images are detected using Eqn. (20)

Removing image highlights

//Structure texture algorithm

The highlights in the images are removed using Eqn. (22)

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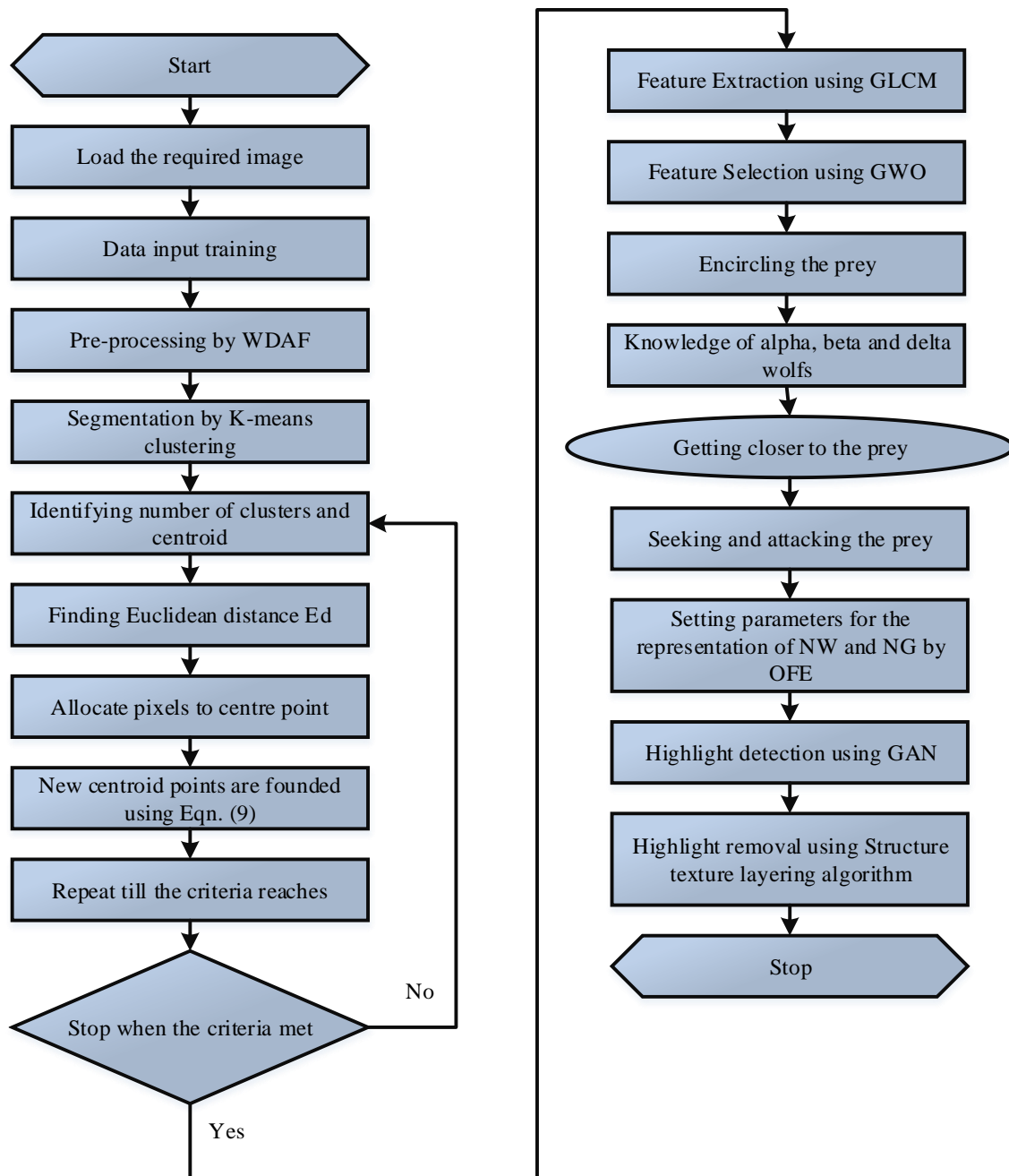


Fig. 3. Workflow of EGWO-GAN model.

## V. RESULT AND DISCUSSION

The proposed method has been examined by some datasets. The Enhanced Grey Wolf Optimization based Generative Adversarial Network is utilized to eliminate the highlights in the image. The input image is taken and pre-processed using WDAF. Then, the segmentation process is done by k-means clustering process. Then the feature is extracted using GLCM. After that the feature selection is done by GWO. After that the highlighted part is detected using GAN. Finally, the highlight spectral is removed using structure texture layering algorithm.



Fig. 4. Initial input image.



Fig. 5. Processed output image.

Fig. 4 shows the initial input image with specular highlights and Fig. 5 shows the processed highlight detected image.

The planned method can be compared using some parameters like Accuracy, Precision, Recall, F1-score.

#### A. Performance Metrics Evaluation

1) *Accuracy*: The accuracy may be defined as the proportion of properly classified illustrations. Accuracy is expressed in Eqn. (23),

$$\text{Accuracy} = \frac{T_{\text{Positive}} + T_{\text{Negative}}}{T_{\text{Positive}} + T_{\text{Negative}} + F_{\text{Positive}} + F_{\text{Negative}}} \quad (23)$$

2) *Precision*: The ratio of suitable examples between the obtained incidences is known as precision or positive prediction value. Precision is computed from Eqn. (24),

$$\text{Precision} = \frac{T_{\text{Positive}}}{T_{\text{Positive}} + F_{\text{Positive}}} \quad (24)$$

3) *Recall*: The proportion of the applicable occurrences that is returned is termed as recall or sensitivity. Recall is uttered in Eqn. (25),

$$\text{Recall} = \frac{T_{\text{Positive}}}{T_{\text{Positive}} + F_{\text{Negative}}} \quad (25)$$

4) *F1-score*: The weighted average of the image augmentation measurements, compared between 0 and 1 is used to estimate the score function. It is signified in Eqn. (26),

$$\text{F1 - score} = \frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \quad (26)$$

Table I and Fig. 6 show the comparison and performance evaluation of Accuracy, Precision, Recall and FI-score. When comparing those parameters with the following three existing methods, i) Exemplar-based inpainting algorithm ii) Intrinsic image layer separation method iii) Computer aided diagnosis algorithm, the proposed EGWO-GAN algorithm produces greater accuracy (99.91%), greater precision (97.92%), greater recall (97%) and greater score function (96.5%).

TABLE I. COMPARISON TABLE OF ACCURACY, PRECISION, RECALL, FI-SCORE

Method	Accuracy (%)	Precision (%)	Recall (%)	FI-score (%)
Exemplar-based inpainting algorithm [34]	98.49	75.75	88.69	81.71
Intrinsic image layer separation method [35]	99	59	71	64
Computer aided diagnosis algorithm [36]	90.6	92.8	86.7	89.7
Proposed EGWO-GAN algorithm	99.91	97.92	97	96.5

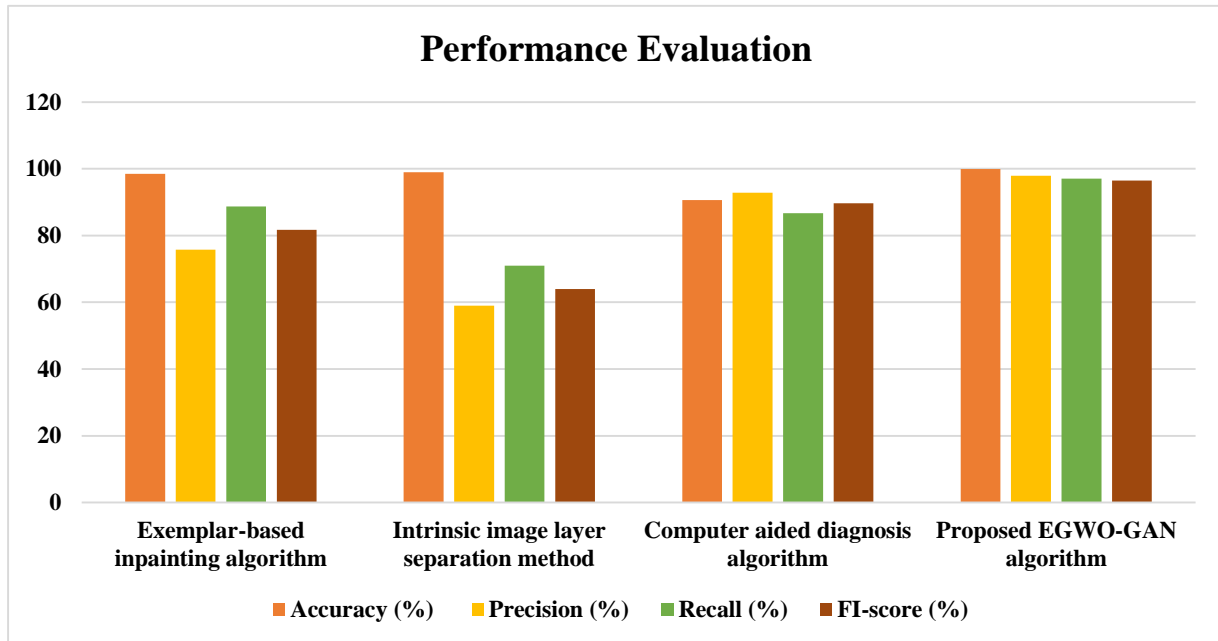


Fig. 6. Performance comparison chart for Accuracy, Precision, Recall and FI-score.

## B. Discussion

Comparing the suggested EGWO-GAN approach the previously used highlight removal techniques like Exemplar-based inpainting algorithm, Intrinsic image layer separation, Computer aided diagnosis algorithm in Table I results in greater efficiency. The accuracy of the Enhanced GWO based Generative Adversarial Network is higher than that of the performance measured using EGWO and GAN separately. By using this EGWO-GAN model the accuracy level reached is 99.91%. This indicates that the EGWO based GAN will reduce the highlights from the hyper spectral image.

Table I inclines the evaluation outcomes of different algorithms that are based under the Kaggle dataset. When comparing with various approaches the value of Accuracy, Precision, Recall and FI-score in the planned techniques illustrate healthier results. When comparing the accuracy of the proposed method with [35]'s accuracy, the planned method is (0.91%) higher than [35] and lower than [36]. Then, the planned method is better in precision of about (5.12%) when compared to [36]'s precision and the precision is less than [35]. Furthermore, the recall of the proposed method is very much higher (8.31%) than [34]'s recall and lower than [35]. The score function of the proposed method also provides (7.5%) higher score function than that of [36] and provides lesser score function than that of [35].

In this work, K-means clustering is cast-off for the separation process. It will convert the nameless dataset information into various cluster elements. When comparing to the previous techniques, the highlights cannot be removed easily because the hyperspectral images contain heavy noisy particles and the exact particulars are also unclear. The parameters of accuracy, precision, recall and score function of the suggested method gives healthier outcomes than the existing approaches. This will also provide greater efficiency.

## VI. CONCLUSION AND FUTURE WORK

Image processing is one of the latest resources in the domain of hyperspectral photography. But in some circumstances the images will be unspecified due to noise. Therefore, to classify, identify and to divide the planned technique highlight removal process is emphasized. Various datasets are used to detect highlight in the image. To remove the unwanted noise from the hyperspectral images a Wavelet Decomposition Anisotropic Filter (WDAF) is used in the pre-processing stage. Then the Gray-Level Co-Occurrence Matrix (GLCM) in the feature extraction process will determines exactly how frequently a combination of pixels with a particular value appears in the image while defining an image's characteristics. Moreover, the proposed method, Enhanced Grey Wolf Optimization based on the Generative Adversarial Network (EGWO-GAN) is employed to separate the highlighted spots from the hyperspectral images. Improved recognition and estimated accuracy also investigated using this EGWO-GAN process. Then the highlighted region is removed using Structure texture layering algorithm. Finally, the estimated accurateness of the technique was found to be 99.5% and the efficacy of this method is enhanced by the Generative Adversarial Network (GAN) that is based under the machine learning (ML) process.

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# Developing a Security Policy for the Use of CCTV in the Northern Border University

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**Abstract**—The use of closed-circuit television (CCTV) in universities is a challenging task due to global strong opposition to its implementation at education institutions. The ministry of higher education of Kingdom of Saudi Arabia (KSA) has initiated a plan for monitoring educational institutes across the Kingdom. Therefore, this paper proposes a new framework for developing a comprehensive security policy for using CCTV in the Northern Border University, which streamlines the implementation, usage, and securing of the CCTV footage contents. In this regard, a new policy was developed combining the principles of activity theory, international standards, and design science methodology. It considered six key elements from both theoretical and practical perspectives, namely government rules, technical aspects, training, security requirements, users, and legal issues. Based on them, a standard 12-principal policy was developed; to help organizations easily implement and evaluate the developed policy and secure the contents, the principles were classified into three categories: performance, security, and policy management. The findings showed that the implementation of the policy developed in this study not only improved the security measures of the university, but also built trust among the stakeholders due to the high internal security and effective evaluation of the surveillance system.

**Keywords**—Closed circuit television; security policy; surveillance; educational institutes

## I. INTRODUCTION

Numerous social issues are happening in the world today, including crime, robbery, and intrusion. Anyone can become a target of a crime at any time, whether it be against their body, property, or even life. Different crime-preventive strategies are developed to minimize its effects. In this regard, one of the most extensively adopted technologies is CCTV surveillance systems [1]. People are experiencing various technological developments in contemporary society, such as the use of CCTV systems in crime avoidance and public wakefulness. Most people actually trust that CCTV systems can secure them because if criminals feel that they are being viewed, they will not hazard their lives to pledge crimes or other unusual acts [2]. The fast identification and, in some cases, prevention and disruption of crime are two common objectives of all CCTV monitoring systems. The existence of a CCTV monitoring system, according to [3], instills confidence in people and lowers their crime-related anxiety. Additionally, CCTV systems offer practical corporate management tools that can be used to safeguard employees and encourage health and security efforts [4]. They also facilitate the process of inquiries, provide investigators with vital sources of evidence, and help to prove

individuals' innocence or guiltiness [5]. Furthermore, these systems can be useful in workplaces with unsuitable working conditions for production and control management. A great deal of information could be archived and studied when required.

A CCTV system can be created to match any installation situation, whether it is inside or outside, extremely visible or completely hidden, static or mobile depending on the recording position [6]. With a total of 5.9 million cameras (out of which 750,000 are placed in critical spaces like hospitals and schools), the United Kingdom (UK) is a country with one of the highest numbers of CCTV systems deployed worldwide, putting its nation the maximum-viewed one with roughly one camera for each 11 people. Airports, schools, streets, parking lots, and shopping malls all have these cameras installed. This technology's primary goal is to keep an eye on actions and prevent problems in numerous areas of individuals' lives and activities [7]. For instance, it is predicted that all state schools in the UK have operational CCTV systems to reduce violence and illegal activities [8]. CCTV cameras in educational institutions give parents and guardians the assurance that overall child safety and security is being taken seriously. Considering that a CCTV system is constantly watching its surroundings, it is one of the best applications to identify potentially risky and hazardous circumstances. In the past few years, numerous studies have been carried out in this area to identify such potentially dangerous scenarios. For instance, [9] developed a method for automatically identifying an attempted theft. The study [10] also used the CCTV network to automatically identify fires in buildings and in high-risk regions. In addition, police can use CCTV networks to identify automobiles on the road that are either stolen or have a history of criminal behavior [11]. This study aims to critically evaluate the existing studies in this domain and explore how CCTV can safeguard the students and employees' lives and working environments in the Northern Border University (NBU), Saudi Arabia. As a result, the deployment of CCTV systems in NBU is discussed from legal, cultural, religious, traditional, and technological aspects.

The situation of the CCTV deployment in a university in Saudi Arabia seems to be an important research topic from both the cultural/social and scientific viewpoints, considering what has been discussed above. On the other side, the educational institutes of the country seem to be in urgent need of more CCTV systems deployment. Social and cultural factors, especially those related to education, must be carefully considered by policymakers in order to achieve a more

balanced and successful plan. Overall, the analysis on the installation of CCTV systems in a university is innovative from both technological and social perspectives, and the conclusions could be beneficial to all educational institutes with comparable social and cultural frameworks. To achieve this goal, this paper makes multifold contributions: first, developing a new security policy containing 12 principles for using CCTV in NBU by combining the activity theory, international standards, and design science methodology; and second, categorizing the principles into three groups to be easily implemented and applicable to different educational institutes. The research paper identifies a research gap in the area of CCTV surveillance systems in educational institutions, specifically focusing on the case of Saudi Arabia. While the paper provides a comprehensive analysis of the challenges and policy recommendations for implementing CCTV systems in the Northern Border University, there is a need for further research to explore the actual effectiveness and impact of these systems on enhancing safety and security in educational settings. Additionally, future studies could investigate the perceptions, attitudes, and experiences of students, teachers, and other stakeholders regarding the use of CCTV surveillance in educational institutions, as well as its potential implications on privacy and ethical considerations. Understanding these aspects would contribute to a more nuanced understanding of the benefits and potential drawbacks of CCTV systems in the Saudi Arabian context and beyond.

The rest of the paper is organized as follows: the next section discusses the related work, followed by research methodology in Section III. Then, Section IV discusses not only the implementation of the CCTV policy, but also the practical, theoretical, and legal challenges of the policy. Next, Section V describes how the developed policy was implemented in the NBU clinic. Section VI presents the findings and discussions. Finally, the paper concludes in Section 6.

## II. RELATED WORK

As stated earlier, the literature evaluation must consider a wide range of criteria that typically play a part in CCTV deployment to achieve the study's objectives. In particular, it is important to carefully study topics such as the crime hindrance component of CCTV deployment, permissible and ethical concerns, technological limitations, and cultural and religious contexts. The purpose of installing security cameras in homes, offices, schools, and other locations is a significant query presented in this study. By using a security system, businesses may be able to protect their assets from theft and other crimes by using a solution that could be comparable to the necessity for health insurance when the person is correct. In parking lots [12], in small enterprises [13], on buses [14], in public locations [14], as well as for security and criminal detection, CCTV systems have been a popular tool for ensuring protection against unwelcome situations. Note that CCTV systems are not regarded as an innovative approach to preventing crime. Since most CCTV systems established by the government only cover and monitor public areas, they are unable to prevent physical and sexual attacks committed in private spaces; they are, rather, well known to function in open spaces. CCTV cameras in such areas have a reputation for

detecting and identifying less serious crimes such as sudden heated arguments between people. But the police usually take a very long time to respond to these incidents, and these persons are only arrested much later [15]. The success of CCTV surveillance depends heavily on the human component when it comes to its deployment. When the most modern and efficient technology is considered, surveillance systems must be taken into consideration as well. This is exactly the case when the system depends on automatic non-human workers [16]. Because of the significance of operator attentiveness and the fact that the produced CCTV models overlook the perceptual cognitive activities associated to the operator's visual monitoring, it is understandable why many CCTV models do not function as predicted. Regardless of whether you are in favor of or opposed to the use of CCTV, the validity of such a surveillance system is a continuous concern. In a number of instances, according to [17], the personal freedoms of residents have been violated in favor of the installation of CCTV systems, which have been shown to be ineffectual at reducing crime [18]. A straightforward TV monitor created by Walter Bruch and deployed in 1942 in Germany to safeguard and keep an eye on the notorious V-2 rockets is thought to be the earliest known use of the CCTV technology. However, the technique was not accepted and employed on marketable grounds in the USA until 1949 [19]. These straightforward systems were primarily implemented in sensitive and logistical military locations, but they have since been shown to be quite useful for securing both companies and public areas. To retain the data acquired, crude reel-to-reel recording devices were subsequently devised in the late 1950s for the earlier versions of these cameras that had no recording capabilities. Manually switching the magnetic tapes turned out to be a time-consuming and expensive process. The widespread availability of video cassette recordings in the middle of the 1970s, which was swiftly merged into surveillance systems and provided a new application for the cameras, can be said to have been a significant development in the history of CCTV systems. With this technology, the cameras could be installed and left to operate independently, allowing reviewers to later evaluate the material captured. This technique had a drawback because the tapes needed to be replaced frequently or rewritten. Multiplexing and digital video recording, which emerged in the 1990s, made it possible to integrate and display video signals from various CCTVs on a single monitor. This development improved the effectiveness of CCTV systems and contributed to an increase in their appeal in virtually all sorts of businesses and public spaces. Additionally, since the turn of the millennium, digital technology has advanced enough to allow digital video recorders (DVRs) to replace VCRs, simplifying and improving the usability of CCTV systems [20]. To quickly identify and maybe prevent crime and disruption is a common objective of all CCTV monitoring systems. There have also been assertions that the mere presence of a CCTV monitoring system serves to reassure the people and serve as a deterrent, lowering their fear of crime [21]. CCTV systems also offer useful corporate management features, which may be used to safeguard employees and assist health and safety programs [22]. Additionally, it aids in investigations, gives authorities an important source of evidence, and can exonerate those who are not responsible [23].



Additionally, it can be useful in workplaces with unsuitable working conditions for production and control management. Data gathered by CCTV allows for the storage and later evaluation of all information. A CCTV system can be made to match any installation situation, whether it is indoor or outdoor, visible, or hidden, static or mobile, depending on the recording position. There are 5.9 million cameras in the UK alone, with 750,000 of those cameras placed in sensitive locations including schools and hospitals. This works out to around one camera for every 11 residents of the country. These cameras are set up in parking lots, roadways, airports, schools, and retail centers. This technology's primary goal is to keep an eye on behavior and prevent problems in numerous spheres of a person's life and activities [23]. According to estimates, all state schools in the UK have CCTV systems in place to deter

crime and illegal behavior [8]. CCTV camera installations at educational facilities give parents and guardians the peace of mind that the general security and protection of their children is being taken seriously. A CCTV system's best application would be to identify potentially hurtful and risky conditions because it is constantly watching its surroundings. In the past few decades, numerous research projects in this area have been carried out in an effort to identify such potentially dangerous scenarios. The research [9] for instance, suggested a system that would automatically identify an armed burglary. The study [10] used the CCTV network in a similar way to use automatic fire detection in buildings and high-risk regions. Police can also employ CCTV networks to detect automobiles on the road that are either looted or have a history of illegal activity [24]. Table I summarizes the key literature.

TABLE I. SUMMARY OF THE LITERATURE REVIEWED IN THIS STUDY

Author and year	Title	Framework	Findings
[25]	Security and the Political Economy of International Migration	A security paradigm analyzing policy development through a case-study approach	Policymaking in the United States, Germany, France, and Great Britain, four leading industrial states
[26]	Redrawing the line: Borders and security in the twenty-first century	Framework to monitor border security	Attempts to limit territorial access and border security
[27]	Airport screening, surveillance, and social sorting: Canadian responses to 9/11 in context	Framework to monitor airport conditions	The creation of a coordinated plan under the new Canadian Air Transport Security Authority, together with the use of Advanced Passenger Information (API) and the Passenger Name Record (PNR) as tools for tracing travelers (CATSA)
[28]	Security is coming home: Rethinking scale and constructing resilience in the global urban response to terrorist risk	Monitoring urban security to minimize terrorists' attacks	Worldwide urban resilience to terrorism threat
[29]	Surveillance, security and social sorting: emerging research priorities	Surveillance and security measures for social sorting	This framework has been examined and criticized for its impact on governance in general and civil liberties in particular.
[30]	China on the edge: China's border provinces and Chinese security policy	Security policy for Chinese frontiers border.	As a result, the country developed a security policy, a minority policy, and a border management policy.
[31]	European foreign and security policy: states, power, institutions, and American hegemony	European foreign and security policy	The actual making of foreign policy in institutions for security.
[32]	Using a deep convolutional neural network and surveillance cameras, scalable flood level trend tracking	Framework for Flooding control in Urban areas	This method is flexible and can be used in situations such as floods and different surveillance camera models without requiring on-site camera calibration.
[33]	Integrating the procedures of reporting port security incidents and the follow-up investigation to build a national maritime security policy: a case study in Mexico	National maritime security policy	To enhance port security measures in urban countries to report incident and follow the investigation
[34]	Pedestrian detection for advanced driver assistance systems using deep learning algorithms	To recognize pedestrian for advanced driver assistance systems using CNN	This technique is used in many applications such as surveillance. Advanced robotics, intelligent vehicles, advanced drivers Assistive Systems (ADAS)
[35]	The Making of Post-Socialist Citizens in South Korea?: The Case of Border Crossers from North Korea	Border Security from North Korea	Aims to capture the complex process through which former socialist North Koreans are remade as South Koreans.
[36]	An analysis of video Surveillance technology	Automated monitoring systems using cameras to monitor their surroundings.	The qualities, benefits, and drawbacks of various existing surveillance systems were compared, and the results are given in this study.
[37]	Geopolitics of security and surveillance in Nepal and Afghanistan: A comparative analysis	A comparative analysis for security and surveillance	Security logic presents specific racial and gender bodies as suspects and examines how individuals inhabiting these spaces experience, understand, and challenge these security regimes.
[38]	Assessment of Trans-Border Surveillance Strategies on National Security at Isebania, Migori County, Kenya	Framework for Border Surveillance Strategies on National Security	The purpose of this document is to provide a framework for implementing border surveillance strategies related to national security. Research has shown that modern and effective methods have been found to be effective and are recommended by researchers. There is a need for the country to adopt technology at its borders as well as deploy skilled personnel to manage it at the right time as soon as possible.

Despite the extensive literature on security policies related to CCTV systems, there has been very little research on issues with educational institutes in Arabic countries. In addition, to the best of our knowledge, no study has addressed yet the security policy for using CCTV systems in Arab Education institutes. Therefore, in this paper, we propose a framework for developing a security policy in this regard.

### III. RESEARCH METHODOLOGY

The policy development for CCTV implementation has three main issues: first, people do not like to see their movements are recorded; second, sharing of this information in case of investigation, and third, every organization has its own distinguished organizational structure. This paper aims to propose a policy that can resolve all the above issues. Therefore, a combination of activity theory, international standards, and design science methodology is used to develop a new CCTV policy for NBU.

Fig. 1 presents the recommended structure for the CCTV policy of NBU. This paradigm emphasizes six key elements from both theoretical and practical standpoints. These locations serve as the overall perimeter and purview of the CCTV implementation within the NBU specifically, as well as throughout the kingdom's educational institutions generally.

#### A. Placement and Application of CCTV

This should be presented considering the theoretical concerns regarding the deployment and use of CCTV surveillance systems at NBU, as well as delicate subjects such as cultural and religious considerations.

#### B. Security and Risk Management

This will discuss several security issues and risk management concerns pertaining to CCTV surveillance in educational settings.

#### C. Legal Issues

The significance and necessity of the legal framework for CCTV surveillance systems will be covered in this article. This has proven to be a difficult task, particularly considering the religious and cultural foundations of Saudi Arabia's educational institutions. This section also contains legal paperwork from both the national and international levels in support of the deployment and implementation of CCTV systems.

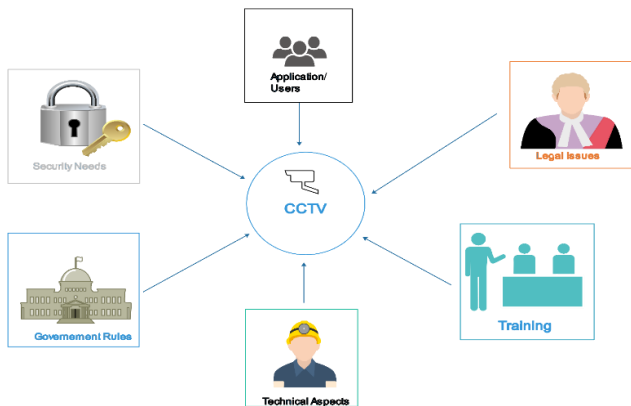


Fig. 1. Key elements from the practical and theoretical perspectives for the Northern Border University CCTV policy.

#### D. Technical Aspects

Technology limitations may be a factor in the difficulties that may arise with the implementation and deployment of CCTV surveillance systems in NBU. This section aims to pinpoint the areas where technical limitations can have a negative suggest the deployment of successful CCTV systems and to suggest methods in which technological development might significantly reduce these limitations.

#### E. Staff Developmental Training

This section tries to emphasize the significance of effective and practical training programs and the pertinent education needed to build a sizable workforce that is trained and accountable for supporting CCTV management. The proper certification obtained through education and training can increase employee productivity and knowledge of the delicate challenges associated with monitoring and controlling CCTV footage and evidence.

#### F. Governmental Rules and Policies about the Surveillance

The Saudi Arabia government is expected to develop a reasonable and practical set of policies for the placement, installation, and administration of CCTV surveillance systems in order to produce effective and efficient systems of surveillance in a university. This section discusses pertinent issues about the Saudi government's CCTV system protocol.

Considering these six key elements, the CCTV policy for the NBU is advised. The organizational structure and university culture provides the basis for these elements. All these elements collectively provide a standardization for the CCTV policy applicable to NBU. The working framework for the policy development is presented in Fig. 2.

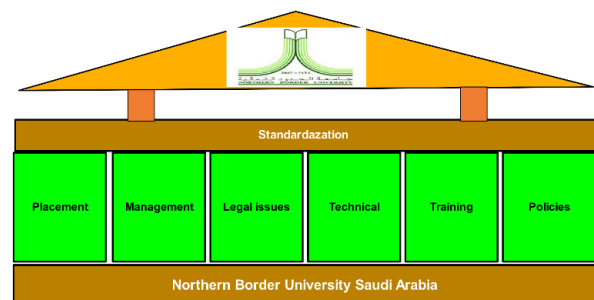


Fig. 2. Framework for the developing security policy for using CCTV in NBU.

### IV. IMPLEMENTATION OF THE CCTV POLICY

This section provides the details related to the implementation and evaluation of developed CCTV policy. The practical and theoretical implications are also discussed in this section. In addition, the legal and ethical challenges are explained in this section.

#### A. Practical Implications of the CCTV Policy

There are two key issues that merit consideration when assessing the practical elements and ramifications of CCTV surveillance system deployment. The first is how CCTV deployment will be designed and developed in the future according to cultural, legal, and other sociopolitical factors. Secondly, how to implement the CCTV.

1) *Design facets of development:* The installation of CCTV surveillance systems in Saudi Arabia has so far raised questions regarding their efficacy and financial usefulness. Although there is often hostility to its placement in public locations, the popular perception of its potential to reduce crime may be favorable. Advanced technology and a culture with strong cultural and religious boundaries are a delicate combination that requires careful consideration. The government of the Kingdom of Saudi Arabia has so far managed to deal with difficult regimes. Modern technology has made it possible to install sophisticated cameras in public areas. Additionally, the deployment of mobile CCTV surveillance will be made much simpler soon when drone technology is fully standardized because considerations regarding camera placement would no longer be necessary. However, it appears that there is more at stake than just the technological feasibility and economic limitations of CCTV surveillance systems. As previously noted, the layout of CCTV surveillance and its upcoming development plans must closely follow the issues presented below:

- Considering the findings, several techniques must be used to combat the problem of misuse in surveillance. The first requirement is that ethical and management obligations and responsibilities are included in the staff's education and awareness programs. Second, hiring and educating more female employees can make a big difference in this circumstance. Finally, as the results of the literature review demonstrated, there were few and poor supervision hours and weekly frequency of all recorded films. It is the responsibility of the project manager or risk manager to ensure that there is an increase in service quality and supervision frequency to lessen the possibility of employee exploitation.
- According to the literature, 42.3% of highly educated individuals oppose the use of CCTV surveillance system. Thus, spreading correct and unambiguous information about CCTV technology and its possible advantages can greatly lower worry about CCTV.
- Concerns about protection and security, particularly those related to the incidence of crimes and thefts. The government has previously been successful in similar safety and security measures simply as the public recognized that the security risk was considerably bigger than other hazards related to CCTV controlling.

2) *CCTV development and governance:* Saudi Arabia is still developing the installation and use of CCTV cameras, but some common practices have been developed to effectively manage the technology. In the case of a new technology like CCTV, the arrival of regulation is closely tied to the process of technological dispersal (Wood & Webster, 2009). CCTV surveillance systems in Saudi Arabia are mostly based on UK and European standards, but a set of local regulations based on cultural and traditional values of the population is needed, especially for educational institutions.

The main goal of governance is managing various initiatives and activities efficiently and fairly; in other words, acting responsibly and being accountable and transparent. Policymakers shall adhere to all governmental policies and guidelines regarding the process of implementing and deploying a CCTV surveillance system at NBU. The deployment process should be documented at every stage, highlighting the regions that will be impacted and outlining the actual costs and advantages of the placement. Such paperwork must also outline certain potential upcoming developments, their advantages and disadvantages, and the procedures for their control. The public must have access to these documents and be able to comment on them.

NBU should work to create a center of excellence for the CCTV investigation protocol. The implementation and ongoing management of all CCTV systems at the institution must be completely under the control of this center. As previously stated, this center needs a respectable budget to carry out its delicate work of instructing students, offering training courses for staff, estimating the correct costs and paybacks of any deployment task, gauging the projects' actual efficacy, and lastly gathering and collecting valuable statistics for the calculation of threats and doubt arising from new projects in the future.

#### *B. Theoretical Implication of the CCTV Policy*

After being launched and executed, the project should be regularly validated. Conducting regular surveys of the participants is the finest method of project validation. Therefore, it is advised that a regular survey of students, instructors, and technical personnel be carried out. The outcomes will assess the efficiency of all 12 principles of CCTV surveillance. The policies, infrastructure, and training will all be updated as necessary to reflect the findings and results in the services.

#### *C. Legal and Ethical Challenges of the CCTV Policy*

The widespread use of CCTV has always prompted certain moral and legal concerns. Additionally, the widespread misuse of CCTV footage and the absence of ethical guidelines around "dumb" CCTV surveillance have both been shown in many instances. As a result, it is only reasonable to say that the broad adoption of such CCTV systems would not be supported by the entire populace and would be closely scrutinized in terms of how the data gathered by CCTV. The current legal framework for the control of CCTV data is relatively constrained and largely focused on data protection laws, which are not the best fit for CCTV data. In a similar vein, the evolution of Japanese data security has demonstrated that CCTV is subject to very lax data security regulations. Despite the fact that CCTV installations are becoming more and more common in Japan (placed in public, semi-public, and even semi-private spaces such as office cafeteria areas), this issue is still not seen to be a problem and is not adequately regulated [39]. Strict rules and regulatory measures are now both required and desirable since the number of CCTV systems in public locations throughout the world has been increasing exponentially. Regulators will be less effective if a nation is not committed to protecting privacy and does not have the institutional safeguards to safeguard it [18]. In essence, according to [18], CCTV surveillance has

changed the notion of privacy, which has made the job of regulators and attorneys in most European nations more difficult. By doing a comparable assessment on data privacy and legislation in Africa, [40] demonstrated how underdeveloped the continent is at the moment. The study has concluded that because of Africa's lack of self-governing experiences, its collectivism culture, and its solid religious heritage, the continent continues to lag far behind the legal status of Europe in terms of the implementation and effective use of CCTV cameras in open places. This is done by considering issues such as data privacy policies, culture, and religion. Other ethical concerns with CCTV surveillance include the lack of reciprocal eyes, which occurs when the subject of the monitoring is unaware that he or she is being watched and/or who is doing so. Data are compiled with an increase in interest from unauthorized parties, hence exacerbating the privacy problems as smart CCTV systems with facial detection are implemented.

### V. IMPLEMENTATION OF DEVELOPED POLICY IN THE NBU CLINIC

The developed CCTV policy can be implemented for several fields of NBU. For example, a CCTV was installed for the NBU clinic to monitor and record the patients. The purpose of implementing the CCTV Policy for the clinic of BNU is to ensure the safety and security of both patients and staff at the clinic. This policy outlines the measures that will be taken to ensure the security of the clinic, including the installation and use of CCTV cameras and video recording systems. These measures will help to deter any criminal activity and provide a safe environment for both patients and staff. Additionally, the policy will ensure that the clinic is compliant with all relevant laws and regulations. Fig. 3 shows the details and implementation of the CCTV policy for the NBU clinic.

<b>Policy statement</b>	<ul style="list-style-type: none"> <li>This policy will cover the CCTV surveillance system in the NBU clinic. It will ensure a fair and secure use and implementation of the CCTV. This policy will cover all the equipment, software, technical staff, users, authentication, authorization, and any other issues related to the CCTV surveillance system in the NBU clinic.</li> </ul>
<b>Users</b>	<ul style="list-style-type: none"> <li>This policy will cover the use of the CCTV surveillance system. It will ensure the rights and authentication of the users. It will also distinguish among the manager, authorized users, and patients in the clinic.</li> </ul>
<b>Management and Maintenance</b>	<ul style="list-style-type: none"> <li>It will be the responsibility of the authorized technical team to manage the security of the CCTV system, its maintenance, and 24/7 availability. They will also ensure the backup, recovery, and availability of the data at the time of need.</li> </ul>
<b>Training</b>	<ul style="list-style-type: none"> <li>The NBU managers will make the arrangement to provide necessary training to the users of the CCTV surveillance system, managers, IT staff, and other relevant personnel.</li> </ul>
<b>Policy Update</b>	<ul style="list-style-type: none"> <li>The management of NBU will review the NBU clinic surveillance system time to time and will make necessary modifications according to changing requirements.</li> </ul>

Fig. 3. CCTV implementation in the NBU clinic to monitor the patients and security.

### VI. FINDINGS AND DISCUSSION

To protect kids, the Saudi Arabian Ministry of Education reportedly declared that 33,000 schools across the country would soon have CCTV camera systems installed. This initiative's primary goal is to encourage a culture of safety and security among instructors and pupils as well as among the private security guards who might be employed to enforce safety standards. Additionally, there are 5 million students and 700,000 teachers in Saudi Arabia, who are carrying out their jobs in their institutes. If these measures are successful, this will significantly increase the personal safety and security of one-third of Saudi students and teachers. The installation of CCTV surveillance systems is therefore highly wanted in Saudi Arabia due to the country's developing infrastructure and industry.

However, most evaluations have produced ambiguous and conflicting conclusions when taking into account the situation studies of CCTV efficiency in the United State and European countries [41] [42]. However, in brief, as most academics have argued, the issue of whether CCTV systems might be useful should be taken into account in conjunction with a wide range of social, cultural, legal, economic, and religious aspects influencing our recent existence [43] CCTVs are expected to be installed in Saudi Arabia's most significant regions, including educational institutions.

The NBU is advised that in the short-term certain norms of conduct should be adopted by the personnel who are engaged in all aspects of CCTV surveillance. As a result, the 12 guiding principles listed below are ideal places to start when it comes to establishing CCTV surveillance at NBU in the first place. In Fig. 4, these principles are classified and summarized in a way that is easy to understand.

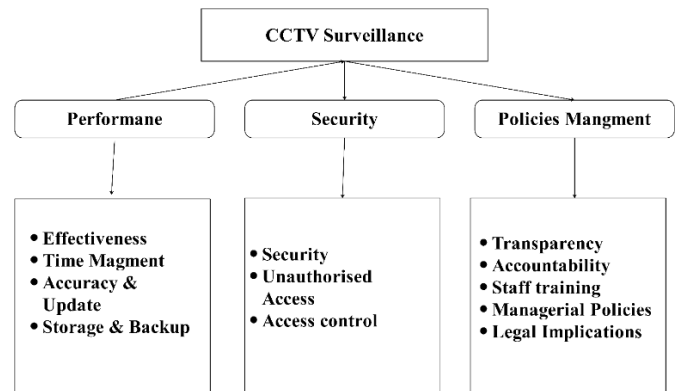


Fig. 4. Categorization of the key principles for implementing, securing, and evaluating the policy.

- **Effectiveness:** To protect the public, CCTV surveillance cameras should be deployed as effectively as possible to promote public safety and law enforcement.
- **Time Management:** A CCTV surveillance camera system must only ever be used for a specific purpose with the legal intent to deter crime.
- **Accuracy and Updates:** An accurate and current database should be used to support any surveillance camera system.

- Storage and backup: Images and other types of information should only be kept for a specific amount of time before being deleted entirely.
- Security: It is important to carefully assess and reevaluate on a regular basis how using a surveillance camera system may indirectly affect people and their privacy.
- Unauthorized Access: Images and data from surveillance cameras should be saved private and safe to prevent unwanted access and usage.
- Access Control: Any access to saved data should be controlled, and stored data should only be disclosed when it is required for a specific purpose or for rule execution.
- Transparency: When deploying a surveillance camera system, transparency must always be practiced regardless of any individual or private gain.
- Accountability: There must be clear accountability for all activities employing surveillance camera systems, including the collection, saving, and utilization of images and data.
- Trained Staff: CCTV system operators should be fully trained and qualified in order to handle technical, operational, and competency standards relevant to a system.
- Managerial Policies: Before using and deploying CCTV cameras, managers or supervisors have a responsibility to provide clear rules, regulations, and procedures.
- Legal Implication: To guarantee that all legal requirements are properly followed in practice, a regular review and auditing mechanism should be in place. This policy is developed by considering the requirement of the security management team. All the factors from design stage to the implementation and evaluation stages are considered in this policy. To make the implementation process easier, a comprehensive list of principles is categorized into three categories. These categories cover the different actors from top management to security staff. This policy is applicable to NBU as well as any educational institutes governed by the Ministry of Higher Education in KSA. The policy is critically analyzed and evaluated to check the social challenges, security measurements, authorization, and the roles offered to the human actors. Thus, the categorized principles will help the organizations to implement the policy for implementation of CCTV systems in their environment.
- Upon analyzing the findings and engaging in thorough discussions, it becomes evident that there is a need to address the identified research gap in the field of CCTV surveillance systems. While previous studies have explored the effectiveness of such systems in various contexts, there remains a lack of comprehensive understanding and evaluation of their performance, particularly in the specific setting of educational institutions. Therefore, this research aims to bridge this gap by providing a detailed analysis of the implementation and impact of CCTV surveillance systems in Saudi Arabian schools. By investigating the challenges, benefits, and implications associated with their deployment, this study offers valuable insights into enhancing the safety and security measures in educational environments. The findings shed light on the unique considerations and potential improvements required to ensure the successful implementation and operation of CCTV systems in schools, thereby advancing the state-of-the-art in this domain.

## VII. CONCLUSION AND FUTURE WORK

In this paper, the authors evaluated different challenges in implementing the CCTV surveillance system, in general, and KSA. According to the guidelines of the Ministry of Higher Education of the Kingdom, a detailed CCTV policy was advised in this study for the Northern Border University keeping in view all the challenges of the sharia, culture, and educational institute requirements. The policy also considered the requirements of the key stakeholders as well as the students and staff members. The policy was made based on the standard principles that were categorized into three classes: performance, security, and policy management. In the security section, the aim was to maximize the benefits of the surveillance system and, at the same time, ensure data security. If this policy is implemented in all its aspects, it will not only ensure the university's safety, but also build trust in the stakeholders. Exploring emerging technologies, such as machine learning and video analytics, can also be a promising area for future research to enhance the capabilities of CCTV surveillance. Furthermore, investigating the long-term effects of CCTV implementation, including any unintended consequences or potential privacy concerns, would contribute to a more holistic understanding of its implications. Lastly, considering the perspectives of various stakeholders, such as students, teachers, parents, and policymakers, can provide valuable insights into the acceptance and effectiveness of CCTV surveillance in educational environments. These future research directions will contribute to the ongoing development and improvement of CCTV systems in educational institutes.

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# Enhanced Gravitational Search Algorithm Based on Improved Convergence Strategy

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**Abstract**—Gravitational search algorithm (GSA) is one of the metaheuristic algorithms that has been popularly implemented in solving various optimization problems. The algorithm could perform better in highly nonlinear and complex optimization problems. However, GSA has also been reported to have a weak local search ability and slow searching speed to achieve its convergence. This research proposes two new parameters in order to improve GSA's convergence strategy by improving its exploration and exploitation capabilities. The parameters are the mass ratio and distance ratio parameters. The mass ratio parameter is related to the exploration strategy, while the distance ratio parameter is related to the exploitation strategy of the enhanced GSA (eGSA). These two parameters are expected to create a good balance between the exploration and the exploitation strategies in eGSA. There are seven benchmark functions that have been tested on eGSA. The results have shown that eGSA has been able to produce good performance in the minimization of fitness values and execution times, compared with two other GSA variants. The testing results have shown that the enhancements made to GSA have successfully improved the algorithm's convergence strategy. The improved convergence has also been able to improve the algorithm's solution quality and the processing time. It is expected that eGSA could be applied in many fields and solve various optimization problems efficiently.

**Keywords**—Enhanced gravitational search algorithm; variant; improved convergence; exploration; exploitation

## I. INTRODUCTION

Gravitational Search Algorithm (GSA) is a physics based metaheuristic algorithm which has been adapted to solve various optimization problems. The algorithm has been one of the popular optimization algorithms that has been adopted by the researchers [1]. GSA has been reported to have the capability to solve highly nonlinear and complex engineering optimization problems effectively [2-4]. Based on literatures, GSA has demonstrated better performance in solving optimization problems such as for constrained, unconstrained, continuous, discrete and multi objective optimizations [5, 6]. The algorithm has produced better performance than the other well-known algorithms such as Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) in solving various optimization problems [5, 7, 8].

Among of the advantages of GSA are such as simple concept, less control parameters and able to balance the exploration and exploitation in the optimization [9-12]. The exploration capability is related to the ability of the algorithm to expand the search space for good solutions. Algorithms must use exploration strategies at the beginning to avoid trapping in

the local optimum. Exploitation in the metaheuristics is related to the convergence strategy or the ability to find the near optimal solution among good solutions. The strategies to achieve convergence are different for each of the algorithms. An optimal result is determined by the good balance between the exploration and exploitation capabilities.

As for GSA, the algorithm's exploitation characteristic has been reported to produce longer execution time to reach the optimal solution [13, 14]. The presence of agents with heavier masses at the end of run has contributed to longer computational time needed for the algorithm to reach the optimal solution. It has been reported that GSA suffers long computational time compared to other well-known algorithms. Based on literatures, the original GSA has been reported to have a poor local search ability and slow searching speed in the last iteration. The particles tend to get stuck in the local optima in the last stage of iterations. Due to the problem, the swarm cannot converge to the optimal point even though the particles could cluster to a small domain [15-17]. The algorithm requires more time to reach the optimal solution due to the presence of heavier masses at the end of run [18, 19].

Based on the reported problems, GSA has been suffering from the weak exploitation in certain problem domains. Due to the weakness, many enhancements and modifications have been done to GSA in order to improve its performance. Various GSA variants have been designed in order to improve its convergence rate, computational time and the solution quality. Some of the variants have focused on the modifications of the behavior of GSA by introducing new parameters or functions to the algorithm's structure. Among of the previously introduced parameters are Levy flight operator and disruption operator [20,21]. The Levy flight operator is designed to avoid the premature convergence, while the disruption operator improves the exploration and exploitation abilities of GSA. The other concepts are the adaptation of clustering method, stochastic local neighborhood search, chaos theory and natural selection rules [22-25]. These concepts have been introduced to reduce the complexity and computation of GSA and to avoid from local optima. The concepts which are related to physics theory such as astrophysics, mass dispersed gravity and wave function have also been introduced to the standard GSA in order to improve the algorithm's performance [26, 27, 21]. These modifications could enhance the global searching capability of GSA and also help the agent to escape from local optima.

The previous enhancements have considered the balance between the exploration and exploitation capabilities of the

algorithm to achieve efficient searches. The good balance of the exploration and exploitation capabilities could be achieved by assigning the specific parameters or operators to the algorithm to produce specific capabilities [21]. Based on literatures, there are many additional parameters that have been introduced such as the escape velocity operator to improve the velocity [28], differential factor parameter to balance the global and local searches [29], chaotic perturbation operator to improve the exploitation [24] and disruption operator to avoid weaker agents [21]. GSA tends to get stuck in the last iteration after performing well at the beginning. Due to the problem, there is a need to add new operators into GSA in order to increase its efficiency in solving nonlinear optimization problems [30]. Hence, this research is proposing the enhancement of GSA with the introduction of mass ratio parameter and distance ratio parameter to the algorithm. The mass ratio parameter is designed to improve the exploration strategy, while the distance ratio parameter is designed to improve the exploitation strategy. The objective of the research is to improve the convergence of GSA by improving both of the exploration and exploitation capabilities of the algorithm. In this research, the original structure of GSA is modified to further improve its performance. The new parameters have been designed based on the basis that the parameters should be able to select only better agents as the active agents for the calculation of forces, while improving the exploration and exploitation capabilities. It is expected that this proposed convergence strategy could improve GSA in obtaining better optimal solution and improve its computational time.

This paper is organized into several sections. The earlier sections present the introduction and overview of GSA. The later sections explains the enhancements of GSA, the benchmark testing, results of the analyses and discussion. Finally the paper is summarized through the conclusion of the research.

## II. LITERATURE REVIEW

### A. Gravitational Search Algorithm (GSA)

Gravitational Search Algorithm (GSA) was developed by Rashedi et al. in 2009, which was based on Newton's law of gravity and law of motion [31]. In Newton's law of gravity, the force between two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between the objects. The second law of motion states that when a force is applied to an object, the acceleration is depending on the force and the mass. GSA is represented by agents, which carry their own masses in the search space. The following steps show the basic procedures of GSA:

- 1) *Randomized initialization.*
- 2) *Fitness evaluation of agents.*
- 3) *Update  $G(t)$ ,  $best(t)$ ,  $worst(t)$  and  $M_i(t)$  for  $i = 1, 2, \dots, N$ .*
- 4) *Calculation of the total force in different directions.*
- 5) *Calculation of acceleration and velocity.*
- 6) *Updating agents' position.*
- 7) *Repeat steps 2 to 6 until the stopping criterion is reached.*

Based on the GSA procedures, the first step is the random initialization of the population of agents. The fitness values of the agents are evaluated in the second step. In the third step, the gravitational constant  $G(t)$  is updated based on the time execution, while the agents' masses, best and worst of the population are evaluated. In the fourth step, based on the evaluations, the total force in different direction of agents is calculated. The total force value leads to the updates of the acceleration and velocity of an agent as in the fifth step. Equation (1) and (2) show the computation of the acceleration  $a$  and the velocity  $v$  respectively. The acceleration  $a$  of an agent at iteration  $t$  is calculated based on the total force,  $F_i^d(t)$  and mass,  $M_{ii}(t)$  as shown by (1). In the sixth step, the position value  $x$  of an agent is calculated based on (3) after the velocity value  $v$  has been obtained. After the maximum iteration has been reached, the execution would stop and return the optimal solution. In GSA, the biggest mass corresponds to the optimal solution while its position is the solution to the problem.

$$a_i^d(t) = F_i^d(t) / M_{ii}(t) \quad (1)$$

$$v_i^d(t+1) = \text{rand}_i \times v_i^d(t) + a_i^d(t) \quad (2)$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad (3)$$

## III. METHODOLOGY

### A. Enhancements of GSA

GSA has widely been improved since its introduction in 2009. Over the years, various GSA variants have been designed in order to improve its performance. The significant contributions in GSA have been focusing on improving the convergence rate, reducing computational efforts and improving the solution quality. Based on the previous studies on the improvement of GSA, the enhancements could be categorized into two approaches. One of the approaches is the modifications of the behavior of GSA by introducing new parameters or functions to GSA structure, while another approach is the hybridization of GSA with other intelligent techniques.

In this research, the exploration and the exploitation strategy of GSA is studied to overcome its convergence issues and improve the execution time. There are two new parameters that have been designed in the enhancements, namely mass ratio and distance ratio parameters. The mass ratio parameter is related to the exploration strategy, while the distance ratio parameter is related to the exploitation strategy of the enhanced GSA (eGSA).

### B. Mass Ratio Parameter

The first enhancement of eGSA is the introduction of the mass ratio parameter, which is aimed to reduce the number of active agents in the search space. Based on the original concept of GSA, only  $K_{best}$  agents should attract other agents to improve the algorithm's performance [31].  $K_{best}$  agents are the set of agents with better fitness values and bigger masses. In GSA, only  $K_{best}$  agents should apply forces to the others to control the exploration and exploitation capabilities of the algorithm. This research is proposing a mass ratio parameter to select the set of  $K_{best}$  agents in the search space. Based on the parameter, only agents with bigger masses will become active

in attracting the other masses in the search space. The formula for the mass ratio parameter is shown in (4).

$$\text{Mass Ratio} = M_i / M_{\text{best}} \quad (4)$$

where:

$M_i$  = mass of an agent

$M_{\text{best}}$  = biggest mass in the search space

Based on (4), the mass ratio of an agent is obtained by dividing its mass with the biggest mass in the search space. The set of *Kbest* agents is the agents with mass ratio values in the interval [0.1, 1.0]. These *Kbest* agents would apply forces with each other within the given mass ratio values. This mass ratio approach is introduced to control the search for good candidate solutions in the search space based on the ratio of the biggest mass. Fig. 1 shows the concept of mass ratio approach among the agents. This approach is applying exploration at the beginning when all of the *Kbest* agents apply forces to each other. However, since *Kbest* is a function of time, its initial value of  $K_0$  will decrease linearly with lapse of time. By the end of the iteration, there will be only one *Kbest* agent that applies force to the others. By the end of the iteration, exploitation is obtained by the decrement of the *Kbest* agents in the forces attractions. This mechanism could improve the exploration strategy as only the good solutions would be considered, eliminating the worse ones. The global search efficiency of GSA could be improved by selecting only better masses for the accumulation of forces. This approach could attain the good coordination between exploration and exploitation capabilities as the exploration would fade out when the exploitation starts to fade in.

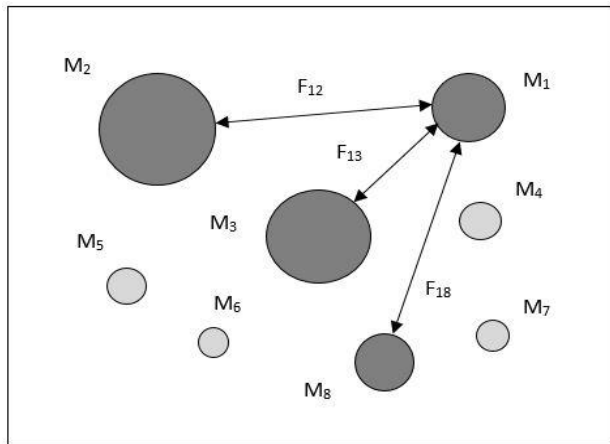


Fig. 1. Only agents with bigger masses apply forces to each other in eGSA.

### C. Distance Ratio Parameter

The second enhancement of eGSA is the introduction of the distance ratio parameter. This enhancement is inspired by the reported GSA's local search weakness [32]. This second enhancement is based on the distance factor in the accumulation of forces between the agents. Based on the gravitational force formula as seen in the (5), the forces between two agents ( $F_{12}$ ) are directly proportional to the gravitational constant,  $G$  and their masses ( $M_1$  and  $M_2$ ). The forces are indirectly proportional to their distance ( $R_2$ ).

$$F_{12} = GM_1M_2 / R^2 \quad (5)$$

Based on (5), the force between the two agents ( $M_1$  and  $M_2$ ) would be higher when the distance between them is smaller. This formula has shown that an agent would have more attraction with other agents which are in shorter distances. Furthermore, the law of motion has stated that the force is directly proportional to the acceleration of the object. Equation (6) shows the acceleration,  $a$ , of an object is directly proportional to its force,  $F$  and indirectly proportional to its mass,  $m$ . Based on the equation, the smaller force would generate lower acceleration and vice versa.

$$a = F/M \quad (6)$$

In GSA, the acceleration is necessary to determine the velocity of an agent. Equation (2) has shown the formula for the velocity of the next iteration of an agent,  $v_i(t+1)$  that is significantly influenced by the acceleration,  $a_i(t)$ . Based on (2), the low acceleration value would result in the lower velocity of an agent. Due to the lower velocity, the agent would continue their search in the bad area which would contribute to the decreased of the optimization result. Since the acceleration is depending on the force and the force is depending on the distance, the agents that are far away in the search space would generate lower velocities. The  $rand_i$  is a uniform random variable which is in the interval of between 0 and 1. The purpose of the random number is to give a randomized characteristic to the search.

In this research, since the agents have already been selected through the mass ratio approach, the active agents in the search space are only the ones with the bigger masses. These agents are more efficient, have higher attractions and move slower than other lighter agents [31]. In order to help the agents to search the space more locally, the distance ratio parameter is introduced. Based on this parameter, only agents in shorter distance are selected for the accumulation of forces between agents. The accumulated force would be used to calculate the acceleration which would determine the velocity and position of an agent. The formula for the distance ratio is as shown in (7).

$$\text{Distance Ratio} = D_{ij} / D_{i,\text{max}} \quad (7)$$

where:

$D_{i,j}$  = distance of an agent from other agent.

$D_{i,\text{max}}$  = the farthest distance with an agent.

Equation (7) has shown that the distance ratio is obtained by dividing the distance of an agent from another agent with the distance of the farthest agent in the search space. The distance of the farthest agent changes with each agent in the search space. In this research, the distance ratio is set in the interval of [0.1, 1.0]. The distance ratio approach is adapted into GSA in order to speed up the process of obtaining the forces between agents while improving the quality of solution. This approach would select agents in shorter distances depending on the ratio setting and this would help the algorithm to search the space more locally. This distance ratio parameter is introduced to help in the search for optimal solution or global optima more efficiently. Based on the

literature, GSA requires more time to reach the optimal solution due to the presence of heavier masses at the end of run [33]. This approach would reduce the number of agents to be considered in the determination of the optimal solution at the end of run, hence could improve the algorithm's local search efficiency and is expected to improve the execution time.

#### D. Procedural Steps of eGSA

This section provides a more detailed description on the procedural steps of the enhanced GSA (eGSA) by showing the formula in each step of the algorithm. There are altogether 10 steps involved in order to obtain the final optimal result in each execution. The steps of the standard GSA has been briefly described in the earlier section. In eGSA, the concept of the algorithm is still based on the standard GSA, but with the additional enhancements to its structure. In the procedure, Step 4 to Step 7 is the new enhancement in eGSA. The following shows the procedural steps of eGSA:

Step 1: Agents initialization.

Step 2: Fitness evaluation, best and worst fitness computations.

Step 3: Gravitational constant ( $G$ ) computation.

Step 4: Agent's Mass ( $M_i$ ) and  $M_{best}$  computations.

Step 5: Selection of  $Kbest$  agents based on mass ratio parameter.

Step 6: Farthest distance,  $D_{i,max}$  computation.

Step 7: Selection of agents based on distance ratio parameter.

Step 8: Accelerations of agents' computation based on total forces.

Step 9: Velocities and positions of agents' computation.

Step 10: Repeat steps 2 to 9.

The first step of eGSA is the agents' initialization in the search space. Equation (8) shows the first step of GSA which is to initialize the positions of the  $N$  number of agents.

$$X_i = (x_i^1, \dots, x_i^d, \dots, x_i^k), \text{ for } i=1, 2, \dots, N. \quad (8)$$

Based on (8),  $x_i^d$  represents the positions of the  $i^{th}$  agent in the  $d^{th}$  dimension, while  $k$  is the space dimension.

The second step covers the computation of fitness evaluation for each agent, which led to the determination of the best and worst fitness among the agents. For example, the minimization function of GSA is selected. Equation (9) and (10) show the formula for the minimization problem.

$$\text{best}(t) = \min \text{fit}_j(t) \quad (9)$$

$$j \in \{1, \dots, N\}$$

$$\text{worst}(t) = \max \text{fit}_j(t) \quad (10)$$

$$j \in \{1, \dots, N\}$$

Based on (9) and (10), the  $\text{fit}_j(t)$  represents the fitness value of the  $j^{th}$  agent at iteration  $t$ ,  $\text{best}(t)$  and  $\text{worst}(t)$  represents the best and worst fitness at iteration  $t$ .

In the third step, the gravitational constant ( $G$ ) is computed. Equation (11) shows the formula to calculate  $G$ , which is computed at iteration  $t$  [34].

$$G(t) = G_0 e^{-\alpha t/T} \quad (11)$$

Based on (12),  $G_0$  and  $\alpha$  have to be initialized at the beginning and will be reduced with time to control the search accuracy. The  $T$  is the total number of iterations.

The fourth step is the computation of the agents' masses. In the theoretical physics, there are actually three kinds of masses that have been identified. The masses are the active gravitational mass, passive gravitational mass and the inertial mass. In GSA, the active, passive and inertia masses of an agent are considered to be equal based on the theory of the general relativity [32]. Based on (12),  $M_{ai}$  and  $M_{pi}$  are the active and passive gravitational masses respectively, while  $M_{ii}$  is the inertia mass of the  $i^{th}$  agent. Equation (12) shows that the three masses are actually equal. Equation (13) shows that the mass for each agent is calculated based on the worst and best fitness at the iteration  $t$ . Each of the mass  $i$  is then updated based on the other masses  $j$  as shown in the equation (14).

$$M_{ai} = M_{pi} = M_{ii} = M_i, \quad i = 1, 2, \dots, N. \quad (12)$$

$$m_i(t) = \frac{\text{fit}_i(t) - \text{worst}(t)}{\text{best}(t) - \text{worst}(t)}$$

$$m_i(t) = \text{fit}_i(t) - \text{worst}(t) / \text{best}(t) - \text{worst}(t) \quad (13)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^N m_j(t)}$$

$$M_i(t) = m_i(t) / \sum_{j=1}^N m_j(t) \quad (14)$$

In this step, the calculation of masses for each of the agents has led to the determination of the best mass,  $M_{best}$ . In order to apply the mass ratio parameter, the determination of  $M_{best}$  has to be done in this step.

In the fifth step, the  $Kbest$  agents are selected based on the mass ratio parameter as shown in (4). Based on the mass ratio approach, only  $Kbest$  agents would become active and apply forces with each other in the search space. The sixth step is the calculation of the farthest distance,  $D_{i,max}$  among the  $Kbest$  agents. This step is necessary in order to apply the distance ratio parameter in the next step.

The seventh step applies the other new distance approach parameter. In step 7, the active agents would be selected again based on the distance ratio parameter as shown in (7). Based on the distance ratio approach, only agents with shorter distances are selected for the calculation of forces between the agents.

The eighth step covers the calculation for the acceleration of agents. Before the calculation of the acceleration, the value for  $F_{ij}^d(t)$  has to be computed based on (15). Based on (15),  $F_{ij}^d(t)$  is the force acting on agent  $i$  from agent  $j$  at  $d^{th}$  dimension and  $t^{th}$  iteration.  $R_{ij}(t)$  is the Euclidian distance between two agents  $i$  and  $j$  at iteration  $t$ .  $G(t)$  is the computed

gravitational constant at the same iteration while  $\epsilon$  is a small constant.

$$F_{ij}^d(t) = G(t) \cdot (M_{pi}(t) \times M_{aj}(t) / R_{ij}(t) + \epsilon) \cdot (x_j^d(t) - x_i^d(t)) \quad (15)$$

After the calculation of  $F_{ij}^d(t)$ , only then the total force that acts on the  $i^{th}$  agent,  $F_i^d(t)$  could be calculated based on (16). The total forces are calculated based on all of the agents that have been selected after the implementation of the distance ratio parameter.

$$F_i^d(t) = \sum_{j \in Kbest, j \neq i} rand_j F_{ij}^d(t) \quad (16)$$

The acceleration of the  $i^{th}$  agents at iteration  $t$  could be computed as already shown in (1). The ninth step covers the calculations for the velocity,  $v_i$  and position,  $x_i$  of each agent. The velocity and the position of the agents at the next iteration ( $t+1$ ) are computed based on (2) and (3) respectively. The  $rand_i$  is the random variable in the interval [0,1] which would give the randomized characteristic to the search.

The final step is to repeat the step 2 to step 9 until the iterations reach the maximum limit. The best fitness value at the final iteration is computed as the global fitness while the position of the corresponding agent is computed as the global solution of this problem.

Based on these enhancements, the new flowchart for eGSA is shown in Fig. 2. The highlighted parts in the Fig. 2 show the enhancement that has been implemented in eGSA.

### E. Benchmark Functions Testing

The enhanced GSA (eGSA) has been tested with seven benchmark test functions in order to validate its capabilities. The selected functions are the commonly used benchmark functions that have been applied to test the performance of an optimization algorithm [31, 35, 36]. The function names, their mathematical representations, characteristics and the search spaces are given in Table I.

TABLE I. BENCHMARK FUNCTIONS APPLIED IN THE EXPERIMENTS

Function Name	Mathematical Representation	Characteristic	Search Space
Sphere	$F_1(X) = \sum_{i=1}^n x_i^2$	Unimodal	$[-100,100]^n$
Schwefel 2.21	$F_2(X) = \max \{ x_i , 1 \leq i \leq n\}$	Unimodal	$[-100,100]^n$
Step	$F_3(X) = \sum_{i=1}^n ([x_i + 0.5])^2$	Unimodal	$[-100,100]^n$
Quartic Noise	$F_4(X) = \sum_{i=1}^n i x_i^4 + random[0,1]$	Unimodal	$[-.28,1.28]^n$
Rosenbrock	$F_5(X) = \sum_{i=1}^{n-1} [100(x_{i+1} - x_i^2) + (x_i - 1)^2]$	Multimodal	$[-30,30]^n$
Schwefel 2.26	$F_6(X) = \sum_{i=1}^n -x_i \sin(\sqrt{ x_i })$	Multimodal	$[-500,500]^n$
Rastrigin	$F_7(X) = \sum_{i=1}^n [x_i^2 - 10 \cos(2\pi x_i) + 10]$	Multimodal	$[-12.5,12]^n$

\* n = dimension

Based on Table I, four of the functions are the unimodal functions while another three are the multimodal functions. The unimodal functions are the functions with only one single local minima and are commonly applied to test the convergence rate of a search. As for the multimodal, the functions have many local minima and are commonly applied

to test the ability of the algorithm to escape from the local optima. The final result in the multimodal function is important as it shows the ability of an algorithm to find the global optima. In this benchmark testing, eGSA has been compared with another two modified or variants of GSA algorithms. The other two variants of GSA algorithms have been selected based on their almost similar concepts for enhancement with eGSA. Both of the algorithms have also been based on the distance of agents for their points of change in the GSA's structure. The comparison algorithms are the Improved GSA (IGSA) and Hybrid Gravitational Search with Lévy Flight (HGSLF) [37, 38]. The IGSA has been based on the disruption phenomena in the outerspace, where a star of the system could disrupt other objects under the influence of its gravitational force. In the IGSA algorithm, an agent is disrupted if the ratio of the distance between its mass and the neighbouring mass to its distance from the best solution is smaller than a specified threshold. As for the Lévy flight operator, it is applied to one of the mass if the distance between the two masses have become very near and both of them are not good solutions in the search space.

The parameter settings for each of the algorithm have been provided in the Table II to Table IV respectively. Based on the tables, the standard GSA parameters are the gravitational initial value, alpha and epsilon. The value of  $G_o$  and  $\alpha$  determine the convergence speed and help to balance the exploration and exploitation of GSA [39]. As for the epsilon,  $\epsilon$ , it helps in the updating strategy of GSA. The other parameter settings are for the new introduced parameters, which are the mass ratio and distance ratio for eGSA, the constant operator  $\theta$  and small value  $\rho$  for IGSA and the threshold constant  $\xi$  for HGSLF. These new parameters would determine the exploration or exploitation capabilities of the algorithms respectively.

TABLE II. PARAMETER SETTING FOR EGSA

Parameter	Value
Gravitational initial value, $G_o$	100
Alpha, $\alpha$	20
Epsilon, $\epsilon$	0.00001
Mass ratio	0.1
Distance ratio	0.9

TABLE III. PARAMETER SETTING FOR IGSA

Parameter	Value
Gravitational initial value, $G_o$	100
Alpha, $\alpha$	20
Epsilon, $\epsilon$	0.0001
$\theta$ (constant operator)	100
$\rho$ (small value)	$10^{-16}$

TABLE IV. PARAMETER SETTING FOR HGSLF

Parameter	Value
Gravitational initial value, $G_o$	100
Alpha, $\alpha$	20
Epsilon, $\epsilon$	0.0001
$\xi$ (threshold constant)	$10^{-3}$

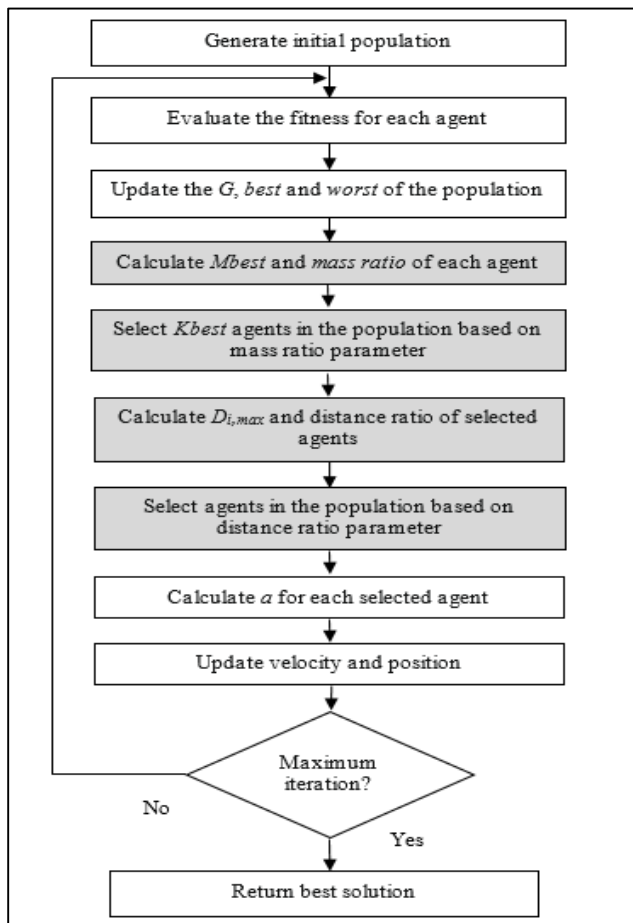


Fig. 2. Flowchart of the enhanced GSA (eGSA). Adapted from (Rashedi et al.,2009).

#### IV. RESULT AND DISCUSSION

The experimental results in this research have been divided into the fitness values and processing times evaluations. These performance measurements have been evaluated based on the statistical analyses.

##### A. Fitness Values

This section provides the fitness value analyses from the results of the benchmark testing between eGSA and the other two comparison algorithms, IGSA and HGSLF. In the benchmark functions testing, each of the dimension of the function is 30 ( $n=30$ ), the population size is 50 ( $N=50$ ) and the maximum iteration ( $t_{max}$ ) has been set to 1000. Based on Table I, the minimum values ( $f_{opt}$ ) for all of the 7 functions are 0, except for  $F_6$  which has a minimum value of  $-418.9829 \times n$ . The minimization results of the benchmark functions testing for each of the algorithm are shown in the following Table V. The best, worst and the mean fitness of the solutions, which have been averaged over 30 runs have been recorded in the table.

Based on Table V, the performance of eGSA is acceptable in all of the seven functions. Based on the overall results, eGSA is able to minimize the unimodal and multimodal functions. The mean fitness values for  $F_1$  (0.4822) and  $F_2$  (0) have been able to reach 0, while for  $F_3$  (6.6875),  $F_4$  (4.2713)

and  $F_5$  (1.7320), the mean fitness values are almost reaching 0 values. For  $F_6$  and  $F_7$ , these multimodal functions have many local optima and are difficult to optimize. However, eGSA has been able to minimize the functions and the results are satisfying. Based on Table V, the overall results show that the performance of eGSA is better than IGSA and HGSLF in almost all of the functions.

TABLE V. MINIMIZATION RESULTS OF BENCHMARK FUNCTIONS

Test Function		eGSA	IGSA	HGSLF
F1	Best	0.0191	20224.06	16124.47
	Worst	1.4021	28298.42	24884.73
	Mean	0.4822	24072.19	20618.17
F2	Best	0	0	0
	Worst	0	0	0
	Mean	0	0	0
F3	Best	6.0192	78.2867	17771.13
	Worst	7.5000	306.7619	22977.62
	Mean	6.6875	147.2939	20447.29
F4	Best	1.3216	72.7237	69.0424
	Worst	7.7193	137.6973	85.0527
	Mean	4.2713	104.4885	78.1088
F5	Best	0.2022	305.2722	472.9982
	Worst	3.4489	342.4960	613.2155
	Mean	1.7320	324.3189	538.8112
F6	Best	-3360.7363	-2598.1066	-3937.7373
	Worst	-2852.5944	-2187.7641	-3586.5394
	Mean	-3150.2839	-2396.7062	-3780.7486
F7	Best	270.7417	378.7011	379.4766
	Worst	293.9898	445.3634	391.2795
	Mean	278.5284	414.4412	385.0295

The performance of eGSA, IGSA and HGSLF for the minimizations of the unimodal functions  $F_1$  to  $F_4$  have been illustrated in Fig. 3 to Fig. 6. The figures show that eGSA is able to minimize and is able to converge with better mean fitness values compared to the other algorithms. As for IGSA and HGSLF, the algorithms still have been able to minimize and converge with larger values in most of the functions. However, IGSA has not been able to further minimize the results in  $F_1$  and  $F_4$ . This is due to the decrement of the values in the minimization that have been very small, which is in decimal point values. In the early iteration of IGSA, most of the agents have been disrupted and their position values have been changed to become much smaller due to the multiplication with the  $D$  value.

In this research, the algorithms have been coded using Java for experimental purposes. Java has some limitations such as limited floating point representation and the random numbers are generated based on the pseudorandom numbers. The initial seeding of the population is important as it would affect the final results. However, the HGSLF is still able to minimize most of the benchmark functions. In this research, it is the IGSA that has difficulties in the function minimizations, most probably due to its more complex additional structure and also due to Java limitation in the floating point representation.



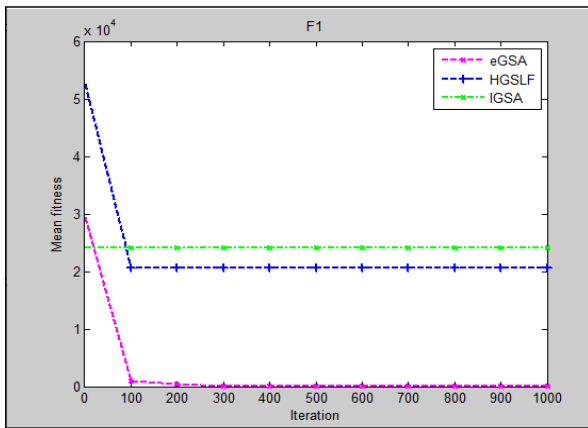


Fig. 3. Performance of the algorithms in the minimization of F1.

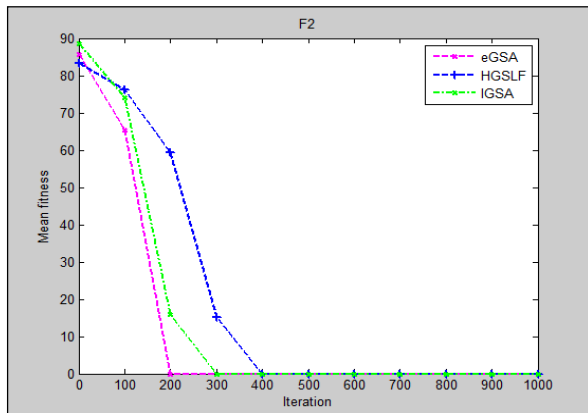


Fig. 4. Performance of the algorithms in the minimization of F2.

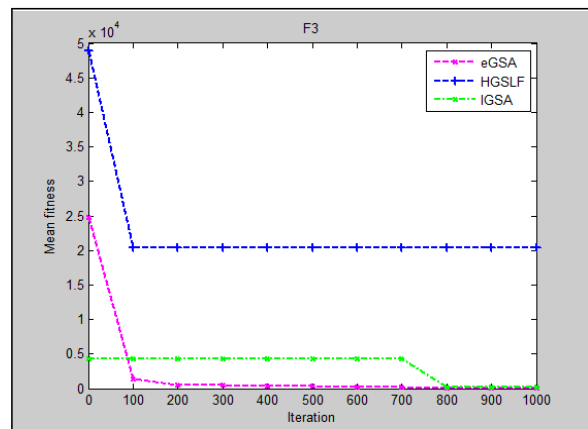


Fig. 5. Performance of the algorithms in the minimization of F3.

As for the multimodal functions, the performance results have been illustrated from Fig. 7 to Fig. 9. Fig. 7 shows that all of the algorithms have been able to minimize and obtain the  $f_{min}$  values of 0 for function F5. Fig. 8 and Fig. 9 show that for functions F6 and F7, eGSA and HGSLF have been able to minimize and have obtained acceptable mean fitness values. However, IGSA is unable to further minimize as it tends to trap in the local optima as shown in the F6 and F7 results. In this experimental study, it is difficult for IGSA to search for the global optimum in the minimization of the F6 and F7

functions. This is also due to the very small decrement values in the minimization of the functions.

In this experimental study, the results of IGSA and HGSLF were not as good as that had been previously reported. The reported previous results have been tested using Matlab which has limitless floating point numbers. However, in this research, Java has been selected and used for experimental purposes compared to the standard Matlab tool. Java is also a popular, powerful and robust programming language that has been implemented in various applications. This research has shown that Java could also be used for the minimization of test functions for optimization problems.

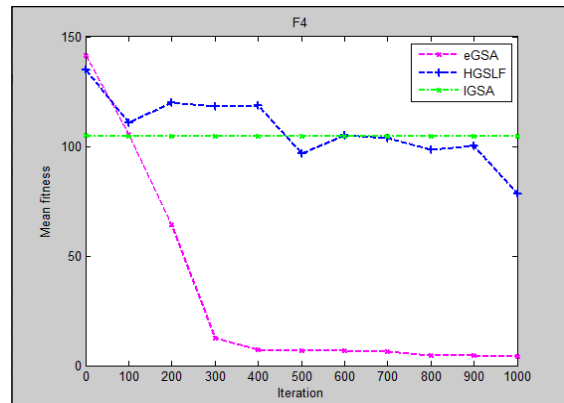


Fig. 6. Performance of the algorithms in the minimization of F4.

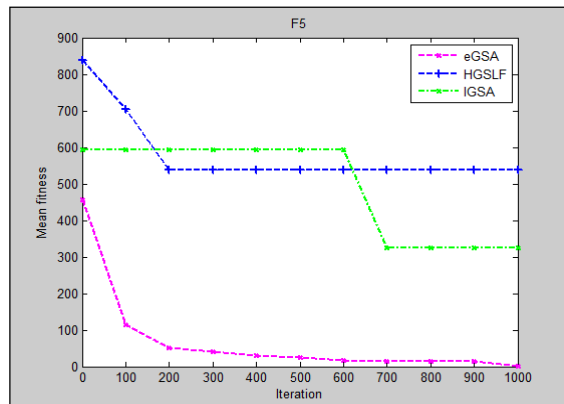


Fig. 7. Performance of the algorithms in the minimization of F5.

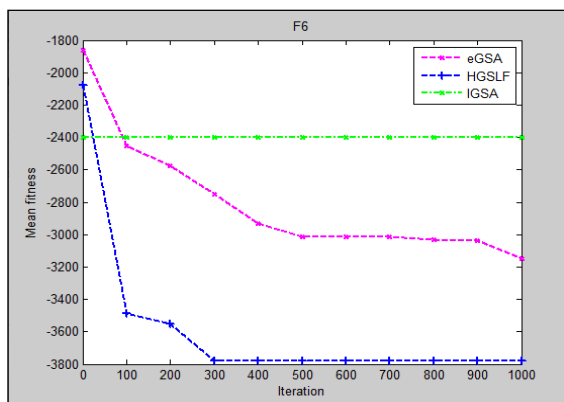


Fig. 8. Performance of the algorithms in the minimization of F6

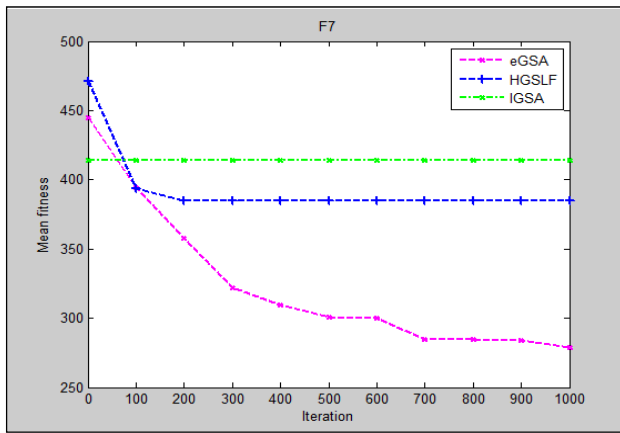


Fig. 9. Performance of the algorithms in the minimization of F7

### B. Processing Times

This section provides the processing times taken by eGSA, IGSA and HGSLF to minimize all of the seven benchmarks functions in this experimental study. Table VI shows the processing times for the seven benchmark test functions.

TABLE VI. PROCESSING TIMES FOR BENCHMARK TEST FUNCTIONS (MS)

Test Function		eGSA	IGSA	HGSLF
F1	Min	671	3686	2215
	Max	814	3809	5042
	Mean	<b>732</b>	3745	3489.75
F2	Min	239	2883	2711
	Max	433	4435	4582
	Mean	<b>314.40</b>	3780	3543.25
F3	Min	615	3836	2702
	Max	650	3926	4618
	Mean	<b>633.67</b>	3871.25	3542.25
F4	Min	609	2448	4088
	Max	689	2576	6197
	Mean	<b>646.25</b>	2489	5280.75
F5	Min	800	3726	2873
	Max	994	4031	5353
	Mean	<b>898.33</b>	3866	3891.25
F6	Min	4707	4566	3932
	Max	5749	6095	4763
	Mean	5304.20	5242.75	<b>4328.50</b>
F7	Min	3822	3975	3885
	Max	4283	6021	5537
	Mean	<b>3979</b>	4845	4508.33

Based on Table VI, the mean processing times of eGSA for most of the functions, except F6, have been the lowest compared to the other 2 algorithms. These faster processing times have been due to the eGSA concept which is to reduce the number of active agents in the search space. In eGSA, the active agents would be selected initially based on the mass ratio and then would further be selected based on the distance ratio. Table VII shows the average number of active agents in eGSA over the 30 runs after the mass ratio and distance ratio parameters have been applied in the search space. Based on the table, it could be seen that the number of active agents have

been reduced from the initial number of 50 after the mass ratio parameter have been applied. These active agents are the agents with bigger masses and represent good solutions in the search space. This mass ratio has been applied to improve the exploration of good solutions in the search space. In order to further improve the solution quality and the processing times, the active agents are further selected for the accumulation of forces between agents. Thus, the number of active agents would further be decreased after the implementation of the distance ratio parameter. This distance ratio parameter has been applied to improve the exploitation capability of eGSA. Based on the distance ratio, only the neighboring agents within the specified ratio would be selected for the accumulation of forces.

TABLE VII. AVERAGE NUMBER OF ACTIVE AGENTS BASED ON eGSA CONCEPT

	F1	F2	F3	F4	F5	F6	F7
Mass ratio	11	21	10	23	18	23	25
Distance ratio	8	16	7	20	14	19	21

As for IGSA and HGSLF, the number of active agents in the search space would not be reduced. Based on their respective concepts, only the positions of the related agents would be changed in the search space. Thus, the processing times of both of the algorithms would not be reduced in this functions minimizations. In both of the algorithms, the position changes have been designed in order to further improve especially in the exploration capabilities of the algorithms.

### C. Discussion

In the benchmark function testing, eGSA has been able to minimize and produce acceptable results. Based on the testing, the proposed enhancements have been able to improve the algorithm's convergence strategy. In the minimization results, the mean fitnesses of eGSA in almost all of the test functions are better than IGSA and HGSLF. The execution time of eGSA are also lesser than the other two variants in all of the test functions testing. This shows that the introduction of the two new parameters has been able to improve on the exploration and exploitation capabilities of the algorithm [30]. The mass ratio parameter would improve the exploration, in which the algorithm would select only the good solutions based on the mass ratio in the search space and eliminate the weaker solutions. After the exploration, the distance ratio parameter would take over to improve the exploitation capability of the algorithm. Based on the distance ratio, only the nearest agents would be selected in finding the optimal solution. Due to this approach, the search space would become smaller in scale and the algorithm would be inclined to search more locally [31]. These two parameters are expected to create a good balance between the exploration and the exploitation strategies in the enhanced algorithm. It is expected that the enhanced GSA (eGSA) could achieve both the efficient global and local searches in order to improve its convergence to optimal solution. This would help in obtaining better solution quality and reduce the execution time in solving real world optimization problems.

## V. CONCLUSION

This paper has discussed on the improvement of GSA convergence strategy, which is based on the two enhancements. The first enhancement is to assign *Kbest* agents based on the mass ratio parameter. This approach could filter and reduce the number of active agents in the search space. The second enhancement is the implementation of the distance ratio parameter to select only the nearest agents for the accumulation of forces among the *Kbest* agents. This second approach would reselect the agents based on the distance in order to further improve the execution time and also improve the solution quality.

The contribution of the research is the introduction of a new variant of GSA, namely enhanced GSA (eGSA) which could improve the algorithm's convergence strategy. Improved convergence strategy is expected to improve the performance of GSA in terms of its solution quality and computational time. In this research, eGSA has been designed mainly to reduce the number of active agents for the accumulation of the gravitational forces. The mass ratio and distance ratio operators have been designed to select only the bigger masses which represent the best solutions in the search space. It is expected that eGSA could improve the exploration and exploitation capabilities compared to the standard GSA and other variants. Significantly, eGSA has been able to perform better than two other GSA variants in the benchmark testing. The conclusion that could be derived based on the testing results is that the enhancement made to GSA has been successfully improve the algorithm's convergence, thus improving its solution quality and the processing time. The enhancements in the exploration and exploitation strategies of eGSA has enabled the algorithm to produce better results. The benchmark function testing results have shown that eGSA could produce good performance in solving minimization problems.

In future, the research on the enhancements or modifications of GSA would continue to expand as GSA has increasingly gained attentions due to its acceptable performance in solving various optimization problems. Besides, currently there are various real world optimization problems that need to be explored and solved using metaheuristics approaches.

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# Proposed Secure Activity Diagram for Software Development

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**Abstract**—Unified Modeling Language (UML) activity diagrams are derived from use case diagrams. It becomes essential to incorporate security features and maintain consistency in the diagrams during analysis phase of Software Development Life Cycle (SDLC). As part of current software development practices, software security must be a constant effort. The activity diagrams are used to model business process. The detailed analysis of activity diagram is done. The challenge lies in viewing the main activity diagram from attacker's perspective and providing defense mechanism to mitigate the attacks. This paper presents an extension of the activity diagram named SecUML3Activity to provide security with Object Constraint Language (OCL) constraints using Five Primary Security Input Validation Attributes (FPSIVA) parameters for input validation. It also proposed three security color code notations and stereotypes in activity diagrams. White color is used to represent activity diagram in normal state. Red color in dotted line is used to represent attack activity components. Blue color with double line is used to represent the defensive activity components. The defense mechanism algorithm against SQL Injection (SQLI) attack, Cross Site Scripting (XSS) attack, DoS/DDoS attack, access validation attack is provided. The mapping of Secure 3-Use Case diagram with SecUML3Activity diagram is done through mathematical modeling.

**Keywords**—Unified modeling language; activity diagram; object constraint language; SQL injection; use case diagram

## I. INTRODUCTION

Unified modeling language (UML) is a visual language rather than a programming language to help software developers. It is used to build real-time systems and shows visual representation of the behavior and structure of the system in software development [3]. UML modeling can be done with the help of tools like StarUML, Microsoft Visio, ArgoUML, MagicDraw, BOUML, Visual Paradigm and the like [24]. UML or Object Constraint Language (OCL) is used in designing financial systems where incorporation of security is a primary concern.

Activity diagram is used to show the diagrammatic flow of events taking place in a use case diagram. It shows the dynamic behavior of a system like control flow and object flow from one action to another which is one of the main UML modeling techniques [1][4]. It is used to model security requirements in the business processes, modeling parallel and concurrent flows in an actual system and illustrate the scenario of detailing complex use cases [2][7][25].

In earlier work, Colored Petri Net (CPN) has been proposed to ensure consistency between use cases and activity diagrams [26][27][28]. Jurjens proposed UMLsec to specify security information during the development of security critical systems and provided tool-support for formal security verification using security scenarios into a system design [33]. UMLsec employs use case diagrams to capture security requirements. UMLsec defines 21 stereotypes to represent fair exchange, non-repudiation, role-based access control, secure communication link, confidentiality, integrity, authenticity, freshness of a message, secure information flow among components, and guarded access. Some stereotypes also have associated tags and constraints.

The foundation of secure SRS is consideration of security requirements to mitigate severe vulnerabilities mentioned in the vulnerability databases [15]. Secure SRS considers security requirements like input validation, multi-factor authentication to enhance UML use case, class and state transition diagrams [4][5]. In this paper, we proposed security stereotypes, colored notations to distinguish main activity diagram from attackers' activity diagram and defensive activity diagram. FPSIVA parameters based on OCL constraints are used to provide defense mechanisms in activity diagram and mitigate vulnerability in the analysis phase of SDLC. These stereotypes help developers to build functionalities carefully and flawlessly during the implementation process. Also, defense mechanism algorithms are proposed in this research work to build secure activity diagrams. The consistency between UML diagrams is maintained through relationship between proposed SecUML3Activity diagram and Secure 3-Use Case diagram proposed by authors in earlier work [2].

The paper is organized as follows. Section II describes a detailed literature survey of activity diagram, notations to draw activity diagram, relationship of activity diagram with use case diagram. Section III covers the proposed secure activity diagram: SecUML3Activity with security color notations and stereotypes using FPSIVA parameters, and defense mechanism algorithm. Section IV is used for result and discussion related to this work. Section V concludes the paper and gives direction to the future work.

## II. LITERATURE SURVEY

UML diagrams are used to visualize various perspectives of the software system. Since they are dependent on each other, the consistency between the diagrams is desired in earlier phases of SDLC. In comparison to static modeling, consistency is a more delicate issue in dynamic modeling. Non-compliance

of consistency among these diagrams lead to errors being introduced during software development and make it vulnerable to attacks like SQLI, XSS, DoS/ DDoS attack and access validation attack [12][13]. Relational Language for Advanced Security (ReAlSec) is a security engineering tool to find security threats [31]. A specification cannot be fully represented by a UML diagram on its own. Consequently, the dynamic diagrams would require a common notation among them. The external behavior of the systems to be built is meant to be expressed using use case diagrams and activity diagrams. Activity diagrams are used to show the dynamic behavior aspect of a given system by modeling data flow [1][2][18].

The Object Constraint Language (OCL) is a declarative language and forms part of the UML standard and plays a crucial role in the analysis phase of SDLC. It is an expression language used to describe constraints and other modeling artifacts that cannot be stated using conventional grammatical notations [4][28]. OCL constraint is acting as a restriction on a model to ensure consistency. Although it is designed at the class level, its semantics are applied at the object level [1][3][9][10][29]. The security of activity diagrams can be enhanced using OCL [2][4].

Activity diagrams are basically used to represent flow of events used in use case diagrams, modeling complex requirements and implementation details [11][26]. These diagrams look like data flow diagrams (DFDs) in structured analysis (SA), However, DFDs in SA are used for capturing, analyzing, and documenting requirements. They are best suited for modeling parallel and concurrent flows in an actual system. The activity can be explained as an operation of the system [6][7]. Due to the richer constructs, it offers, such as concurrency, split, and synchronization, the UML activity diagram has been utilized in process modeling and workflow modeling [20]. They have a significance in software testing [10][17][30]. They are divided into two kinds such as atomic activity diagram and compound activity diagram based on sub activity state. Managing the compound activity diagram is a significant problem when creating test cases [1].

#### A. Analysis of UML Activity Diagram

Some definitions of the activity diagram can be presented in a formal manner.

1) Activity diagram (AD) is a tuple consisting of –

$$AD = (N, E, C, R)$$

where  $N, E, C, R$  are a finite set of activity nodes, directed edges, containment and flow relationship between the nodes or containments respectively.

Activity nodes consist of action nodes  $N_a$ , object nodes  $N_o$  and control nodes  $N_c$ .

$$N = N_a \cup N_o \cup N_c$$

Directed edges are a finite set of edges.

$$E = \{e_1, e_2, e_3, e_n\}$$

$C$  contains graphical elements for containment and it is formally defined as a tuple consisting of activities, interruptible regions, exception handlers, expansion regions.

$$C = (Activities, IR, EH, ER)$$

The flow relationship  $R$  is explained as follows.

$$R \subseteq (N \vee C) \times E \times (N \vee C)$$

The control node consists of given disjoint sets as below.

$$N_c = I \cup D \cup M \cup P \cup J \cup F$$

where  $I, D, M, P, J$  and  $F$  are finite sets of initial nodes, decision/branch, merge, forks, joins and final nodes that cover activity final and flow final nodes. So,  $F$  can be denoted as  $F = F_a \cup F_f$ , where  $F_a$  is a finite set of activity final nodes and  $F_f$  is a finite set of flow final nodes. And  $F$  are finite sets of initial nodes, decision/branch, merge, forks, joins and final nodes that cover activity final and flow final nodes [19].

2) Activity diagram (AD) is a tuple consisting of –

$$D = (A, T, F, C, aI, aF)$$

where  $A, T, F, C, aI, aF$  are a finite set of activity states, completion transitions, guard conditions, flow relationship, initial activity state and final activity state respectively and described as below.

$$A = \{a_1, a_2, \dots, a_m\}$$

$$T = \{t_1, t_2, \dots, t_n\}$$

$$C = \{c_1, c_2, \dots, c_n\}$$

$$F \subseteq (A \times T \times C) \cup (T \times C \times A)$$

$$aI \in A$$

$$aF \in A$$

There is only one transition  $t$  such that  $(aI, t, a) \in F$ , and  $(a, t', aI) \notin F$  or  $(aF, t', a) \notin F$  for any  $t', a$ . The activity diagram is used to represent composite activities. Each activity node is handled individually and treats concurrent activities as an interleaving sequence of activities [17][18].

3) Since every use case *useCase* gets converted to activity diagram, the complete set of all activity diagrams  $AD$  contains many  $ad_{useCase}$ .

$$ad_{useCase} \in AD$$

As each activity diagram consists of initial node, activity nodes and activity partitions,

$$AD = \{IN, AN, AP\}$$

where,  $IN$  denotes the initial node. Every activity diagram must have an initial node.

$$IN_{useCase} \in IN$$

$AN$  denotes the activity node. There may be zero or more activity nodes in an activity diagram.

$$AN_{useCase} \in AN$$

$AP$  denotes the activity partitions. There may be zero or more activity partitions in an activity diagram.














$$AP_{useCase} \in AP$$

### B. Activity Diagram Notations

The graphical notations are used for modeling activity diagrams including nodes and edges. The diagrams must ensure their semantics to conform to the UML activities metamodel [6][8]. The activity diagram notations are shown in Table I.

TABLE I. ACTIVITY DIAGRAM NOTATIONS

Element	Symbol	Description
Start		Start symbol in activity diagrams is used to indicate the start of a process or workflow.
Activity		It outlines the tasks that participate in a modeled process. It serves as the foundation of an activity diagram.
Connector		It indicates the directional flow or control flow of the activity. After a step in an activity is complete, the flow is continued by an outgoing arrow. A step in an activity is initiated by an incoming arrow.
Joint/Synchronization bar		Two ongoing tasks get combined and reintroduce them to a flow in which only one task is carried out at once.
Fork		Two concurrent operations are split from one main flow of activity.
Decision		Minimum two paths diverge at a decision and users get to view options. This symbol indicates the branching or merging of various flows.
Send signal		It conveys to a receiving activity that a signal is being sent.
Receive signal		It shows that an event has been accepted. Flow that comes from this action is completed once the event is received.
Option loop		It gives the designer the ability to depict a repeating sequence inside the loop symbol.
Flow final		It denotes the end of a particular process flow. The end of a process should be done with a flow final symbol.
Condition text	[Condition]	The developer comes to know under what condition an activity flow should split off in that direction.
End		It denotes the finish of an activity and the end of all process flows.

### C. Relationship of Activity Diagram with use Case Diagram

A systematic mapping of activity diagram with use case Diagram is described below [22][23][26][27][28].

Rule 1: Every use case must be represented by at least one activity diagram, else there will be inconsistency leading to fault in software development.

$$\exists useCase \in UseCase_{sysModel}: \exists AD_{useCase} AD_{sysModel}$$

Rule 2: An actor in a use case must be an activity partition in the corresponding activity diagram.

$$\exists actor, (assoc(actor, UseCase), \exists ap \in AP_{useCase})$$

Rule 3: Let use case diagrams UC1 includes UC2 where UC1 is the including use case and UC2 is included use case. Then event flows of both UC1 and UC2 must be specified in

the activity diagram. The action node in UC1 should refer to the activity diagram specifying use case UC2.

$$include = (including, included) \in Include$$

$$where\ including, included \in UseCase : act_{included} \in ACT_{including}$$

Rule 4: Every flow of event mentioned in the use case description or implied therein needs to be described in detail in the related event of the activity diagram. This rule is only applicable if the use case is further described in the activity diagram.

Rule 5: The event in the use case diagram has a one-to-one mapping with an action/activity state in the corresponding activity diagram.

### D. Object Constraint Language (OCL)

OCL is a formal specification language that can be used to define expressions and constraints on object-oriented models and other object modeling artifacts. IBM created the Object Constraint Language in 1995. It was initially used as a business engineering language, but it was later incorporated into the Unified Modelling Language (UML) as a formal specification language. Starting with version 1.1, OCL was included in the official OMG (Object Management Group) standard for UML. It enables programmers to communicate restrictions and guidelines that control the organization and operation of software systems. OCL 2.0 is the latest version as of September 2021. OCL is a powerful language with built-in capabilities for iterating over collections of objects, finding the value of an item, and navigating across a group of related objects. Primitive types such as Integer, Real, Boolean, and String, as well as Collections types such as Set, Bag, ordered set, and Sequence, are included in OCL's predefined standard library [14]. OCL can be used in many ways. For any expression over a UML model, it can be used as a query language to specify invariants on classes and types in the class model, type invariants for stereotypes, pre- and post-conditions on operations and methods, guards, target (sets) for messages and actions, constraints on operations, and derivation rules for attributes [3][4]. As each OCL expression has a type, it is considered as a typed language [4].

An activity diagram becomes more comprehensible when it is modeled using UML notations. To non-technical individuals, such as a client, the pictorial depiction makes knowledge transfer simple. However, there can be certain discrepancies in the diagrams if a programmer uses them as a reference when building implementation code. For instance, it's possible that the diagram doesn't show the beginning values for some characteristics or doesn't clearly indicate the limitations. In these circumstances, it is impossible for the programmer to develop the entire program without consulting the required specification or other documentation. OCL aids in the improvement of the UML diagrams and, as a result, writes the complete code for the same [4].

1) **INVARIANT**: It is a constraint that specifies a condition that must always hold true for a particular class or a set of objects. Invariants are used to define the integrity rules of a system and ensure the consistency of the data.

*Example-*  
*context Person*

*inv: self.age > 0 and self.age < 120*

A "Person" class that has an invariant specified on it. According to the invariant, a person's age must be more than 0 and less than 120. By doing this, it is ensured that a person's age is within a suitable range and that inaccurate or unrealistic figures are avoided.

Invariants are typically expressed in the context of a class and use the keyword "context" followed by the class name. The "self" keyword refers to the instance of the class on which the invariant is being evaluated. In this case, "self.age" points to the age of the Person object.

2) **PRE-CONDITIONS:** In OCL, preconditions and postconditions are used to define the conditions that must hold true before and after an operation or method is executed, respectively. They help define the expected behavior and constraints associated with an operation.

*Syntax*

*context <classifier>: <operation> (<parameters>)*

*Pre [<constraints name>]:*

*<Boolean OCL expression>*

The examples of a precondition in OCL is as below.

Let's consider a class called "BankAccount" with a method "withdraw" that deducts a specified amount from the account balance. The precondition for this method could be that the withdrawal amount should be positive and not exceed the current balance.

*context BankAccount :: withdraw(amount: Integer)*

*pre: amount > 0 and amount <= self.balance*

In this example, the precondition specifies that the "amount" parameter passed to the "withdraw" method should be greater than 0 and less than or equal to the current balance of the bank account. This ensures that a valid withdrawal amount is provided and prevents overdrawing from the account.

3) **POST-CONDITIONS:** Preconditions and postconditions are used to document and enforce the expected behavior of operations. They help in validating inputs and ensuring the desired outcomes or effects of operations on objects or systems.

*Syntax*

*Context <classifier> :: <operation> (<parameters>)*

*Post [<constraints name >]:*

*<Boolean OCL expression>*

The examples of a postcondition in OCL is-

Let's consider the same "BankAccount" class with a method "deposit" that adds a specified amount to the account balance. The postcondition for this method could be that the account balance should increase by the deposited amount.

*context BankAccount::deposit(amount: Integer)*

*post: self.balance = self.balance@pre + amount*

In this example, the postcondition specifies that the "balance" property of the bank account after executing the "deposit" method should be equal to the balance before the method was called plus the deposited amount. This ensures that the deposit operation updates the account balance correctly [14].

### III. PROPOSED SECURE ACTIVITY DIAGRAM: SECUML3ACTIVITY

In this proposed SecUML3Activity diagram, dynamic aspects of the system are shown with security stereotypes in color code notations, OCL constraints and defense mechanism algorithms. An illustration of a dynamic security specification is the operation of an authentication mechanism. There is not a comprehensive design-level behavioral definition of security stereotypes in any of the dynamic security standards that developers and programmers might employ during the implementation stage. In this paper, we are proposing security features for SecUML3Activity diagram which is an extension of detailed analysis of Login Use Case of Secure 3-Use Case diagram proposed by authors [4].

#### A. Proposed Security Notations and Stereotypes in Activity Diagrams

It is easier to understand an activity diagram when it is modeled using UML notations. Information can be easily communicated to non-technical staff members, such as a client by way of a picture. However, there might be certain gaps in the UML diagrams when a programmer uses them to write implementation code. For instance, it is possible that the diagram doesn't show the initial values for certain attributes or doesn't clearly define the constraints. Writing the entire code without consulting the requirement specification or other documentation becomes challenging for the programmer. OCL plays an important role to clarify the UML diagrams, and accordingly write the complete code for the same. Since activity diagram is a behavior model, the relationship between model elements is usually more complex. Software engineering research encourages systematic literature review for identifying, evaluating, and interpreting research question [32]. The use of colors has been recognized in software engineering research to make software modeling more comprehensible. The proposed activity diagram notations are represented in various colors codes along with color description as mentioned in Table II.

The proposed colored notations are helpful in visual representation and reduce the cognitive load of software developers. The white color is used to represent normal activity diagram notations; red color in dotted line represents attacks performed by external entities. The double lined blue color is used to represent the attack mitigation and providing defense mechanism. These colored notations for SecUML3Activity

diagrams are mentioned in Table III for attack and defensive activity.

TABLE II. COLOR NOTATIONS DESCRIPTION

Color	Description
White	White represent component is in normal state.
Red	Red color is used to represent/highlight insecure or threatened components. These components are more likely to get attacked successfully by outside entities.
Blue	Blue is to represent the defensive or precautionary components. These components act as defensive measures to avoid or mitigate attack.

TABLE III. PROPOSED NOTATIONS FOR SECUML3ACTIVITY DIAGRAM

Symbol	Activity Diagram Notations	Attack Notations	Defense Notations
Start			
Activity			
Connector			
Joint/Synchronization bar			
Fork			
Decision			
Send signal			
Receive signal			
End			

The stereotypes proposed by authors are used to develop secure implementation. The developer can prevent attacks like Buffer Overflow (BOF), SQL Injection (SQLI), Encryption, Session Expiration, Connection flooding for login into the system.

Stereotype: << BufferOverflow >>

Tag: {BOF}

Stereotype: <<Encryption>>

Tag: {Encryptfield}

Stereotype: <<SQLi>>

Tag: { SQLfield }

If the logged in user remains idle for more than specified time, the session must be forcibly killed to prevent session expiration attacks using

Stereotype: <<SessionExpiry>>

Tag: {Exp\_Time}

If there is a vulnerability in an application to allow more connections than the service provider supports, the stereotype must be inserted in the diagram part that represents the maximum number of allowed connections.

Stereotype: <<maxconn>>

Tag: {Maxconn}

### B. Proposed Secure Constraints in SecUML3Activity Diagram

The OCL constraint is proposed to check the length, any special characters in entered username and password in the login page with the help of constraints. The foundation for applying Five Primary Security Input Validation Attributes (FPSIVA) in the web design phase is OCL [16][21]. It defines FPSIVA which can be used to design activity diagrams in software development. The below mentioned stereotypes used in activity diagrams are designed using FPSIVA parameters.

<<Precondition >>

Context Login :: checkCredentials()

Pre: user name <=12

Pre: Pwd >=8

<<Invariant >>

Context Login :: checkCredentials()

user name =Boolean

Pwd=Boolean

<<Invariant >>

Context Login :: checkCredentials()

Is active=Boolean

It must be ensured that post condition invariants to be applied after login entry to homepage as mentioned below –

<<Postcondition>>

Context Home :: checkAllowUser()

Post: valid User=Boolean

Post: Pwd=Ecrypt(password)

The password needs to be encrypted for transferring over the communication network. Number of attempts by malicious user can be detected with the help of following constraint -

Context Login Invariant :

No. of attempt : self. User > 5

FPSIVA parameters can be used for input validation in activity diagram such as -

(i) var.type : < type > - It is used to validate the type of input data and verify if it can be accepted < type >.

user name: string

(ii) var.format : < pattern > - It is used to validate the format of input data and verify if it can be accepted < pattern >.

(iii) var.length : < number > - It is used to validate the length of input data.

user name.length : 12, Pwd.length :8

(iv) var.Charset: < pattern > - It is used to check characters with its < pattern >

user name.charset : [A-Z, a-z, 0-9].

(v) var.value : < reasonableness > - It is used to check reasonable values of input data.

No of attempts.value:5.

### C. SecUML3ActivityDesign

The proposed SecUML3Activity diagram for Login use case of College Management System (CMS) is divided into three swim lanes like Login Activity, Attack Activity, and Defense Activity. The complete flow of the system is shown by the Activity diagram. The swimlane of the activity diagram will be mapped with 2 swim lanes. The first swimlane will be simulated for attack. Each activity with a dotted line in red color notation and second swimlane will be simulated for providing defense mechanisms in blue color double line notations for the attacks. Due to space constraint, we have shown the Login activity of the case study. The proposed security color code notations, stereotypes and constraints are simulated with the login activity diagram in College Management case study as shown in Fig. 1. The login activity end element A is connected to start element of attack activity diagram. The end element of attack activity diagram B is connected to start element of defense activity diagram.

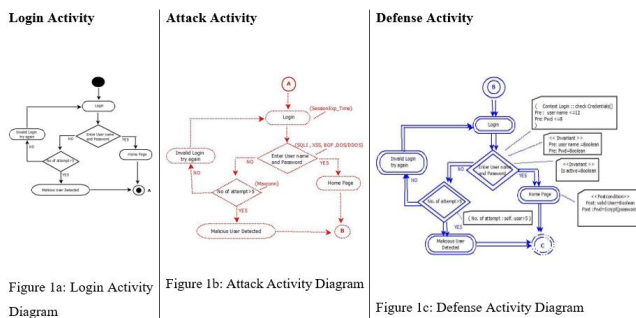


Fig. 1. Proposed SecUML3Activity diagram of Login CMS Use Case.

For clear visualization of the activity diagram, each activity as well as complete proposed SecUML3Activity diagram is shown in Appendix A (Fig. 2 to Fig. 5).

### D. Proposed relationship between SecUML3 Activity and Secure 3 Use Case Diagram

Activity diagrams are basically behavioral representations of use case diagrams with the flow of events. The login use case proposed by the author at [2] is simulated in SecUML3 Activity Diagram. The Secure 3-UseCase is already proposed with the Secure SRS model with CIA-AAA verification during authentication of user's login to the system. The security of use cases is enhanced by considering functional requirements, non-functional requirements, and quality attributes in Secure SRS model [2]. The notations, stereotypes and defense algorithms used in Secure 3-UseCase are inherited in SecUML3 Activity Diagram of College Management System (CMS) to mitigate the attacks in the real world.

Based on SecUML3Activity diagram for Login use case shown in Fig. 1, i.e.

$$Login_{CMS} \in Secure3UseCase_{CMS}$$

$$adLogin \in SecUML3AD_{CMS}$$

where Initial node is  $IN_{Login} \in IN_{CMS}$

and Activity partition is  $Faculty \in AP_{Login}$

There is consistency between Secure 3-UseCase diagram and SecUML3Activity Diagram through the relationship mentioned below.

$$\exists Login \in Secure3UseCase_{CMS}: \exists adLogin \in SecUML3AD_{CMS}$$

### E. Proposed Defense Mechanism Algorithm

The following Defense Mechanism Algorithm against Web based attacks were defined.

1) *SQL injection*: SQLI attacks take place on software applications through different methods like Tautologies, Illegal/Logically Incorrect Queries, UNION Query, Piggy-Backed Queries, Timing Inference attack.

Incident  $\in$  {Web page Field Access, URL Header Access}

#### Algorithm 1: Defense Mechanism Algorithm against SQL Injection

INPUT: SQL Injection through text fields in the web page.

OUTPUT: A secure web page that is free from SQLi.

Start

Read text entered by user in text fields

Create insert parameterized queries instead of string concatenation

Create roles.

For each role,

```
{
  Assign a User
}
```

For each user,

```
{
  Grant appropriate permissions to accomplish Role
  Based Access Control
}
```

---

```
| }  
  
| If User has permission to perform action on Database  
| | {  
| |   Fire Query  
| | }  
| Else  
| | {  
| |   Drop user inserted malicious query.  
| |   Use escape Queries for user inputs to get rid of  
| |   special characters.  
| | }  
End
```

---

2) *Cross Site Scripting (XSS)*: XSS attack occurs when dynamic content that hasn't been checked for malicious content, proper validation makes entry into a web page field.

Incident  $\in$  {Web page Field Access, URL Header Access}

---

**Algorithm 2:** Defense Mechanism Algorithm against Cross Site Scripting

---

INPUT: Input field on web page, URL header access used for taking input

OUTPUT: External script is executed

Start

Insert <body onload=alert (Testing XSS')> into input field.

Submit input

```
| If alert is shown in web browser then  
| | {  
| |   Simple XSS is performed.  
| |   Web service is vulnerable to XSS attack.  
| | }  
| Else  
| | {  
| |   Web service is not vulnerable to XSS attack.  
| | }
```

End

---

3) *Check for DoS/DDoS attacks*: DoS/DDoS attacks are classified into different types like Ping of Death, TCP SYN Attack, ICMP Smurf, UDP Flood attack. TCP SYN Attacks arising due to bugs in operating system can be prevented using security patches. Intrusion Detection Systems (IDS) are helpful to identify and stop illegal intrusion into the systems. Firewalls can be placed into the network to block traffic coming from unknown IP. Routers can be used to limit network access and dropping suspected traffic using Access Control List (ACL).

Incident  $\in$  {URL Header Access}

---

**Algorithm 3:** Defense Mechanism Algorithm against DoS/DDoS attack

---

INPUT: DoS/ DDoS attack through URL header access of web page.

OUTPUT: A secure web page that is free from DoS/ DDoS attack.

---

Start

Read (User Inputs like Source IP address, Destination IP address, Payload)

Extract IP header

```
| If Source IP  $\in$  BlackIP List, then  
| | {  
| |   Drop Packet  
| | }  
| Else if Payloadsize > Payloadthreshold then  
| | {  
| |   Drop packet and add to BlackIP List  
| | }  
| End if
```

End

---

4) *Check for access validation*: Due to absence of centralized middleware in Web page, it becomes necessary to specify the address (URI) of the page and the transport protocol (HTTP). Hence, Access validation can be done with the help of secure key management like security tokens for secure authentication.

Incident  $\in$  {Web page Field Access, URL Header Access}

---

**Algorithm 4:** Defense Mechanism Algorithm to check for access validation

---

INPUT: request through text fields, URL header access in the web page.

OUTPUT: A secure web page that is free from mis-user access attack.

Start

Issue security tokens to WSC through Security Token Service  
Bind the same security token with WSP

Validate security token for transaction

```
| If WSC Security Token  $\in$  WSP Security Token, then  
| | {  
| |   Allow payload for transaction  
| | }  
| Else  
| | {  
| |   Drop payload and cancel the transaction  
| | }
```

End

---

#### IV. RESULT AND DISCUSSION

Based on extensive literature survey, security with OCL constraints using Five Primary Security Input Validation Attributes (FPSIVA) parameters for input validation is provided. The web modeling of software applications consisting of various security-colored notations and stereotypes in secure activity diagrams is proposed to distinguish main activity diagram from attackers' activity diagram and defensive activity diagram. Also, defense mechanism algorithms are proposed to build secure activity diagrams. The consistency between UML diagram is maintained through relationship between proposed SecUML3Activity diagram and Secure 3-

Use Case diagram proposed by authors in earlier work. The various B-Tech and M-Tech software Projects are implemented using secure analysis.

Proposed SecUML3Activity diagram is derived from the Secure 3 Use Case diagram proposed by the author in their earlier work [2]. The proposed strategy is to maintain consistencies between these UML diagrams to avoid errors, defects, vulnerabilities that may arise in software development. This relationship between these two UML diagrams is well explained through mathematical modeling. The input validation of parameters is done through OCL constraints using Five Primary Security Input Validation Attributes (FPSIVA) parameters. The use of colors has been recognized by Software Engineering research to make graphical software models easier to follow, hence as per requirement of secure activity diagrams, three security color code notations and stereotypes in activity diagrams are proposed to distinguish the activities. White color is used to represent activity diagram in normal state. Red color in dotted line is used to represent attack activity components. Blue color with double line is used to represent the defensive activity components. The defense mechanism algorithms against SQL Injection (SQLI), Cross Site Scripting (XSS), DoS/ DDoS attack, access validation is also provided for making system more secure and robust.

## V. CONCLUSION AND FUTURE WORK

The main purpose of this research is to provide security in activity diagrams to prevent external and internal attacks on the web application. The defects, errors, and problems in the software systems occur due to inconsistencies between UML diagrams in analysis phase.

The security features of SecUML3Activity diagram in analysis phase of SDLC can be mapped with component diagram of software architecture, secure data structure design and secure algorithms design against top 10 attacks on software. This standardized proposed secure UML stack with defense mechanism can be used as the reference document for the coding phase and help developers to build more secure applications. The work is in progress.

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APPENDIX-A

1) Login Activity Diagram

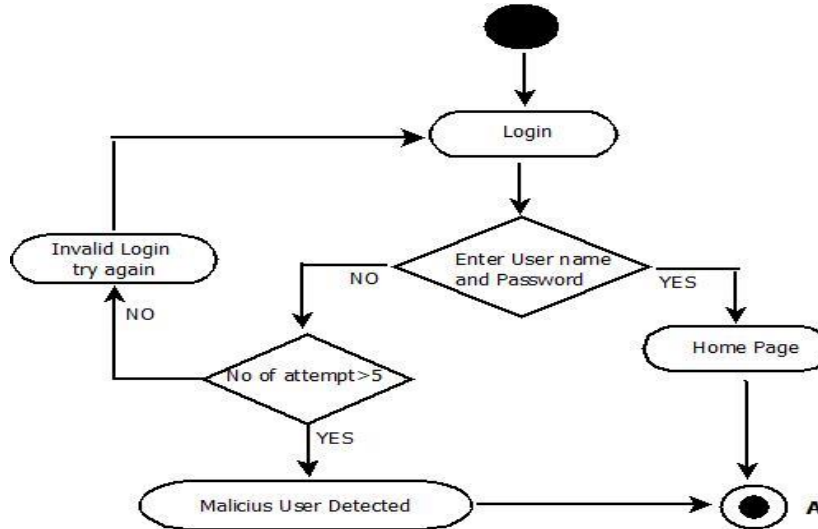


Fig. 2. Login activity.

2) Attack Activity Diagram

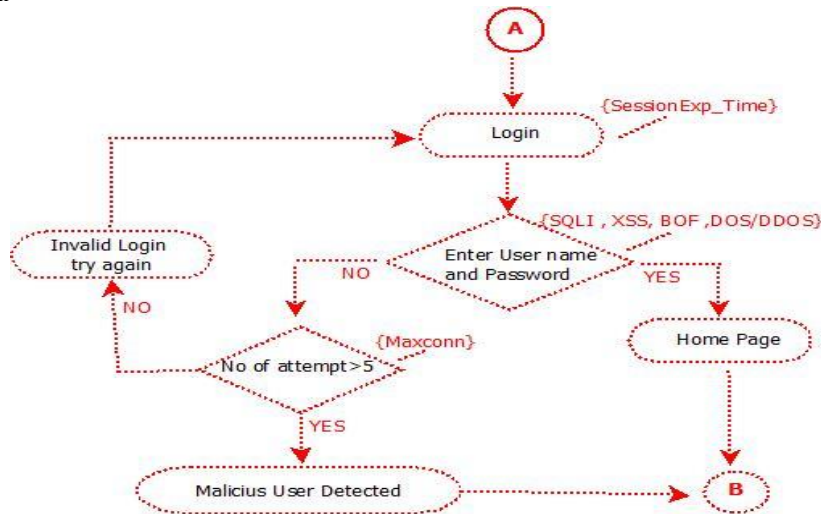


Fig. 3. Attack activity.

3) Defensive Activity Diagram

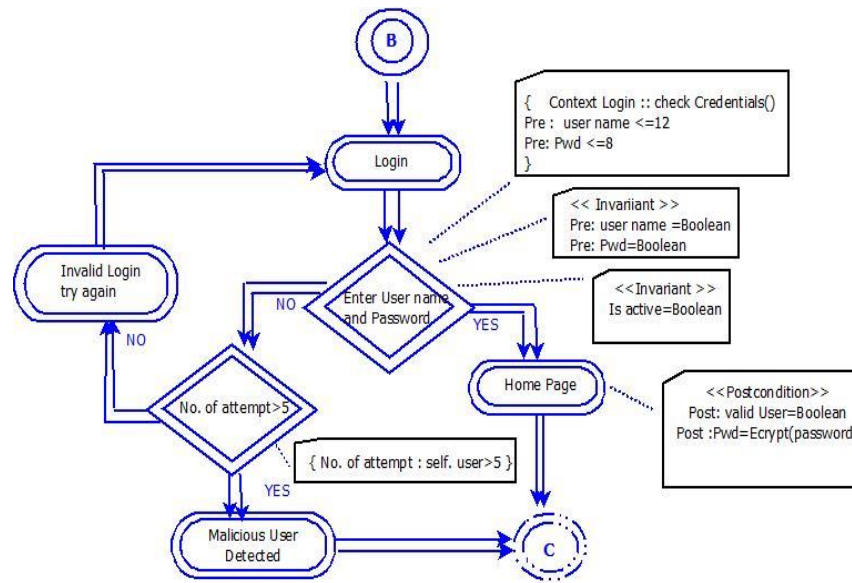


Fig. 4. Defensive activity.

4) Proposed SecUML3Activity Diagram

**Login Activity**

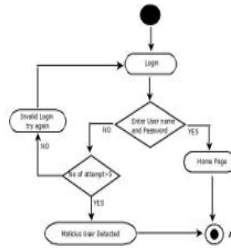


Figure 1a: Login Activity Diagram

**Attack Activity**

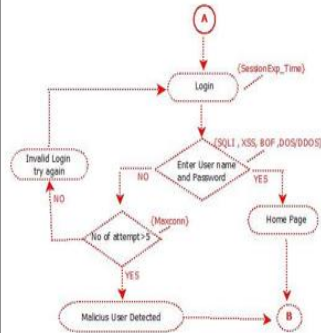


Figure 1b: Attack Activity Diagram

**Defense Activity**

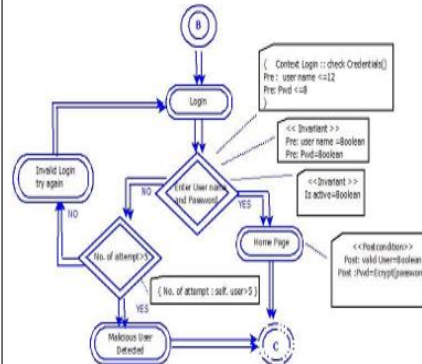


Figure 1c: Defense Activity Diagram

Fig. 5. Proposed SecUML3Activity.

# An Efficient Vision-based Approach for Optimizing Energy Consumption in Internet of Things and Smart Homes

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**Abstract**—One of the primary forces for digital transformation is how quickly the world is changing. Additionally, and at a dizzying pace, the world economy is being transformed by digital technology. The billions of daily online connections between individuals, organizations, devices, data, and processes that generate economic activity are known as the "digital economy." The Internet, mobile technology, and the Internet of Things (IoT) all contribute to hyper-interconnection, or the growing connectivity of people, organizations, and machines, which is the foundation of the digital economy. Simultaneously with these developments, the demand for energy is more than the supply, which leads to energy shortage. In order to keep pace with energy demand, new strategies are being developed. As a result of the emergence and expansion of smart homes, there is a growing need for digitization in applications such as energy efficient automation and safety. With the increase in the amount of electricity consumed and the introduction of new energy sources, the reduction of electricity costs for households becomes increasingly important. Basically, this article uses machine vision technology. In this paper, a YOIO method is used for facial recognition. And compared to all kinds of YOIO methods, the YOIOv5n method was the fastest and most efficient method. So, by using the YOIOv5s method on the Jetson Nano platform, it creates the possibility of authenticating the residents of the houses to identify them to turn on or off the sources of energy consumption in the houses. Therefore, the presented system is designed with the aim of optimizing energy consumption in houses and with the aim of ensuring the safety of the residents of the houses.

**Keywords**—IoT; Internet of things; digital economics; smart cities; digitization; machine vision; YOIO; YOIOv5n

## I. INTRODUCTION

Don Tapscott, an internationally recognized expert on the economic and social effects of technology, popularized the phrase "Digital Economy" in his 1994 book "The Digital Economy: Promise and Peril in the Age of Networked Intelligence." Information in all of its forms is converted to digital form in the new [digital] economy, where it is stored as bits in computers and sent over networks at the speed of light. Although the digital economy did not have a single beginning, significant turning points in its history include the invention of the internet and the introduction of personal computers in the early 1980s, the creation of the world wide web in 1989 and the public launch of that platform in the early 1990s, as well as the introduction of the first smartphones in the late 1990.

The Internet of Things (IoT) is a prevalent concept and an essential part of daily living. which are employed in a wide range of fields, such as transportation, healthcare, and industry, as well as smart homes and smart cities from a security standpoint, it appears that both intelligent devices and users must start a safe communication channel in order to recognize digital form. IoT offers a wide range of options for assisting people in carrying out their regular tasks.

The Internet of Things (IoT) today provides a powerful tool that not only connects wireless communication devices but also remote sensors for heating/cooling or any other necessary utility inside the building to more likely regulate energy usage and improve the living experience in modern homes [1]. A smart home is a house that has been incorporated into the Internet of Things (IoT) and offers its residents comfort, security, convenience, improved quality of life [2]. The IoT is the underpinning platform of a smart home network that connects various smart devices, including wearables, smart meters, and smartphones. Smart home technologies have the potential to improve and facilitate people's lives and independence.

Modern civilization is undergoing a trend known as "smart home technology," which creates intelligent living spaces for daily comfort and ease [3]. Smart homes are automated structures with control, monitoring, and detecting hardware and systems, including heating and cooling, lighting, ventilation, and security. Gateways are the name given to these contemporary systems, which include sensors and switches and communicate via a central axis. These gateways are control systems with user interfaces for smartphones, tablets, and computers. The Internet of Things controls the communication network (IoT).

The quality of human life, well-being, productivity, energy efficiency, and safety may all be impacted by the usage of smart technology in a house, building, or environment, including sensors, actuators, and artificial intelligence (AI) [4]. According to the chart below, the share of energy efficiency among smart home technology trends was 31% in 2018 and increased to 42% in 2020 and is in third place.

In the following, the second part of study refers to studies from 2020 to 2021 in the field of using the Internet of Things to optimize energy consumption in smart homes. The third part defines the methodology, the fourth part specifies results and model evaluation. The fifth part of the findings and finally the sixth part refers to the conclusion and future studies.

The main research contributions of this study are as follows,

- 1) The research paper introduces a facial recognition method based on YOLOv5n, showcasing enhanced efficiency and speed compared to other YOLO methods.
- 2) The integration of YOLOv5s onto the Jetson Nano platform enables the deployment of facial recognition systems for energy consumption optimization in residential houses with limited resources.
- 3) The presented system combines facial recognition technology with energy management, aiming to optimize energy consumption in houses while ensuring the safety of residents.

## II. RELATED WORKS

By favoring various types of equipment, people nowadays are ignoring the cost and usage of electricity. Numerous innovative methods of controlling, tracking, and monitoring a

home's energy savings have emerged as a result of rising energy prices and demand [5].

A new generation of homes called "smart homes" has been made possible by improvements in energy conversion, communication, and information technologies. These homes allow individuals to enhance the comfort, convenience, safety, and entertainment of their homes while also reducing energy waste. In many nations, Home Energy Management Systems (HEMS) are crucial for accomplishing the objectives of smart energy houses. The market for smart homes is expanding quickly as well. It is particularly getting better in areas like energy efficiency systems, lighting, entertainment, and fire detection, among others.

In Table I studies regarding the optimization of energy consumption through the Internet of Things in smart homes in 2020 to 2021 are presented.

TABLE I. RELATED WORKS

Models and Reference	Method / Applications	Advantages / Disadvantages
An Elman recurrent neural network model and exponential model [6].	the Real-Time Power and Intelligent Systems (RTPIS) laboratory	The Elman RNN model outperforms the exponential model and it is a more efficient approach for real-time and near future electric energy consumption estimation and prediction in an IoT driven building environment. The model will be employed to minimize inefficient energy management
HEMS-IoT (relying on J48 & Weka API, RuleML and Apache Mahout, [1]	Smart homes in Mexico	HEMS-IoT estimates more energy consumption reduction The application only works on Android, system compatibility with only some sensors, only using big data and J48, not recommending energy saving, HEMS-IoT implementation relying on GPS of mobile devices.
Holt-Winters-RNN, M4 Forecasting Competition, symmetric mean absolute percentage error (sMAPE), a multilayer perceptron ANN [7].	IntelliHome smart-home system/ a residential housing complex containing 20 units/Using the R programming language	The lowest sMAPE with Holt-Winters-RNN Using out-of-home data with users' smartphones and developing a native mobile application for Android OS using a cross-platform application development framework such as Angular, Ionic or Cordova
deep extreme learning machine (DELM), Bat algorithm and fuzzy logic [8].	<a href="https://github.com/LuisM78/Appiances-energy-predictiondata">https://github.com/LuisM78/Appiances-energy-predictiondata</a>	Inability to change static user parameters, predicted user parameters have improved overall system performance in terms of ease of use of smart systems, energy consumption and comfort index management. After optimization, the power consumption also decreased and remained at around 15-18 Wh.
an efficient approach for DLC with day-ahead optimization using edge and fog computing, Cloud, fog and edge computing, proving that the integration of IoT and communication protocols such as MQTT[9].	114 single-family houses that form a small community with modern and flexible appliances	Total daily used flexibility and the number of interruptions decreased, Maximum number of interruptions per appliance decreased, while Peak to Average Ratio (PAR) improved when implementing the proposed DLC architecture. Possible future study of mechanisms for sharing surpluses and exchanges between communities The main shortcomings are related to the regulatory framework to adopt the DLC for energy communities
Internet-of-Things (IoT), Wireless Sensor Network (WSN), and a structure of a Sensor Node (SN), DVFS, [10]	Multiprocessor System-on-Chip (MPSoC) platform	Energy-aware approaches that are able to Computational system considerations are not the total power model The lack of scheduling work on processors considering processor temperature and work constraints. Inefficiency to address the communication gap problem in NoC links for heterogeneous MPSoC systems, inadequacy to create an optimal balance between DPM and DVFS for scalable work,
smart grid architecture model (SGAM)[11].	various control functions, incorporated in the local power controller (LPC) or distributed systems, SECS architecture called SmartCom	Reduction of energy losses by (SECS) due to the possibility of ventilation and control of residential energy consumption, data logging by the (IoT), smart sockets (SO) and devices that promote indoor user identification (UII) environments. a way to help balance energy with minimal impact on the daily usability of electrical equipment. Widespread implementation of sensors throughout the residence Misinterpretation of data generated by residents
identification and tracking of multiple users by internal Wi-Fi handover by making use of smartphones, and through the use of SO technology using	Home Energy Management Systems (HEMS) architecture	Technological requirements: the high degree of flexibility and reuse, service transparency, availability of information and modularity. An ability to predict the final amount of energy consumption by using an intelligent module, A Design and control consumption system for both the customer and the

NFC identification to extract accurate data from [12].		power companies, A tracking system for residential homes with multiple residents with the purpose of improving the management of electricity consumption.
a fully automated IoT-based hierarchical framework for smart homes that takes advantage of edge-computing devices for data processing and storage [13].	Resource-constrained Raspberry Pi (RPI)	The proposed system is 5% faster in motion detection and 6% more efficient in terms of energy consumption than existing solutions. This is done through human detection, fire and interior construction detection, suspicious activity detection, etc. Future work: Using RPI for inexpensive multimedia data processing
Tolojescu- Crisan [14].	qToggle, ESP8266 chips and Raspberry Pi boards	qToggle is simple and flexible, more integrated, more secure, instant updates. Users without technical background Future plan: A feature that will be added to qToggle soon is humidity monitoring, integrate video surveillance into qToggle.

### III. METHODOLOGY

#### A. Proposed System Architecture

Due to its understanding of its own things, a smart house provides its people with individualized services. Homes should not only consume less energy but also be more livable and productive because the home environment influences people's quality of life and capacity to work. When using 2D cameras as sensors, deployment should be adjusted so that the financial gains from energy savings outweigh the associated expenses. Controlling the entire home is not practicable nor possible, it should be stressed. In addition to the activity patterns identified by data monitoring, actual 2D camera sensor data on such inputs should be used to optimize final energy management and consumption. Consequently, the gadget can adjust to new circumstances that were not present in the early models, as well as changes in the setting of the house. The three layers that make up this platform's design are sufficiently all-encompassing to address the requirements of various smart settings, including those considered in the context of smart homes. The IoT-based smart home's three-layer structure is as follows:

Layer 1: Measuring or interpreting sensor data in accordance with user preferences and saving this information in a separate cloud server through a network gateway.

Layer 2: Processing and arranging data gathered from user personal information at.

Layer 3: Data reproduction or application layer, which repeats processed data as information about specific interactions between users and equipment and applies the gathered data to enhance the functionality and performance of the device and provide users better services.

A framework with sensors that assess power use has been created in order to enhance home maintenance and make homes "smart" and efficient. In order to assess if someone is at home, the user may also use the motion sensor's processed data from the cloud service, which offer the meaning of "safe." Additionally, a voltage stabilizer will automatically operate on the installed cloud server to prevent any problems. Users may easily connect to the network using their phone service thanks to the building's Wi-Fi connection. Smart technology enables users to make their homes safer. Among the smart home devices, cameras set throughout the home enable environment monitoring from a phone or other device as needed. Residents will interact with the security system through their mobile or smart phone interfaces. The safety system reacts when it notices motion or unusual movement. As a result, it is clear that this intelligent defense is far more dependable and

trustworthy than the emergency siren. To guarantee the effective and efficient operation of all gadgets, residents will also receive the home equipment power consumption control program. Therefore, here are some of the main advantages of our smart home architecture: optimizing and reducing energy consumption, increasing the performance of the home, identify the source of electrical energy leakage, predictive maintenance improves capital use, increasing the security of the home according to the alarm system based on the presence or absence of inhabitants.

#### B. Proposed System

The regulation of energy consumption results in lower energy use throughout the house [16]. The suggested system's objective is to control or lower energy usage by machine vision. A subset of artificial intelligence is machine vision [17]. This technology uses two-dimensional cameras that are already placed in homes as vision sensors from the automobile to decrease the amount of power used. The proposed system detects whether a person is a resident or a non-resident when they enter the house. Of course, this also applies when they depart, and if a resident leaves the house, power is turned on. Electrical equipment is switched off, and if a visitor departs, the system detects him as a stranger and does not turn off the electrical equipment. This paper presents a smart home energy management system that includes 2D cameras, electric vehicles and energy storage units. The process of the system is provided in Fig. 1.

#### C. Resident Authentication

People may now be identified using a number of different authentication techniques. These techniques include visual biometric devices such as retina scans, iris recognition, fingerprint scanning, hand geometry recognition, ear authentication, signature recognition, and facial recognition as well as chemical biometric devices such as DNA (deoxyribonucleic acid) matching and vein or vascular scanners such as Finger vein ID. Behavioral identifiers such as gait and typing recognition are also included. The facial recognition approach is employed in this investigation.

1) *Face recognition process:* The system will upload photographs into the recognized member's database for the facial recognition procedure. Any new record may be added as needed to the database [18]. Add a fresh photo and the face registration name to the database. Face recognition uses the picture that is retrieved from the database and compared to the image that was collected to identify the subject in the front camera module. The door will open if a match is found in the faces. If not, a red bulb will come on. The bell will ring if it is the home's owner. If not, a message that someone is waiting

outside your house will be issued. When the image of an unfamiliar individual is found, this system provides alerts.

2) *Face recognition platform:* The facial recognition algorithm is included in Jetson Nano. In this system, data is sent via the cloud to a remote server from a smartphone. An IoT-based system can be implemented to automate the authentication process for security purposes. The electricity and power consumption in this system is low because it needs very little electricity. It needs at least five volts to work. The Nano Jetson module includes the TensorRT-powered AI development kit in JetPack. It allows the processing of complex deep learning algorithms. The specifications of the Jetson Nano used are as follows:

- GPU: 128-core NVIDIA Maxwell
- CPU: Quad-core ARM A57 @ 1.43 GHz
- Memory: 2 GB 64-bit LPDDR4 25.6 GB/s
- Storage microSD (Card not included)
- Camera 1x MIPI CSI-2 connector

3) *YOLO based face recognition:* The YOLOv5 based algorithm used for facial recognition. A single neural network was utilized by YOLO to identify and estimate positions. It predicts the positions of items based on the characteristics of the entire picture [4]. The four network model variations of YOLOv5—YOLOv5s, YOLOv5m, YOLOv5l, and YOLOv5x—are based on the differences in network depth and breadth. According to the literature, the YOLOv5s network's

detection and placement speed is quicker than YOLOv4's, and its accuracy is comparable. The backbone, neck, and head are the three primary parts of the YOLOv5 network. Backbone gathers and creates image characteristics on various pictures when the image is input. Next, the Head predicts the image characteristics to provide bounding boxes and predicted categories after the Neck stitches the image features and delivers them to the prediction layer. The GIOU is the network loss function used by the YOLOv5 network, as illustrated in Equation (1).

$$GIOU = IOU - \frac{|C-(A \cup B)|}{|C|} \quad (1)$$

Where  $A, B \subseteq S \subseteq R^n$  represent two arbitrary boxes.  $C$  represents the smallest convex box,  $C \subseteq S \subseteq R^n$ , enclosing both  $A$  and  $B$  and  $IOU = |A \cap B| / |A \cup B|$ .

Combining the GIOU loss function with the non-maximum suppression method filters the best target frame when the input network predicts picture features [15].

#### D. Dataset

In this research, a dataset including 500 images was used. The images are about 50 people and collect 10 images from each. Among them, 80% of the images were used for training and 20% for evaluation. These images are labeled according to the training and evaluation of the YOLOv5 model. The YOLO pattern was used to label the images. The images are labeled in ten classes for each person.

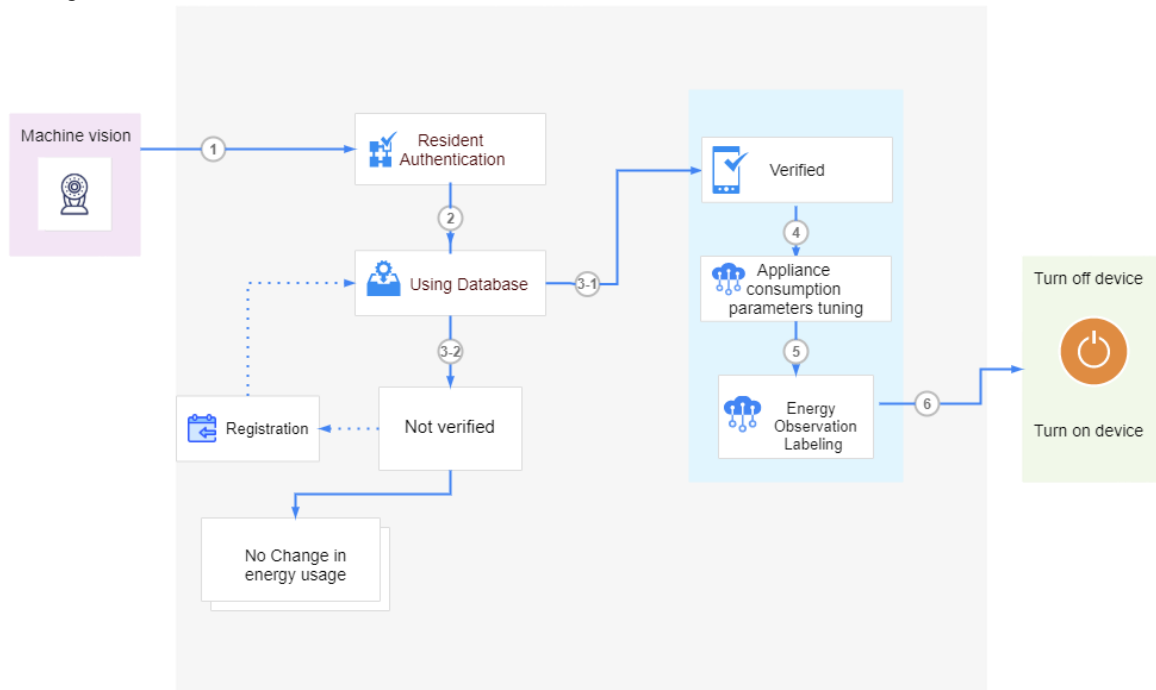


Fig. 1. Proposed system.

#### E. Model Generation

In this study, transfer learning is used to retrain algorithms YOLOv5 series which is based on the dataset of common

objects in the field (COCO). This dataset was trained with 330 thousand images and 80 classes. This model is used as pretrained model for transfer learning. In modeling, it is used a



batch size of 16 and 100 epochs. The modeling processes are performed for different versions of YOLOv5. These versions are v5n, v5s, v5m, v5l, v5x. The model with deep layers performs better in training and converges faster, as seen by the results while training with the same number of repetitions. The v5n model in more epochs is reached in balance and the error has been minimized, but in the v5x model, there is an error in fewer epochs' energy storage units.

#### IV. RESULTS AND MODEL EVALUATION

This section presents experimental results and performance analysis for face recognition using different YOLOv5 models.

##### A. Performance Metric

Performance analysis is checked in this section. The generated model based on YOLOv5 is evaluated. In this study, Precision, Recall, F1 and mAP metrics are used for evaluation of the model.

The first three metrics are computed by TP (true positive), TN (true negative), FP (false positive) and FN (false negative). The explanations are shown in Table II.

TABLE II. THE METRICS DEFINITION FOR PERFORMANCE ANALYSIS

Metric	Explanations
TP	Refers to how many faces are successfully identified
TN	Refers to how many backgrounds are identified as backgrounds
FP	Refers to the number of backgrounds that are wrongly identified as backgrounds
FN	Refers to the number of faces that were misclassified as a backdrop

Precision (P): The precision determines the accuracy and reliability of the positive answers of the models being correct. Equation 2 presents how the P metric is calculated.

$$P = \frac{TP}{TP+FP} \quad (2)$$

Recall (R): Recall metric determines the ability and sensitivity of the models in performing the correct classification. According to equation 3, this is done by calculating the ratio of correct positive answers to the sum of correct positive answers and false negative answers. This standard is also known as the correct positive response rate and model accuracy rate.

$$R = \frac{TP}{TP+FN} \quad (3)$$

F1-score: F-score is determined according to equation 4 by calculating the equivalent weighted average of two metrics, Precision(P) and Recall(R). The detection rate of positive samples, which is the difference between the evaluation metrics, is considered by both precision and recall in the R-P curve. A more visual way to evaluate the models is the average accuracy (AP), which represents the area under the R-P curve (AUC), higher AP means better machine learning model. mAP is an average of AP values. Therefore, the higher and to the right the R-P curve is, the better the model will perform.

$$F1 - score = 2 * \frac{P*R}{P+R} \quad (4)$$

##### B. Performance Analysis

In this study, YOLO algorithm is most popular and the most efficient algorithms are selected for face recognition purpose in the proposed system. In order to do fair comparison, we experimented various versions of YOLO algorithms in the same data to demonstrate which algorithm is better than others. The result of performance analyses shows that, among the models of YOLOv5, YOLOv5n with mAP = 0.77, F1-score=0.74, R=0.70 and P=0.78 is the smallest network model, which has only 1.9 million parameters. Because the models come in various sizes, the smaller model requires less time during diagnosing. As a result, the lowest time for the YOLOv5n model is required for the huge model, which requires more time.

#### V. CONCLUSION AND FUTURE STUDIES

Large data from sensors and energy meters demand extremely effective data processing systems, where contemporary technologies like Big Data and the Internet of Things have found their place in the development of energy applications. The advancement of new data mining techniques has outpaced the capabilities of conventional energy modeling and forecast techniques. Various smart technologies have been used to save energy. Traditional building energy modeling that uses software and statistical methods does not provide the need for quick and precise prediction required by decision-making systems. As a novel approach to energy modeling and assessment for many types of buildings, IOT models have demonstrated considerable potential. The pros and drawbacks of each model are discussed in this study, which gives an overview of IOT models used for benchmarking and predicting building energy usage.

In this paper, a YOIO method is used for facial recognition. And compared to all kinds of YOIO methods, the YOIOv5n method was the fastest and most efficient method. So, by using the YOIOv5s method on the Jetson Nano platform, it creates the possibility of authenticating the residents of the houses to identify them to turn on or off the sources of energy consumption in the houses. Therefore, the presented system is designed with the aim of optimizing energy consumption in houses and with the aim of ensuring the safety of the residents of the houses. Future research can focus on optimizing energy consumption strategies by developing advanced algorithms and techniques, such as reinforcement learning, to dynamically adjust energy usage based on authenticated residents' identities and preferences. Further study should address privacy and security concerns by exploring privacy-preserving techniques and implementing robust security measures to protect sensitive resident data during the authentication process in the facial recognition-based energy optimization system. Moreover, future studies on the use of Internet of Things in smart homes to optimize energy consumption will focus more on the use of mobile phone GPS. Moreover, The Intelligent Computational Engine will be created and used with the established electric energy consumption prediction models to achieve automated, real-time, and optimum control of electric energy consumption. This will reduce ineffective energy management, wasted energy resources, and high energy prices.

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# Application of Medical Brain CT/MRI Image Fusion Algorithm based on Neural Network

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**Abstract**—In recent years, fused images have been developed for fast processing of medical images, which provide a more reliable basis for reducing the burden on physicians because they can contain multiple times the image information. In order to achieve fast and accurate recognition results in medical image recognition, avoid similar blocks and shadow fitting in CT/MR fusion images, and improve the entire medical system, in this study, CT/MRI image fusion of brain images is studied based on algorithms generated by Convolutional Neural Network (CNN). The study utilizes Rolling Guidance Filter (RGF) to divide medical CT/MRI images into two parts, one of which is used for model training and the other for image fusion. In the experiments, the results of all three experiments are compared with the Nonsub Sampled Contourlet Transform - Piecewise Convolutional Neural Network (NSCT - PCNN), and the CNN-RGF MI/IE/SSIM/AG values of CNN-RGF are superior compared to the conventional algorithm of NSCT-RCNN with an average improvement of 10.0% and above, and the resulting CNN-RGF observed meningitis, hydrocephalus, and cerebral infarction with an average of 24.8% higher compared to NSCT-RCNN. The outcomes show that for brain image fusion and detection, the CNN-RGF approach put forward in the study performs better.

**Keywords**—Convolutional neural network; image; integration; CT; MRI

## I. INTRODUCTION

In recent years, medical imaging has been rapidly developing as it has started to be involved in disease diagnosis and widely used in clinical treatment. As the amount of comprehensive information increases, medical images using a single modality mode gradually fail to meet the needs of physicians. The information provided by traditional medical images can be too one-sided, and there are many tissues and organs in the human body, so doctors using the naked eye to identify the images will inevitably produce eye fatigue, thus affecting the accuracy of diagnosis [1, 2]. Moreover, the development of medical devices is really backward, and the blurriness of imaging is sometimes even lower than the resolution of the human eye, so it is necessary to consider the fusion of multiple images together. Through a method to aggregate multiple medical images into one, not only can the useful information be concentrated into one, which improves the image utilization rate, but also can reduce the amount of images for doctors to see, which is convenient for doctors to locate the precise lesion and target medication to patients, and perhaps treat more difficult and complicated diseases [3]. Therefore, research on fusing multiple images together is imminent. Recently, a classical algorithm, Convolutional Neural Network (CNN), has come into the view of researchers

and become popular in image fusion. The CNN has powerful feature extraction capability, and the Rolling Guidance Filter (RGF) is able to handle the similarity blocks and anaglyph of fused images well [4]. Based on the advantages of both, this study establishes a CNN-RGF algorithm to fuse medical images at pixel level considering four plain objective quantities after CT/MRI fusion images. The aim is to achieve fast and accurate recognition results in medical image recognition, and to avoid similar blocks and shadow-fitting CT/MRI fused images. This will reduce the processing burden of doctors, improve their efficiency, and thus improve the whole medical system. The main contribution of the research is to extract and fuse different image information of the same target from different angles, levels, or types of sensors. At the same time, the low transparency information in the image is processed through image denoising, enhancement, and other image processing techniques, thereby significantly improving the accuracy, restoration, and reliability of the image, and providing clearer and more accurate expression for the generation of target images a fused image with complete content and rich image information. The innovation of the research lies in the use of a pyramid based multi-scale image decomposition method, which enables fusion at each decomposition level. Each source image is decomposed through a regional Laplacian pyramid, making the image features more distinct. Therefore, this method plays an important role in medical image fusion.

The research structure is mainly divided into four parts. The first part is a summary of relevant research on medical image fusion at home and abroad. The second part is to build a brain CT/MRI image fusion model based on CNN, and introduce the specific improvement process and research of the algorithm. The third part is to analyze the performance of the constructed model, reflecting its performance through indicators such as accuracy and error. The fourth part is a summary and analysis of the research, discussing the achievements and shortcomings of the research, and proposing suggestions for future research directions.

## II. RELATED WORKS

A very important branch of image processing technology, i.e., medical image fusion, has a very important role in doctors' rapid treatment of patients, targeted drug administration, etc. Wang et al. [5] studied multi-feature fusion in depth and proposed a medical brain image algorithm based on it. Texture information was obtained by feature extraction of CNNs, and morphological features were obtained by feature extraction of voxel information. These two types of features were concatenated and then the feature selection stage was

optimized using a heuristic search algorithm. They analyzed experimentally to select the optimal values of the parameters based on the heuristic search and extracted the optimal feature subset after determining the parameter values. Finally, the algorithm improved the accuracy and efficiency of brain image classification compared to similar algorithms. Polinati et al. proposed a new method for medical image fusion, incorporating content decomposition and sigmoid function [6]. They considered and implemented the use of empirical wavelet transform for content-based decomposition for preserving edges and corner points. They discovered that using detail layer fusion directly results in significant artefacts, so they used the sigmoid function to improve weight scaling. They tested their suggested method with previous fusion methods after fusing 24 pairs of MRI-PET and MRI-SPECT pictures, and they discovered that both the qualitative and quantitative outcomes had significantly improved. By first filtering the CT and MR image sets through a set of various scaled filter sets, different pairs of representations of CT and MR were obtained. Each pair of different representations was then used to train the corresponding CNN to obtain the final fused image, and it was compared with nine recent state-of-the-art multimodal fusion methods. Wang et al. [7] proposed a fusion method based on a multi-CNN combination of fuzzy neural networks. The experimental findings demonstrated that in objective evaluation and visual quality, the fusion approach greatly exceeded other comparative fusion methods. The method excelled in four measures, enhanced multimodal medical picture fusion quality, and helped doctors diagnose diseases more accurately. A brand-new picture fusion technique based on sparse representation was proposed by Yu et al. [8]. They studied that after merging all source images into a joint matrix and training it by an algorithm, an overcomplete coefficient would be obtained that can be used to represent this matrix. The obtained over-completeness was used as coefficients of the image features and combined with choose-max fusion rules. The fused images were reconstructed from the connected coefficients and the overcomplete dictionary and compared with the conventional algorithms. They found that the method had better fusion performance compared to three state-of-the-art algorithms.

Using the non-subsampled shear wave transform (NSST), smooth wavelet transform, and impulsive coupled neural network, Singh and Gupta suggested a multilevel multimodal fusion model [9]. A weighted Laplace pyramid was used to extract structural features from the source image and apply them to an adaptive model that can map the feature weights used for low-band component fusion using absolute maxima and absolute differences, a rule that allows fusion of high-frequency NSST components to preserve complex directional details. The first step was to use NSST to decompose the source image into optimal sparse multi-resolution components. The strategy, when compared to previous methods, dramatically improved medical picture fusion with good visual quality and improved computational metrics, according to experimental results. The non-subsampled contour wave transform (NSCT) domain image fusion approach was proposed by Yu et al. and is based on pulse-output neural networks (PCNN) and hybrid frog-leaping algorithms (SFLA) [10]. First, the source image was decomposed into low-

frequency and high-frequency subbands using NSCT, and secondly, different PCNN fusion rules were designed. Finally, the fused images were reconstructed by inverse NSCT. The fused image preserved more of the original image's information with strong edge retention, according to a visual and quantitative examination of the experimental results. Guan et al. proposed an image fusion algorithm based on multi-scale analysis coupled with approximate sparse representation to better deal with the singularity of high-dimensional features of images and to take into account the fusion of image target features and average intensity information [11]. The high-frequency and low-frequency information of the image was obtained by the scale analysis of the source image, and the specific target detail information was highlighted. The approximate sparse representation was designed to approximate the singular curve with the smallest coefficients. A decision mapping was constructed to analyze the activity and matching degree of all coefficients on the same subband and output the decision values, which were used to match and fuse the images. Then the final fused image was obtained by multi-scale inverse transform. The experimental results showed that better visual effects can be obtained with high robustness and wide application.

Multiple researchers have found that CT/MRI image fusion algorithms are very popular internationally and have achieved relatively successful data in experiments, with an overall success rate of over 80% for image fusion [12-16]. Although image fusion has made some progress, its effectiveness still has a significant room for improvement. Research has found that there is relatively little research on using CNN algorithms to form composite neural networks in image fusion. Therefore, combining CNN and RGF can leverage their respective advantages, compensate for the shortcomings of individual algorithms, and perfectly avoid their own shortcomings. The research aims to further improve the effectiveness of medical image fusion.

### III. CNN-BASED BRAIN CT/MRI IMAGE FUSION STUDY

A medical image fusion method based on pyramid and CNN is proposed. By using multi-scale decomposition of pyramids that are more conducive to human visual perception, the fusion effect is improved. At the same time, the idea of support vector machine (SVM) is used to improve the CNN network, which does not rely on empirical initialization parameters and effectively extracts image features to obtain more suitable weight maps. The pooling and sampling layers in traditional CNN networks is removed to reduce the loss of image information.

#### A. Application of Multi-Scale Geometric Transform in Image Fusion Algorithm

The research on the overall framework of medical image fusion proposes a medical image fusion algorithm that can be summarized into the following four steps. The first step is to input the source image into an improved CNN and generate a weight map. The second step is pyramid decomposition, which uses the multi-scale image decomposition method of the pyramid to fuse at each decomposition level. Each source image is decomposed through the regional Laplace pyramid. The third step is coefficient fusion. The fourth step is the

reconstruction of the Laplace pyramid. The specific framework diagram is shown in Fig. 1.

Computed Tomography (CT) is an important tool for diagnosing lesions because of its rapid scanning capability, while Magnetic Resonance Imaging (MR) has the strongest resolution of soft tissue and can observe lesions without dead space [17-19]. By combining CT/MRI together, the accuracy of unimodal medical images can be greatly improved. For two images of the same target, the levels after fusion can be divided into three kinds, as in Fig. 2.

From Fig. 2, the fusion of images can be divided into three levels: pixel, feature and decision. Among them, direct fusion from the original image is called pixel fusion; feature extraction of the original image once and then fusion is called feature fusion; feature extraction of the image that has been extracted once and then fusion is called decision fusion, implying that a decision can be made directly from the decision fused image. The contribution of decision fusion to CT/MRI of the brain is many, including but not limited to the timely detection of lesions, saving the time of doctors and providing a possibility of cure for patients. In order that no one will suffer, this study investigates the method of brain CT/MRI image fusion, which will be discussed in detail next. Independent individual neurons have simple structures, but neural network systems composed of large numbers of neurons are rich in behavior. The relationships between neurons are intricate and

complex. The expressions of neurons are shown in Equation (1) [20].

$$\begin{cases} y_l = f \left( \sum_{k=0}^{N_2-1} \omega''_{kl} x_k'' - \theta_l'' \right) \\ x_k'' = f \left( \sum_{j=0}^{N_1-1} \omega'_{kj} x_j' - \theta_k' \right) \\ x_j' = f \left( \sum_{i=0}^{N-1} \omega_{ij} x_i - \theta_j \right) \end{cases} \quad (1)$$

In the above Equation (1), the nonlinear function is denoted as  $f$ ; two neurons are defined as  $i, j$ ; then the link between them is called  $\omega_j$  and its threshold is called  $\theta$ . To reflect how much valid information is contained in the image, Mutual Information (MI) is chosen to judge the size of information data in the image. It supposes that there exist  $(X, Y)$  as random variables and their distribution is jointly located at  $p(x, y)$ , then  $p(x)p(y)$  is called the edge of the distribution, then their relationship is as denoted in Equation (2).

$$I(X, Y) = \sum_{x \in X} \sum_{y \in Y} p(x, y) \log \frac{p(x, y)}{p(x)p(y)} \quad (2)$$

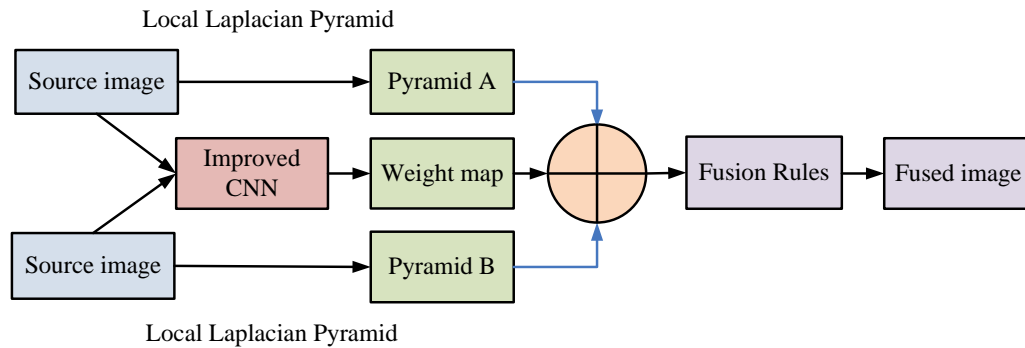


Fig. 1. Overall framework of medical image fusion process.

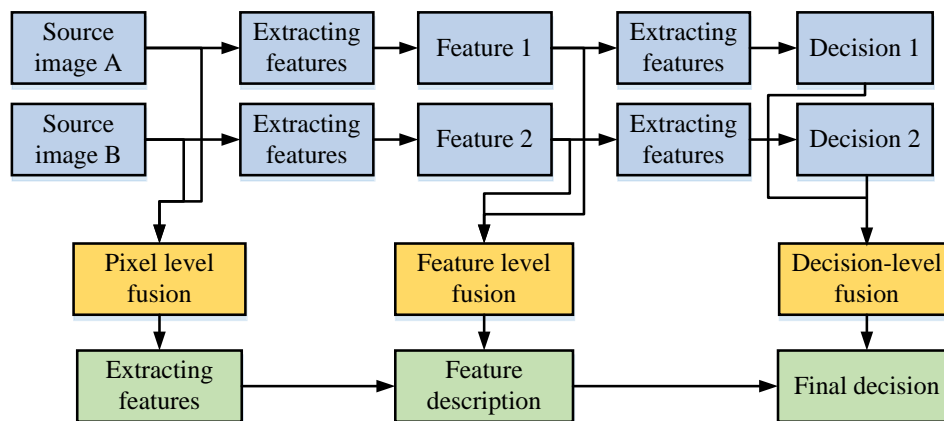


Fig. 2. Three different levels of image fusion.

For problems involving brain images, it is not enough to discriminate the amount of data by MI alone, but also requires the complement of Information Entropy (IE). The smaller the IE, the more residual the image is, as indicated in Equation (3).

$$H(x) = E(I(x_i)) = E\left(\log\left(2, \frac{1}{P(x_i)}\right)\right) = -\sum P(x_i) \log(2, P(x_i)) (i = 1, 2, \dots, n) \quad (3)$$

CNN is the most commonly used network model in medical field. A complete CNN mainly consists of input, convolutional, pooling, fully connected and output layers. Among them, the convolutional layer is the core of CNN and is also the source of the name of CNN. It assumes that  $\omega_i$  represents the full-valued vector, the convolution operation is noted as  $\otimes$ , and the activation function is called  $\otimes$ , the operations in the convolution layer are as expressed in Equation (4).

$$H_i = f(H_{i-1} \otimes \omega_i + b_i) \quad (4)$$

To construct multi-resolution images, the concept of Local Laplacian Pyramid (LLP) is also introduced. LLP has the power to not only accurately distinguish between the edges and textures of an image, but even to fuse the image with the tower layer. Due to many updates, LLP has never had any artifact problems. Before performing LLP operation on an image, a Gaussian Pyramid (GP) decomposition is performed, as in Equation (5).

$$\begin{cases} G_i^*\left(\frac{i+m}{2}, \frac{j+n}{2}\right) = \begin{cases} G_i\left(\frac{i+m}{2}, \frac{j+n}{2}\right) & \frac{i+m}{2}, \frac{j+n}{2} \in Z \\ 0 & \text{Elses} \end{cases} \\ G_i^*(i, j) = 4 \sum_{m=-2}^2 \sum_{n=-2}^2 w(m, n) G_i\left(\frac{i+m}{2}, \frac{j+n}{2}\right) \end{cases} \quad (5)$$

In Equation (5),  $G_i^*$  is the image after GP processing, and  $i, j$  means the current GP layer number. The image after undergoing GP decomposition cannot obtain the risk in the evolutionary process, such as the empirical risk, but also the information is lost [21]. To avoid information loss and at the same time deepen the impression of information in the network, the residual learning module is built according to Equations (3) to (5) as in Fig. 3.

In Fig. 3, the input primitive image can finally obtain an optimized image of size  $6*6*256$  after first undergoing C-level evolution. Then two steps of weighting are performed, and after passing it, it can be input among LLP, which is calculated as Equation (6).

$$\begin{cases} O = \text{collapsywhane}(S_i[I'(v)]) \\ I'(v) = \begin{cases} g + \text{sign}(v-g)\sigma_r \left(\frac{|v-g|}{\sigma_r}\right)^\alpha & |v-g| \leq \sigma_r \\ g + \text{sign}(v-g)\left(\beta(|v-g| - \sigma_r) + \sigma_r\right) & \text{else} \end{cases} \end{cases} \quad (6)$$

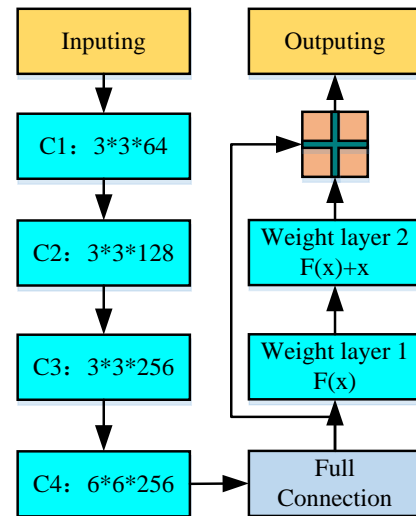


Fig. 3. Residual learning module.

In Equation (6), the image output by LLP is called  $O$ , and the image of each layer is noted as  $S_i$ . After a set of processes in LLP, the coefficients due to the decomposition are obtained, which are denoted as  $v$ , then  $I'(v)$  is also called the standard function based on the decomposition coefficients. The reconstruction operator is then denoted as *collapsywhane* and the pixel value obtained from the LLP can be called  $g$ . In addition,  $\alpha, \beta, \sigma_r$  are three variable parameters of LLP, which are intensity threshold, detail factor and ranging factor. The intensity threshold serves as a boundary to distinguish edges from details; the detail factor and the range factor control the enhancement and reduction, respectively, one controlling the details and the other controlling the range. After the GP and LP, the signal analysis is performed. The signal analysis tool is the well-known Multiscale Geometric Analysis (MGA), whose flow is shown in Fig. 4.

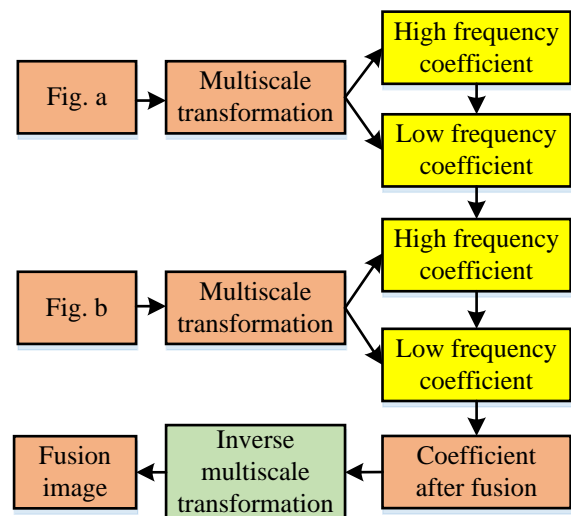


Fig. 4. Multi-scale geometric transformation image fusion.



In Fig. 4, the original image is first multi-scale transformed, which will result in a decomposed source image, and the fusion rule is applied to the decomposed image to fuse high-frequency coefficients or low-frequency coefficients, as appropriate. Then the fused coefficients are inverse multi-scale transformed, and finally the fused image is recombined to form [22]. For the fused image, the gap between the distortion and the original image is contacted, i.e., the Fidelity of Visual Information (VIF) is calculated, as in Equation (7).

$$VIF_k(A, B, F) = \frac{\sum_b FVID_{k,b}(A, B, F)}{\sum_b FVIND_{k,b}(A, B, F)} \quad (7)$$

In Equation (7), the visual information degree of distortion or not is expressed by  $FVID, FVIND$ , respectively.  $A, B, F$  denotes the degree of information of the pixel and  $b$  denotes the value of the coordinate at which it is located.

### B. MR/CT Medical Image Fusion based on the Combination of CNN and Rolling Guide Filtering

RGF has the ability to guarantee smooth details even under scale measurement. RGF works iteratively and converges particularly fast; RGF works over a wide range, and small structure removal and edge restoration are its features, which are well suited for medical image studies. If it assumes that  $I$  is the input image, then  $G$  represents the output image, the standard deviation of the Gaussian filter is noted as  $\sigma_s^2$  and the pixel index can be expressed by  $p, q$  as in Equation (8).

$$G(p) = \frac{1}{K_p} \sum_{q \in N(p)} \exp\left(-\frac{\|p-q\|^2}{2\sigma_s^2}\right) I(q) \quad (8)$$

In Equation (8), when  $K_p = \sum_{q \in N(p)} \exp\left(-\frac{\|p-q\|^2}{2\sigma_s^2}\right)$  is used, it means that it is available for normalization. When the RGF takes another approach to recover the edges, that must be the joint RGF iteration, at which time the source output of the filter is represented by  $J^t$ . When the filter iterates to  $t$  times, the

output at that time is represented by  $J^{t+1}$ , and the relationship between them is as in Equation (9).

$$J^{t+1}(p) = \frac{1}{K_p} \sum_{q \in N(p)} \exp\left(-\frac{\|p-q\|^2}{2\sigma_s^2} - \frac{\|J^t(p) - J^t(q)\|^2}{2\sigma_s^2}\right) I(q) \quad (9)$$

In Equation (9), the weight range is controlled jointly using  $I, \sigma_r^2$ . The CNN model is testing the activity level metric while using a huge number of photos to train its data and create adaptive fusion rules. CNN is able to greatly reduce the difficulty of designing fusion rules because image fusion with CNN is more efficient than manual design, as shown in Fig. 5.

From Fig. 5, a normal image block size is  $16 \times 16$ , and after a nonlinear mapping, it gets 64 feature maps of size  $16 \times 16$ , which should be processed with special care to prevent information loss. 64 images undergo another nonlinear mapping, and then compression in the image, which can get 128 refined images of  $8 \times 8$ . The refined image can also undergo a final expansion to obtain 256  $8 \times 8$  results. This is already the limit of convolutional kernel, if it is too large, it is easy to cause information loss; if it is too small, the feature extraction is not obvious enough [23-25]. For medical class images, fluctuations in other local regions can be better characterized, so a new parametric max-min filtering algorithm is introduced, calculated as in Equation (10).

$$\bar{I}(i, j) = \max_{(m,n) \in \Omega} (I(m, n)) - \min_{(m,n) \in \Omega} (I(m, n)) \quad (10)$$

In Equation (10), the original image is recorded with  $I$ , the center of  $I$  is noted as  $\Omega$  and  $(i, j)$  is any point.

$\max_{(m,n) \in \Omega} (I(m, n))$  and  $\min_{(m,n) \in \Omega} (I(m, n))$  are the max and the mini filters. Images sometimes have similar shared blocks, which can be established in Equation (11).

$$\eta_q = \|P_q - P_r\|_{E_w} \quad (11)$$

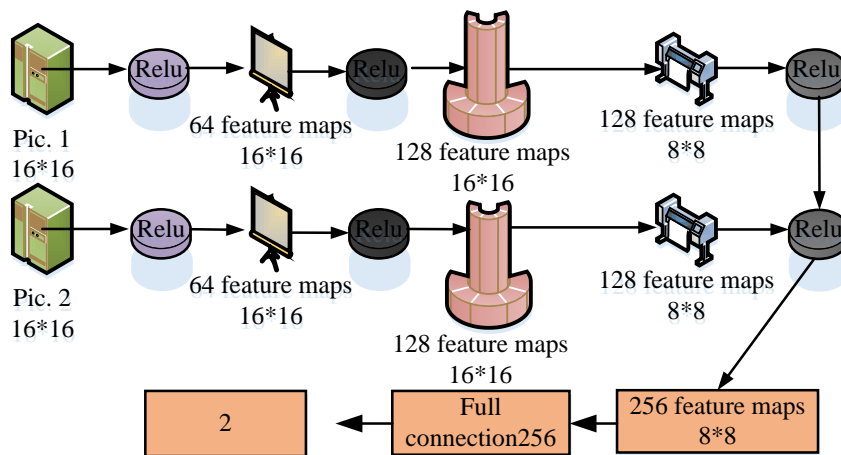


Fig. 5. CNN structure.

In Equation (11),  $\eta_q$  represents the Euclidean distance of the similar parts between the shared blocks. The given reference block is noted as  $P_q$ , and the candidate block is defined as  $P_r$ . The candidate blocks are to avoid gradient reciprocity and gradient destruction, and also to be adaptive to the weights that appear. The fusion of the input graph is set according to the known judging criteria, as in Fig. 6.

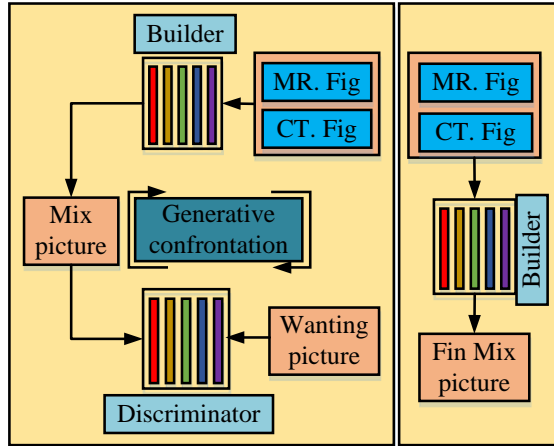


Fig. 6. Image fusion process.

From Fig. 6, if the detail image has the feature of local similarity, then the block can be cut into a large number of square blocks of equal size, called Shared Similar Block (SSB), which is defined by Equation (12).

$$L_W^S(r) = L_{W^A}(r) \cap L_{W^B}(r) \quad (12)$$

In Equation (12), the image  $A, B$  has  $k$  similar blocks to the image  $L_{W^A}, L_{W^B}$ , respectively, and the SSB to be calculated is  $L_W^S(r)$ . The SSB is somewhat different from the traditional perceptron, as reflected in the optimization of the fixed denominator, and the optimization function is as in Equation (13).

$$\min \frac{\|W\|_2^2}{2}, y_i (W^T x_i + b) \geq 1 (i = 1 - N) \quad (13)$$

In Equation (13),  $\min \frac{\|W\|_2^2}{2}$  is defined as the large distance from all points to the shared plane, and  $y_i$  implies a regression analysis that can seek the optimal solution for learning ability and distance. For human vision, the color and state of the image are very sensitive, so a small deficiency in a key location can cause a large change. For medical matters, the larger the area of the image is the more informative it is. Medical imaging characteristics can prove that the largest and smallest pixel difference reflects important information. So for the study of images, the first step is to perform a pyramid decomposition so that the fusion applies to each level, as in Fig. 7.

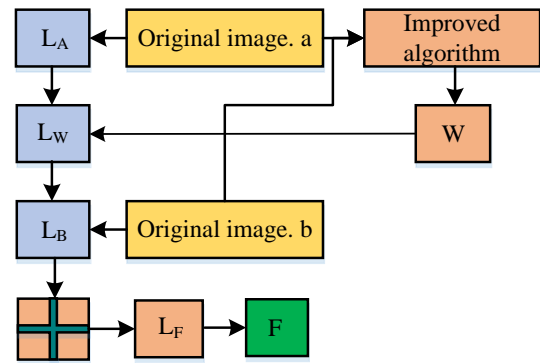


Fig. 7. Improved algorithm for image fusion.

In Fig. 7, the original images  $A, B$  and  $W$  are input to the algorithm based on the combination of rolling filter and CNN to obtain three initial images  $L_A, L_B$  and  $L_W$ . The obtained three images are input into the Laplace pyramid and then feature fusion operation is performed to be able to output the final image  $F$ . The risk in this is mainly in two aspects, containing empirical risk and structural risk, to be considered simultaneously. The empirical risk is to be controlled by the generalization of the CNN, and the study is to control both time and geographic location because it is most influenced by environmental factors and other factors are negligible [26-28]. Structural risk reduction is to be achieved by dimensionality reduction of the CNN, as reflected in the histogram of the probability distribution of the input. The function mapping is then performed by hidden neurons, and assuming that the filter convolves the image support values and the standard convolution kernel of step size is maximally pooled, Equation (14) can be obtained.

$$c_{i,j,o}(\psi) = f \left( \sum_{h=-0.5k}^{0.5k} \sum_{w=-0.5k}^{0.5k} \sum_{u=1}^N \theta_{h,w,u,o} \bullet \psi_{g(h,w,i,j,u)} \right) \quad (14)$$

In Equation (14), the kernel weights are represented by  $\theta$ ;  $u$  denotes the scale of the maximum pool operation;  $(i, j)$  is the coordinate;  $f(\bullet)$  represents the activation function of Relu, which is chosen to represent the elements of the previous layer of feedback for this operation.

#### IV. ANALYSIS OF MEDICAL MR/CT IMAGE FUSION MODEL BASED ON CNN

##### A. Determination of Model Parameters for Fused CNN-RGF

For this study, the dataset from The First Affiliated Hospital of Harbin Medical University was used, and images of normal brains as well as common disease brains, such as brain atrophy, were selected. The experimental environment, i.e., the parameters, is shown in Table I.

For the image processing, the image was first normalized and then compared with NSCT - PCNN for comparison, as shown in Fig. 8 [29, 30].

TABLE I. EXPERIMENTAL PARAMETERS

GPU	Internal storage	Operating system	Channel output
NVIDIA Tesla M60	256GB*2	128Ubuntu 21.02.20	64; 128; 256
Flash memory	Operator	Input	Filter parameters
CUDA Toolkit 23.0	Python	3.0	3*3; Floor2
Step length	Number residual blocks	Display card	CPU
1	32	Tensor flow 2.40	Windows X10

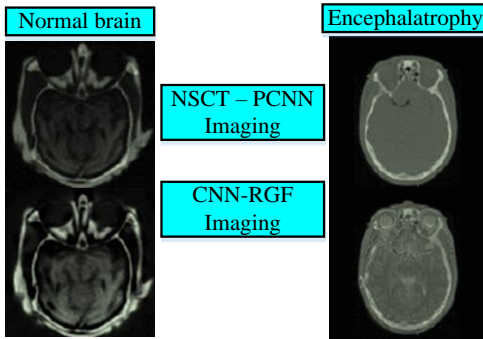


Fig. 8. Comparison chart of CT/MRI fusion effect.

From Fig. 8, the brain luminosity of NSCT - PCNN imaging was not as bright as CNN-RGF, and even in the processing of details, it was obvious that CNN-RGF was more carefully discriminated. Even though NSCT - PCNN was more economically cost effective, it was more important to be medically rigorous. Then the dataset had to be trained iteratively as well as with error training, as in Fig. 9.

From Fig. 9, the accuracy of CNN-RGF was lower than that of NSCT-PCNN until 200 iterations, but the error rate was higher than that of NSCT-PCNN with the increase of the iteration times. However, when the iteration times reached 200 or more, the accuracy of CNN-RGF was unmatched by NSCT-PCNN. Although the increase in the iteration times decreased the operational efficiency of the algorithm, the accuracy also increased with the iteration times. Since the recognition of brain images was important for brain diseases, the accuracy of image recognition was more important, and based on this, the CNN-RGF algorithm proposed in the study had more significant advantages. The corresponding results in Fig. 9 are shown in Table II.

TABLE II. PERFORMANCE MEAN AND STANDARD DEVIATION OF MODEL TRAINING

Algorithm	Precision			Deviation		
	Highest Value	Average Value	Standard Deviation	Minimum	Average Value	Standard Deviation
CNN-RGF	0.94	0.85	0.13	0.52	0.64	0.11
NSCT-PCNN	0.81	0.69	0.18	0.71	0.86	0.13

In Table II, the highest accuracy value of CNN-RGF was 0.94, the average value was 0.85, and the error was 0.13; The highest accuracy of NSCT-PCNN was 0.81, with an average of 0.69 and a deviation of 0.18. The minimum error value of CNN-RGF was 0.52, the average value was 0.64, and the deviation was 0.11. The highest accuracy of NSCT-PCNN was 0.71, with an average of 0.86 and a deviation of 0.13. The results indicated that the proposed CNN-RGF model had higher accuracy and stability.

B. Experimental Data Validation based on CNN-RGF Model

To make the results more generalizable and applicable to all hospitals, this study provided a high-level evaluation of the results based on several common metrics. These were MI, IE, Structural Similarity (SSIM) and Average Grads (AG). The values obtained from the above four box indicators belonged to dimensionless values and were mainly used for comparison. Three common brain diseases were studied based on the four metrics, and the generated results were compared using NSCT-PCNN with CNN-RGF, as shown in Fig. 10.

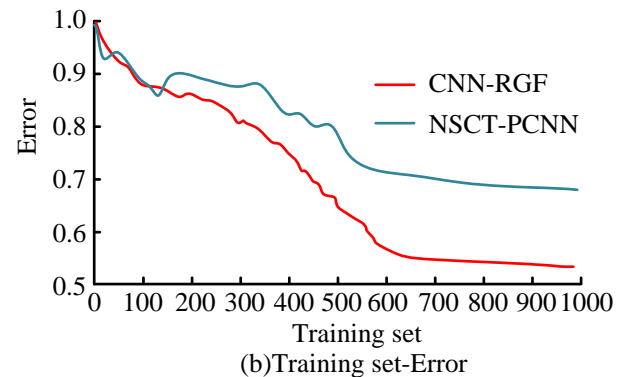
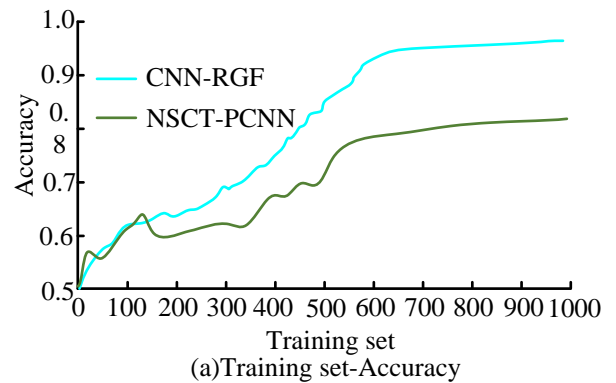


Fig. 9. Iterative training and error training of datasets.

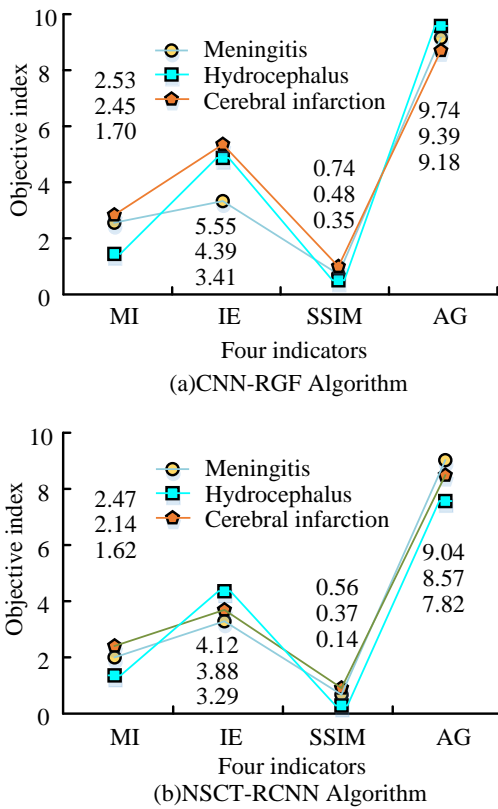


Fig. 10. Comparison of three kinds of encephalopathy and four indexes by using CNN-RGF (a) and NSCT-RCNN (b).

From Fig. 10, firstly three brain diseases, including meningitis, hydrocephalus and cerebral infarction, were characterized in CNN-RGF which was higher than NSCT-RCNN. In other words, the image quality obtained by fusion was better when CNN-RGF was used to characterize brain diseases. The CNN-RGF algorithm reached the optimum in all three groups of experiments for meningitis, hydrocephalus and cerebral infarction, and the enhancements for MI reached 25%, 2.5% and 20.5%, respectively, which were the plain objective constants with the largest enhancements. The smallest improvement was SSIM, but it also reached 16.6%, 1.6%, and 15.0%, respectively. Among them, MI could reflect the rate of change of image brightness, and SSIM could consider both brightness and contrast of the image. The MI and SSIM values were considered together, i.e., the higher their values, the clearer the image. The corresponding results in Fig. 10 are shown in Table III.

In Table III, both CNN-RGF and NSCT-PCNN had higher evaluation values for various indicators in the same disease. In the standard deviation, CNN-RGF also exhibited better stability. To make the test results more comprehensive, their CT/MRI objective indexes were also evaluated, as shown in Fig. 11.

In Fig. 11, CNN-RGF outperformed the NSCT-RCNN algorithm in all objective metrics when observing CT/MRI maps of the brain. The observation of MI in meningitis reached the optimal value, the observation of SSIM in cerebral infarction belonged to the suboptimal value, and the four

objective values based on CT/MRI were improved by 22.5% on average compared with the NSCT-RCNN algorithm, which could provide a large number of medical CT/MRI quality images. Since medical images represent personal privacy, the First Hospital of Harbin Medical University did not keep some data. The dataset for this study required some pioneering, which largely limited the performance of the constructed model. The corresponding results in Fig. 11 are shown in Table IV.

In Table IV, both CNN-RGF and NSCT-PCNN had higher evaluation values for various indicators in the same disease; In the standard deviation, CNN-RGF also exhibited better stability. Taking into account the implications, a complementary experiment was designed and implemented, i.e., based on MR/SPECTION metric observations, as shown in Fig. 12.

TABLE III. DETECTION INDEX RESULTS OF DIFFERENT ALGORITHMS IN ENCEPHALOPATHY

Index		Meningitis	Hydrocephalus	Cerebral infarction
CNN-RGF	MI	1.70±0.13	2.45±0.22	2.53±0.23
	IE	3.41±0.33	4.39±0.36	5.55±0.42
	SSIM	0.35±0.06	0.48±0.09	0.74±0.11
	AG	9.18±0.59	9.39±0.61	9.74±0.62
NSCT-PCNN	MI	1.62±0.12	2.14±0.15	2.47±0.19
	IE	3.29±0.28	3.88±0.31	4.12±0.34
	SSIM	0.14±0.02	0.37±0.05	0.56±0.07
	AG	7.82±0.31	8.57±0.42	9.04±0.47

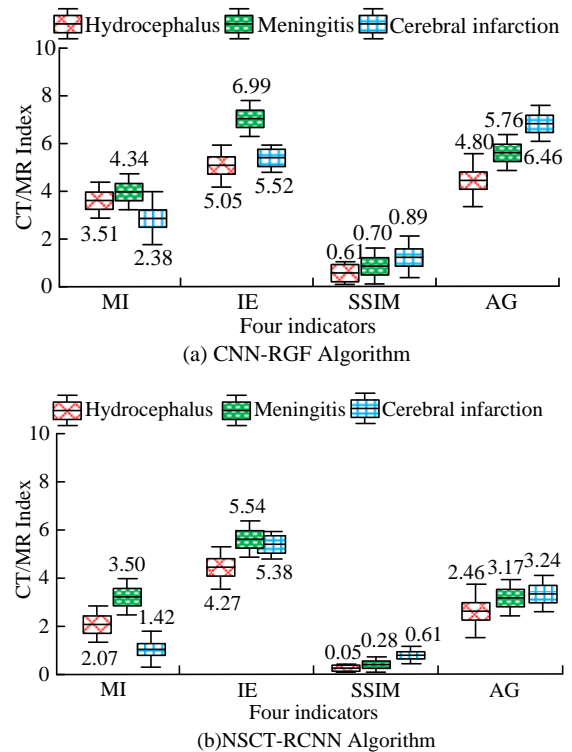


Fig. 11. Comparison of three kinds of encephalopathy and CT/MRI indexes by using CNN-RGF and NSCT-RCNN.



TABLE IV. OBSERVATION RESULTS OF CT/MRI INDICATORS

Index		Meningitis	Hydrocephalus	Cerebral infarction
CNN-RGF	MI	4.34±0.24	3.51±0.33	2.38±0.34
	IE	6.99±0.44	5.05±0.32	5.52±0.31
	SSIM	0.70±0.07	0.61±0.04	0.89±0.07
	AG	5.76±0.70	4.80±0.13	6.46±0.68
NSCT-PCNN	MI	3.50±0.50	2.07±0.34	1.42±0.58
	IE	3.29±0.28	3.88±0.31	4.12±0.34
	SSIM	0.14±0.02	0.37±0.05	0.56±0.07
	AG	7.82±0.31	8.57±0.42	9.04±0.47

TABLE V. OBSERVATION RESULTS OF MRI/SPECTION INDICATORS

Index		Meningitis	Hydrocephalus	Cerebral infarction
CNN-RGF	MI	1.77±0.35	2.20±0.41	0.54±0.08
	IE	3.80±0.47	5.77±0.69	1.04±0.13
	SSIM	2.17±0.08	3.55±0.25	4.07±0.38
	AG	6.45±0.81	8.38±0.76	7.20±0.48
NSCT-PCNN	MI	0.82±0.04	1.03±0.05	0.27±0.03
	IE	4.24±0.39	2.17±0.11	0.46±0.07
	SSIM	0.82±0.16	1.05±0.13	2.17±0.28
	AG	5.82±0.68	6.28±0.75	6.17±0.47

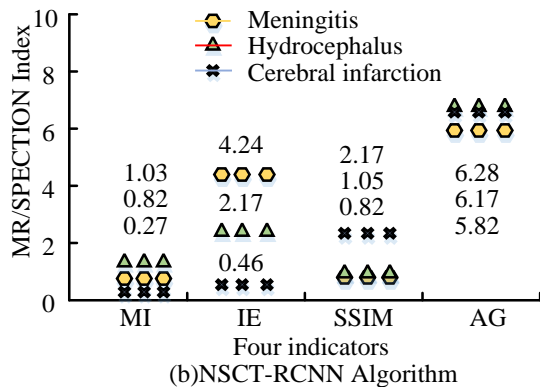
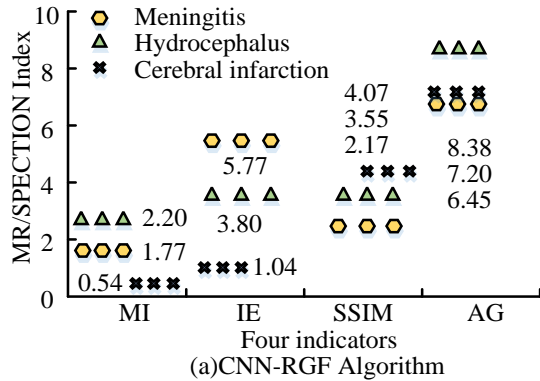


Fig. 12. Comparison of three kinds of encephalopathy and MR/SPECTION indexes by using CNN-RGF (a) and NSCT-RCNN (b).

From Fig. 12, it was indeed very necessary to test the complementation experiment, i.e., it was very different from the previous images. However, the difference was only in the shape, and the specific values of the four indexes of the MR/SPECTION images were still better for CNN-RGF than for NSCT-RCNN. Testing MR/SPECTION images, the MI/IE/SSIM/AG values of CNN-RGF were obtained as 1.77/5.77/2.17/6.45 for meningitis. The average values of MI/IE/SSIM/AG for hydrocephalus were 2.20/3.80/3.55/6.28; MI/IE/SSIM/AG for cerebral infarction were 0.54/1.04/4.07/7.20. The average values were 24.8% higher than those of NSCT-RCNN, and the CT/MRI images produced by the CNN-RGF algorithm were clearer. It is proved that CNN-RGF can retain the details of CT/MRI images well and can provide better quality CT/MRI images. The corresponding results in Fig. 12 are shown in Table V.

In Table IV, both CNN-RGF and NSCT-PCNN had higher evaluation values for various indicators in the same disease. In the standard deviation, CNN-RGF also exhibited better stability. To ensure the without loss of generality of the proposed method, NWPU VHR-10 data set was used to verify the model performance. The NWPU VHR-10 dataset was an aerial photography dataset, and aerial images were also processed using methods such as cropping and stitching. Therefore, CNN-RGF was studied for this dataset, and the performance results were reflected through accuracy and recall indicators. The specific results are shown in Table VI.

TABLE VI. THE APPLICATION EFFECT OF CNN-RGF ALGORITHM IN NWPU VHR-10 DATASET

Comparison algorithm	Precision	Recall
Neural Network	0.673	0.616
K-Nearest Neighbor	0.785	0.690
SVM	0.820	0.714
CNN-RGF	0.913	0.873

In Table VI, the accuracy of CNN-RGF in the NWPU VHR-10 dataset was 0.913, and the recall rate was 0.873. Compared to other models, the performance proposed in the study has significantly improved. Although its accuracy was slightly lower, which might be due to the complex environment of aerial images, the results demonstrated the effectiveness of the proposed method.

## V. CONCLUSION

This research used the brain image data of the First Affiliated Hospital of Harbin Medical University, and used CNN to extract its features. The extracted image used RGF to process the image's similar blocks and artifacts. Using the CNN-RGF method to fuse CT/MRI images, after the fusion was completed, it was first tested for naive objective quantities. The four simple objective indicators of CNN-RGF in meningitis, MI/IE/SSIM/AG, were 2.45/3.41/0.48/9.39; The MI/IE/SSIM/AG in Hydrocephalus was 1.70/4.39/0.35/9.74; The MI/IE/SSIM/AG in cerebral infarction was 2.53/5.55/0.74/9.18. At the same time, NSCT-RCNN algorithm was selected for comparative experiments. The measured MI/IE/SSIM/AG values of NSCT-RCNN in meningitis, Hydrocephalus, and cerebral infarction were 2.14/3.29/0.37/9.04, 1.62/4.12/0.14/7.82, 2.47/3.88/0.56/8.57, respectively. Among the three common brain diseases, the naive objective values obtained by CNN-RGF were higher than

those obtained by NSCT-RCNN, with an average improvement level of over 15%, indicating that the CT/MRI image quality obtained through CNN-RGF fusion was higher. To make the results universal, objective data testing of CT/MRI was supplemented. The CT/MRI objective data of CNN-RGF in meningitis, Hydrocephalus and cerebral infarction were 4.34/6.99/0.70/5.76, 3.51/5.05/0.61/4.80, 2.38/5.52/0.70/6.46 respectively; In NSCT-RCNN, they were 3.50/5.54/0.28/3.17, 2.07/4.27/0.05/2.46, 1.42/5.38/0.28/3.24, respectively. The values obtained from the above results were all dimensionless and were mainly used for comparing the effectiveness of algorithms. Therefore, from the extensive testing, the CT/MRI objective data values obtained from CNN-RGF were higher than those from NSCT-RCNN, with an average improvement level of over 10%. This proved that the CT/MRI obtained through CNN-RGF fusion was more suitable for major hospitals.

Because the first affiliated Hospital of Harbin Medical University lacked some data, the performance of the constructed model was limited. Due to scientific rigor, supplementary experiments were designed and implemented to observe MR/SPECTION indicators. The MR/SPECTION observations of meningitis in CNN-RGF were 1.77/5.77/2.17/6.45, respectively. The observed value of Hydrocephalus on MR/SPECTION was 2.20/3.80/3.55/6.28; The observed values of MR/SPECTION for cerebral infarction were 0.54/1.04/4.07/7.20, with an average of 24.8% higher than NSCT-RCNN. Taking the human eye resolution MI=8.00 as a reference, it could reach MI=2.40 as clear, indicating that for NSCT-RCNN fusion images, the characterization of meningitis and cerebral infarction cannot even reach the minimum standard. Compared with the traditional algorithm NSCT-RCNN, CNN-RGF was more suitable for application in hospitals. But there are not many medical images studied, because medical images have privacy and are not suitable for widespread dissemination. With the increase of volunteers, it is believed that future research can be improved.

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# Motion Path Planning of Wearable Lower Limb Exoskeleton Robot Based on Feature Description

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**Abstract**—Wearable lower extremity exoskeleton robot is a kind of training equipment designed for the disabled or powerless in the lower extremity. In order to improve the environmental adaptability of the robot and better meet the use habits of patients, it is necessary to plan and design the movement path, and a movement path planning model of wearable lower extremity exoskeleton robot based on feature description is proposed, which describes the objects with different wearing frequencies and training intensities. Taking the wearer's natural walking gait as the constraint feature quantity and the control object model, the spatial planning and design of exoskeleton structures such as hip joint, knee joint and ankle joint are adopted, and the traditional single-degree-of-freedom rotating pair is replaced by a four-bar mechanism, which improves the bionic performance of the knee joint. Combining the feature description and the spatial planning algorithm model, an error compensation method based on iterative least square method is adopted to identify geometric parameters. The feature identification model of robot moving path planning is constructed, and the adaptive strong coupling tracking identification and path planning of robot moving path are realized through feature description and spatial distance error identification results. The simulation test results show that the cooperative positioning error is reduced and the torque error is compensated in real time by using this method to plan the movement path of the wearable lower limb exoskeleton robot, which makes the robot obtain better movement planning effect and enhance the stability of the mechanism.

**Keywords**—Feature description; wearable lower limb exoskeleton robot; motion path planning; least square identification; geometric parameter

## I. INTRODUCTION

With the increasing types of robots and the expanding application fields of robots, the application of robots in rehabilitation training of patients with limb injuries has become an important direction of robot design and research. Wearable lower extremity exoskeleton robot is a training device designed for the disabled or powerless. The wearable lower extremity exoskeleton robot is worn on the lower limbs of patients, and the auxiliary parameter identification of multi-dimensional sensors is used as input, and the robot's movement planning design is realized through the robot control system and path planning system, which makes the wearable lower extremity exoskeleton convenient and comfortable to wear, safe and reliable to use, and fast and accurate to respond. Therefore, this paper studies the path planning method of wearable lower limb exoskeleton robot. Through path planning and intelligent

control system design, combined with power-assisted training design, the fitness level of robot under different wearing frequencies and training intensity is improved [1].

In the planning and design of the movement path of the wearable lower extremity exoskeleton robot, it is necessary to dynamically plan and design the movement path in combination with the user's power training needs and the wearer's injury degree. In the traditional methods, the movement path planning and design methods of the wearable lower extremity exoskeleton robot mainly include fuzzy PID control method, variable structure PID control method and inversion control method, etc. [2,3], and a distributed feature sampling model of the movement path of the wearable lower extremity exoskeleton robot is established. Combining spatial path parameter identification and inverse parameter control, the dynamic spatial fusion processing is carried out for patients with different degrees in the process of power-assisted training, and the movement path planning and design of wearable lower extremity exoskeleton robot is realized by using error compensation control algorithm and SLAM algorithm. In reference [4], a zero-force control method of 6-RUS parallel robot based on generalized coordinate form dynamics is proposed, and the influence of mechanism noise on torque data is analyzed. The global area method is used to obtain the actual output torque of the motor at a certain position in the workspace, so as to realize zero-force control and spatial path planning and design of the robot. However, the torque measurement accuracy of this method for robot moving path planning is not high. In reference [5], the configuration, motion mechanism and modeling control model of amphibious bionic robot are analyzed. According to the structural types of amphibious robots, amphibious robots are divided into leg propulsion, wheel-leg/fin composite propulsion, snake propulsion and other methods, and path planning and design are realized through parameter identification of multi-environment motion model, but this method has poor anti-interference and weak spatial recognition ability. Research [6] proposes the establishment of a mathematical model for robots, the construction of a motion situational awareness map, the establishment of an improved artificial potential field, the establishment of a repulsive potential function and priority model between robots, and the application of PID adaptive tracking algorithm. Study [7] proposes the use of adaptive RBFNN algorithm for disturbance estimation and compensation, and the use of nonlinear state error feedback control to achieve attitude tracking of rotor flying multi joint robotic arms, Has strong robustness and fast response ability.

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Aiming at the above problems, this paper puts forward a movement path planning model of wearable lower extremity exoskeleton robot based on feature description.

1) Different wearing frequencies and training intensities are taken as feature description objects, and the natural walking gait of the wearer is taken as constraint feature quantity and control object model, and a four-bar mechanism is adopted to replace the traditional single-degree-of-freedom rotating pair, thus improving the bionic performance of the knee joint.

2) Combining the feature description and the spatial planning algorithm model, the feature identification model of robot moving path planning is constructed by using the error compensation method based on iterative least square method, and the adaptive strong coupling tracking identification and path planning of robot moving path are realized through the results of feature description and spatial distance error identification.

3) The experimental test shows the superior performance of this method in improving the moving path planning ability of wearable lower limb exoskeleton robot.

This method can more accurately predict users' motion intentions and generate motion paths that better meet user needs by analyzing and modeling human motion features. Thus providing more precise and coordinated motion assistance, improving motion performance.

## II. STRUCTURE MODEL AND DESIGN PRINCIPLE OF WEARABLE LOWER LIMB EXOSKELETON ROBOT

Based on the principle of ergonomics, a wearable exoskeleton robot for the disabled or powerless lower limbs is designed. The hip joint, knee joint and leg bar are designed respectively [6]. Firstly, at the left and right hip joints, the parallel mechanism is used to realize the power-assisted movement of the joint center. Then, the traditional single-degree-of-freedom rotating pair is replaced by a four-bar mechanism to realize the bending action of the knee joint. Then, the leg bar is designed according to the human body configuration. Finally, the ankle joint is designed by belt drive.

Among them, the hip joint is composed of Hooke's articulated U-pair, movable P-pair, Hooke's articulated U-pair, fixed platform connecting leg bars, and movable platform tied to the waist; The knee joint is composed of a four-bar linkage formed by articulation, a linear driving electric cylinder and a fixed part of the electric cylinder.

As shown in Fig. 1, the robot wearing the lower limb exoskeleton is composed of a hip joint A, a knee joint B, an ankle joint C, a leg bar D and an inner strap E which are connected by bolts in turn. Among them, as shown in the figure, the leg bar imitates the human body structure, and there is a certain angle between the thigh and the calf on the vertical plane, which makes the structure more suitable for the human lower limbs [7].

Fig. 2 is a schematic diagram of the hip joint structure, and the hip joint is assisted by a parallel mechanism. Among them, the parallel mechanism is composed of Hooke's articulated U-

pair A1, moving P-pair A2, Hooke's articulated U-pair A3, fixed platform A4 connecting leg bars and moving platform A5 tied to waist. The parallel mechanism can achieve three degrees of freedom of hip joint ergonomically required, namely, forward and backward swing (thigh flexion/extension), lateral swing (abduction/adduction) and torsion (external rotation/internal rotation), which is consistent with the freedom of motion required by human hip joint and ensures human comfort [8].

Fig. 3 is a schematic diagram of the structure of the knee joint, which realizes the bending motion of the knee through a four-bar linkage mechanism. Specifically, it consists of a hinged four-bar mechanism B1, a linear driving electric cylinder B2 and an electric cylinder fixing piece B3. Compared with the single-degree-of-freedom rotation, the instantaneous center trajectory of the four-bar mechanism is closer to the trajectory of the human knee joint, thus achieving the goal of better coordination between the exoskeleton and the human body [9].

Fig. 4 is a schematic diagram of the ankle joint structure. As shown in the figure, the ankle joint is composed of an upper joint fixing piece C1, a rotating pair end cover C2 and a rotating pair C3. When the human body walks, it can drive the rotating pair to rotate, improving the comfort experience.

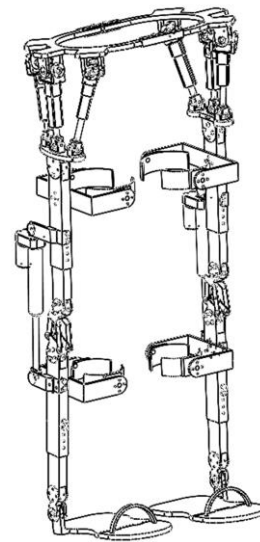


Fig. 1. Structure diagram of robot wearing lower limb exoskeleton.

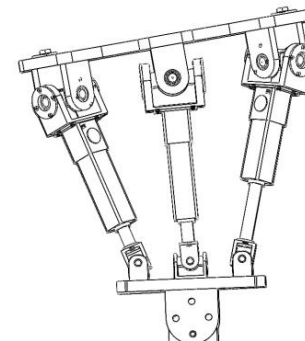


Fig. 2. Schematic diagram of hip joint structure.

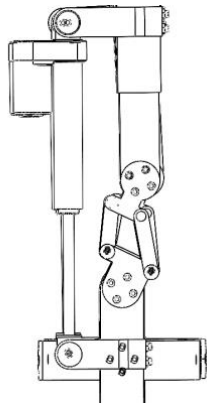


Fig. 3. Schematic diagram of knee joint structure.

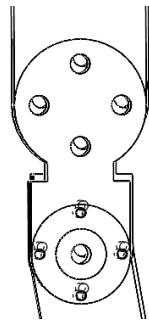


Fig. 4. Schematic diagram of ankle joint structure.

#### Advantages of wearing lower limb exoskeleton robot:

- 1) It is suitable for adjusting the length of lower limbs of people of different ages and heights, and it is convenient for wearers of different heights to perform various operations [10].
- 2) The left and right hip joints are designed in a parallel structure symmetrical about the central axis, and the movement center of the exoskeleton and the center of the human hip joint are more fitted, which ensures that the movement center of the wearable robot falls on the center of the hip joint, thus ensuring the fit between the wearable robot and the human body, being more bionic and enhancing the comfort of users.
- 3) The knee joint adopts a four-bar mechanism to replace the traditional single-degree-of-freedom rotating pair, which improves the bionic performance of the knee joint. Combining with ergonomics, the thigh in the standing state is set to be vertical to the horizontal plane, and there is a certain angle between the calf and the thigh, so that the center of gravity of the human body falls inside the ankle joint and the sole support to enhance the stability of the mechanism.

Both the upper and lower leg connecting rod and the lumbar support structure are telescopic, as shown in Fig. 5 and Fig. 6, that is, the upper and lower leg connecting rod and the lumbar support structure are designed into two sections with adjusting threaded holes, so as to improve the body compatibility with robot wearers, adapt to the bodies of different patients and improve the comfort.

In the design process, according to the bionic design method, the hip joint, knee joint and ankle joint of exoskeleton are designed, in which the hip joint adopts parallel mechanism and the knee joint adopts four-bar mechanism closer to the knee joint instead of the traditional rotating pair. The leg bar part adopts an adjustable two-bar structure, which is convenient for different people to wear.

### III. CONSTRAINT PARAMETERS AND CONTROL OBJECTS OF ROBOT MOVING PATH PLANNING

#### A. Constrained Parameter Model

In order to realize the movement path planning of the wearable lower extremity exoskeleton robot based on feature description, inspired by the musculoskeletal system of human leg [11], firstly, the collection model of the sensitive parameters of the trajectory tracking deviation of the skeletal robot is established, and the Snelson X-shaped mechanism is improved. According to the biological simplified model and deformation feature analysis, the internal biomechanics and motion mechanism of the human leg are analyzed, and the distribution of the sensitive parameters of the timing deviation of the wearable lower extremity exoskeleton robot is obtained as follows:

$$F = \frac{\int_0^{L_z} T_C(x) dx}{L_z} + \frac{M \cos \alpha}{4\pi\mu_0 R^5} [2(2h)^2 - a^2] \quad (1)$$

Where,  $\int_0^{L_z} T_C(x) dx$  represents the number of internal biological spine or trunk joints of human legs,  $L_z$  represents the geometric shape parameters of bone and femoral condyle surfaces,  $M$  represents the dynamic characteristic components of muscle and bone in the equivalent mapping model, and  $h$  represents the flexible dynamic parameters imitating human muscle tissue. Based on the energy loss analysis, the dynamic characteristic parameters of redundant degrees of freedom of tensegrity structure are obtained as follows:

$$P = P_{cu} + P_h + P_e = \sum_{n=m}^{N-1} \left\{ \left[ e^f_{m-1}(n) \right]^2 + \left[ e^b_{m-1}(n-1) \right]^2 \right\} \quad (2)$$

In the above formula,  $P_{cu}$  is the inertia loss of the wearable lower limb exoskeleton robot around each axis of the body coordinate system,  $P_h$  is the force density distribution matrix, and  $P_b$  is the component group of the axial force  $f$  of the node  $P$  in the  $X$  and  $Z$  directions. Assuming that the unit size of the

tensegrity mechanism is  $\mu_1$ , it can be analyzed and identified according to the diagonal matrix composed of axial stiffness deformation, so as to realize the analysis of the changing posture and movement position [12].

### B. Control Object Model

Taking the wearer's natural walking gait as the constraint feature quantity and the control object model, the spatial planning and design of the hip joint, knee joint and ankle joint of the exoskeleton are adopted, and the steady-state control model of the characteristics of the Snelson X tensegrity structure itself is obtained as follows:

$$S = K(t) + \sum_{n=m}^{N-1} \left[ e^b_{m-1} (n-1) \right]^2 \quad (3)$$

Where,  $e^b_{m-1}$  is the complementary sequence of the cooperative positioning errors of the two legs, and  $K(t)$  is the measured distance between the end effectors of the two legs. Based on the identified geometric parameters, the behavior conditions of the two legs are analyzed, and when  $F^T F \leq I$  is met. Calculate the measured distance of the robot end when it is configured as  $i$  and  $k$ , and get the quantitative parameters of the trajectory feature distribution of the wearable lower limb exoskeleton robot as follows:

$$Y_\phi = \frac{\omega \dot{M}}{4\pi R^2} + \left[ e^f_{m-1}(n) e^b_{m-1}(n-1) \right] \quad (4)$$

Where,  $R$  is the characteristic value of the rotation period, based on the kinematic characteristics of nonlinear feedback control, the controlled object model is constructed based on the description and analysis of joint offset, connecting rod length and connecting rod torsion characteristics, and the geometric stiffness equation of the wearable lower limb exoskeleton mechanism is obtained by the method of modifying the geometric stiffness matrix of the mechanism:

$$u(k) = Kx(k - (\tau_{sc} + \tau_{ca})) = Kx(k - \tau_k) \quad (5)$$

According to the kinematics model of the robot from the measuring coordinate system to the end tool coordinate system, the actual arrival position of the end effector is inconsistent with the calculated position of the theoretical model. The geometric parameters are identified and analyzed, and the error compensation terms SA of the left leg and the right leg of the two-legged system are obtained by using the combined control of Coriolis force and centrifugal force  $w^{(k)} \in L_2(0, \infty)$ . When  $\|z(k)\|_2 \leq \gamma \|w(k)\|_2$  is met, according to the dynamic characteristics analysis of joint offset, connecting rod length and connecting rod torsion, the spatial planning function of kinematic model of end tool coordinate system is obtained as follows:

$$V_k = x^T(k) P x(k) + \sum_{i=k-\tau_k}^{k-1} x^T(i) K^T R K x(i) \quad (6)$$

Where  $P$ ,  $R$  are displacement vectors of geometric parameter errors of the robot. For the dynamic modeling of the wearable lower limb exoskeleton robot, the vector between the

origin points of the end tool coordinate system is introduced, and the gradient gain function is obtained according to the detection result of the transformation matrix of the basic coordinate system of the biped robot:

$$\begin{aligned} \Delta V_k &= Vx(k+1) - Vx(k) \\ &= x^T(k+1) P x(k+1) - x^T(k) P \\ &\quad - K^T R K x(k) - x^T(k - \tau_k) K^T R K x(k - \tau_k) \end{aligned} \quad (7)$$

While  $w^{(k)}=0$ , the position detection model of the ends of legs in the measurement coordinate system is constructed, and the spatial planning and design of the robot's moving path is realized according to the position distribution [13].

## IV. OPTIMIZATION OF MOBILE PATH PLANNING ALGORITHM FOR WEARABLE LOWER LIMB EXOSKELETON ROBOT

### A. Feature Description and Spatial Planning Algorithm

The hip joint, knee joint and ankle joint of exoskeleton are planned and designed in space, and the four-bar mechanism is used to replace the traditional single-degree-of-freedom rotating pair, which improves the bionic performance of the knee joint [14]. The gradient vector of cooperative positioning between the theoretical end distance and the real end distance meets the following requirements:

$$\Delta V_k = \Phi_1 \Pi_1 \Phi_1^T < 0 \quad (8)$$

Taking the centroid parameters of the wearable lower limb exoskeleton robot as the constraint object, through error compensation and feature description, the distribution function of the end position in the ontology-based coordinate system is measured as follows:

$$F(x) = \sum_{q=1}^Q e_q^T e_q = \sum_{q=1}^Q \sum_{k=1}^m e_{kq}^2 = \sum_{i=1}^N v_i^2 \quad (9)$$

Where,  $eq$  is the matching sample set of the best trajectory path of the wearable lower limb exoskeleton robot. Through the calibration of geometric error and non-geometric error, the distribution of transformation parameters of the two-leg base coordinate system is obtained as follows:

$$x^T = [w_{11}, \dots, w_m, z_{11}, \dots, z_m] \quad (10)$$

Where,  $w_{11}, \dots, w_m, z_{11}, \dots, z_m$  are the inertia weights, after geometric and non-geometric error compensation, the control function of feature description and spatial planning optimization is obtained as follows:

$$k_m = R / \rho_{m-1} = \frac{P_L}{P_E} = \left\{ \left[ e^f_{m-1}(n) \right]^2 + \left[ e^b_{m-1}(n-1) \right]^2 \right\} \quad (11)$$

Where,  $\rho_{m-1}$  is the tracking expected displacement vector that oscillates during the identification process,  $P_L$  is the change rate of the position distribution of the laser tracker, and

$P_E$  is the joint angle variable of the left leg in the right leg base coordinate system, thus the formula for the tracking step size distribution of the end position trajectory is obtained as follows:

$$C(t) = V_0^2 \cdot G_x = \sigma_{wp}^2 \left( \frac{N+P+1}{N-P-1} \right) \quad (12)$$

Wherein,  $G_x$  is the system gain of the end position and  $\sigma_{wp}^2$  is the transformation parameter of the base coordinate system. The dynamic analysis model of the movement path planning of the wearable lower limb exoskeleton robot is analyzed to realize the dynamic planning and design of the movement path of the skeletal robot [15].

### B. Adaptive Strong Coupling Tracking and Identification of Robot Moving Path

The four-bar mechanism is used to replace the traditional single-degree-of-freedom rotating pair, which improves the bionic performance of the knee joint. The proposed four bar mechanism has significant advantages in improving the bionic performance of the knee joint compared to traditional rotating pairs. It can better simulate the complex motion of the human knee joint and provide torque output that conforms to the physiological characteristics of the human body through improvements in multi degree of freedom control, torque distribution, stability, and controllability. In addition, the four bar mechanism can also save energy, improve energy utilization efficiency, extend battery life, or reduce external energy consumption. Overall, the introduction of a four bar mechanism can significantly improve the bionic performance of the knee joint, making it closer to the motion characteristics and functions of the human knee joint.

Combining the feature description and the spatial planning algorithm model, the control model of the dynamic planning of the left leg in the right leg base coordinate system is obtained by using the error compensation method based on the iterative least square method to identify geometric parameters and the optimization constraint method.

$$\dot{\sigma}_i = \begin{cases} \mu \sin \frac{\pi e}{2\mu}, & |e_i| < \mu \\ \mu, & |e_i| \geq \mu \\ -\mu, & |e_i| \leq -\mu \end{cases} \quad (\mu > 0) \quad (13)$$

Where,  $\mu$  is the sliding mode switching gain and  $e_i$  is the trajectory deviation error, trajectory tracking and spatial planning are carried out according to the correlation between the steady-state disturbance  $w^{(k)}$  of the step tracking of the wearable lower extremity exoskeleton robot and the acceleration measurement matrix  $u_i^{(k)}$ , and the trajectory distribution spatial parameters of the wearable lower extremity exoskeleton robot are obtained based on geometric error and non-geometric error calibration, and the parameter

identification model of the spatial positioning and perception of the mobile robot is described as follows:

$$H_0 = \sqrt{E}KR'(t) + R(t) - \left( \frac{P_e + P_h}{\omega_r} \right) \frac{M}{4\pi\mu_0 R^3} \sqrt{1 + 3\cos^2 \theta} \quad (14)$$

$$T(\alpha) = T + Y(r) - (P_w + P_b) / \omega_r \quad (15)$$

Wherein,  $\mu_0$  is the dynamic distribution parameter with the smallest linearization error of the system,  $M$  is the fuzzy distribution matrix in the robot base coordinate system,  $P_e$  is the error of identifying geometric parameters,  $P_h$  is the base coordinate system from the right leg to the left leg,  $R(t)$  is the coordinate matching point of each mechanism node,  $R'(t)$  is the parameter matrix of the mechanism unit node. The error compensation method based on iterative least square method is used to identify geometric parameters, and the feature identification model of robot moving path planning is constructed. The adaptive strong coupling tracking identification and path planning of robot moving path are realized through feature description and spatial distance error identification results [16].

## V. EXPERIMENTAL TEST

In this simulation experiment, we choose ROS as the simulation environment, and use SolidWorks modeling to create a lower limb Exoskeleton robot model. Obtain joint angle data as motion features through sensors and input it into a feature based path planning algorithm. In the experimental scenario, we simulated walking tasks and set different environmental conditions, with a ground slope range of [0,10] and 10 obstacles randomly distributed in the environment. The robot can complete the movement and reset of hip joint and knee joint with a single motor drive, and the input pressure reaches the maximum at 100N, and the dynamic error difference of trajectory tracking is set to 0.14mm. When the robot stands and locks, the deviation of the constraint point is 12.7%, the offset length is 1.355mm, the torsion angle of the connecting rod is 1.570rad, and the length of the connecting rod is 3.125. A four-bar mechanism is adopted to replace the traditional single-degree-of-freedom rotating pair, and the maximum/average position error of the robot is 0.2814mm/0.1431mm, and the average inverse kinematics calculation time of the robot's hip joint driven by DC motor is 0.01134ms, which is the longest for the robot. The setting parameters are shown in Table I.

According to the above parameter setting, given that the time of lower limb flexion is 0.064s, the support ability of the lower limb in the standing state is tested, and according to the statistical analysis results of mechanical characteristic parameters, the wearable lower limb exoskeleton robot is realized, and the detection results of robot movement path tracking parameters are shown in Fig. 5.



TABLE I. DH PARAMETER DISTRIBUTION

Joint node	Joint angle /rad	Offset length /mm	Connecting rod torsion angle $a_i$ /rad
1	0.921	76.456	5.626
2	1.059	79.955	6.656
3	0.598	83.033	3.666
4	1.245	76.936	8.900
5	1.225	80.504	8.371
6	1.627	80.435	9.400
7	0.627	81.337	8.469
8	1.931	79.710	7.665

By analyzing Fig. 5, it is known that this method can accurately detect the moving path of the robot, and the trajectory tracking and recognition ability is good, and the legged robot always maintains a stable locking state during the process of increasing the load. The convergence curve of the test robot's moving path tracking is shown in Fig. 6.

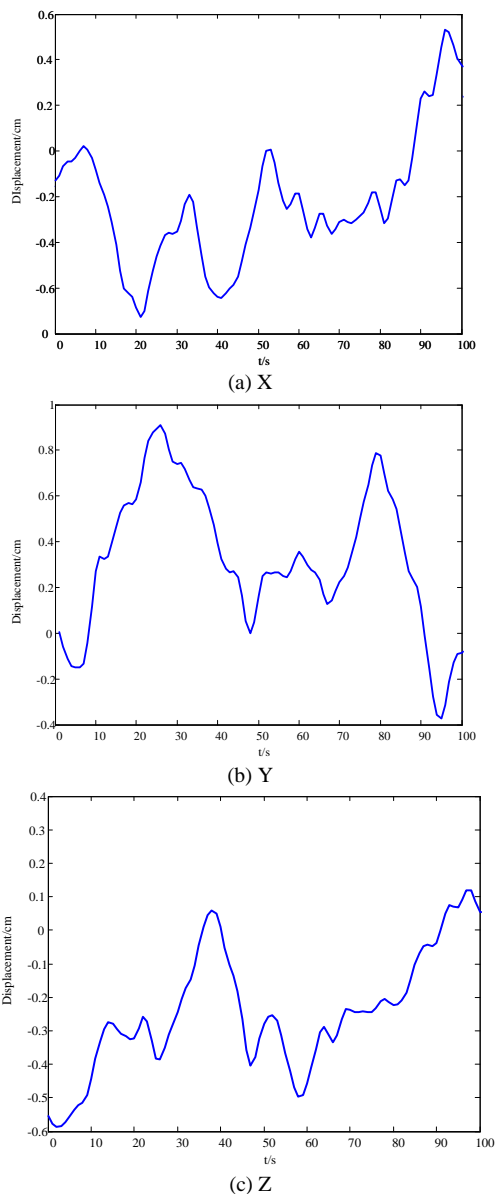


Fig. 5. Detection of robot moving path tracking parameters.

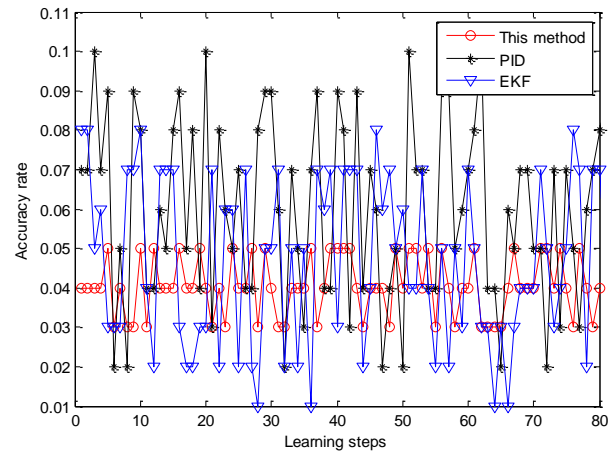


Fig. 6. Convergence curve of robot trajectory tracking.

By analyzing Fig. 6, we know that the method in this paper has a good convergence when planning and tracking the movement path of the wearable lower extremity exoskeleton robot, while the traditional PID control method has a large oscillation and the convergence error of EKF control method is high. The tracking error of the movement path of the wearable lower extremity exoskeleton robot is tested, as shown in Table II. By analyzing the results in Table II, we know that the method in this paper has a good adaptability and strong oscillation suppression ability, which improves the stability and robustness of the movement planning of the wearable lower extremity exoskeleton robot.

TABLE II. COMPARISON OF TRAJECTORY TRACKING ERRORS

Iterations	This method	PID	EKF	Integral control
100	0.041	0.135	0.403	0.189
200	0.018	0.084	0.132	0.151
300	0.006	0.057	0.136	0.177
400	0.000	0.023	0.110	0.074

Through the analysis of the comprehensive experimental results, the method proposed in this paper shows accuracy and stability in the path planning of the wearable lower limb Exoskeleton robot. The experimental results show that this method can accurately detect the motion path of the robot and has strong trajectory tracking and recognition capabilities. Even with increased load, the legged robot can still maintain a stable locking state. In addition, the method shows good convergence and low tracking error when planning and tracking the path of the wearable lower limb Exoskeleton robot.

Through experimental verification, we found that our method has excellent performance in path planning. It can accurately identify the user's motion intention and generate motion paths that match the user's needs. At the same time, this method can also adaptively adjust according to environmental changes and individual differences of users to provide more comfortable and efficient motion assistance. In addition, the method shows stability and accuracy in the tracking process, and can accurately track the user's trajectory, so that the Exoskeleton robot can effectively work with the user.

However, it should be noted that although the method presented in this paper has shown good performance in experiments, there are still some limitations. For example, the accuracy of feature extraction and description may be influenced by factors such as sensor accuracy, noise, and interference. In addition, further research is needed to consider individual differences and adaptability. Therefore, before applying this method to practical scenarios, it needs to be further validated and improved.

## VI. CONCLUSIONS

In order to improve the environmental adaptability of the robot and better meet the usage habits of patients, it is necessary to plan and design the movement path. A movement path planning model of the wearable lower limb exoskeleton robot based on feature description is proposed, with different wearing frequencies and training intensities as the feature description objects, and the wearer's natural walking gait as the constraint feature quantity and control object model, and the hip joint, knee joint and ankle joint of the exoskeleton are used for spatial planning and design. A four-bar mechanism is used to replace the traditional single-degree-of-freedom rotating pair, which improves the bionic performance of the knee joint. Combining the feature description and the spatial planning algorithm model, a feature identification model of robot movement path planning is constructed by using the error compensation method based on iterative least square method, and the adaptive strong coupling tracking identification and path planning of robot movement path are realized through the results of feature description and spatial distance error identification. The simulation test results show that this method can reduce the cooperative positioning error and compensate the torque error in real time, which makes the robot obtain better movement planning effect and enhance the stability of the mechanism. The trajectory tracking of the wearable lower extremity exoskeleton robot has good adaptability and strong oscillation suppression ability. There may be differences in the motion characteristics and needs of each user. The current research mainly focuses on average feature descriptions and models, and the consideration of individual differences is not sufficient. Therefore, in practical applications, further research is needed on how to incorporate individual differences and adaptability into the path planning process.

## ACKNOWLEDGMENT

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# Robust Analysis of IT Infrastructure's Log Data with BERT Language Model

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**Abstract**—Now-a-days, failure detection and prediction have become a significant research focus on enhancing the reliability and availability of IT infrastructure components. Log analysis is an emerging domain aimed at diminishing downtime caused by IT infrastructure components' failure. However, it can be challenging due to poor log quality and large data sizes. The proposed system automatically classifies logs based on log level and semantic analysis, allowing for a precise understanding of the meaning of log entries. Using the BERT pre-trained model, semantic vectors are generated for various IT infrastructures, such as Server Applications, Cloud Systems, Operating Systems, Supercomputers, and Mobile Systems. These vectors are then used to train machine learning (ML) classifiers for log categorization. The trained models are competent in classifying logs by comprehending the context of different types of logs. Additionally, semantic analysis outperforms sentiment analysis when dealing with unobserved log records. The proposed system significantly reduces engineers' day-to-day error-handling work by automating the log analysis process.

**Keywords**—System log; log analysis; BERT; classification; failure prediction; failure detection

## I. INTRODUCTION

IT infrastructures, consisting of complex and interconnected systems, are vulnerable to various failures, such as hardware failures, software glitches, network outages, security breaches, and other unforeseen events that can disrupt critical business operations. With rapid development in size and functionality, IT infrastructures have become increasingly complex and agile. Enriched accessibility to IT infrastructure is vital as the usage of computer systems has penetrated all aspects of society. Moreover, a small failure in any of the infrastructure components gives rise to catastrophic failures accompanied by downtime [1]. Research [2] shows that these failures can lead to financial losses, reputational damage, and customer dissatisfaction. Thus, developing a system that can perform accurate and timely failure detection is paramount. Such a system will be helpful for organizations to proactively detect and resolve potential problems, minimize downtime, and improve the overall reliability and efficiency of IT operations.

System logs are one of the most worthwhile records that register important events, various services, and the state of operations. By analyzing system logs, IT teams can monitor for signs of anomalies or irregularities that may indicate potential failures. Accordingly, system logs have been widely used to understand the behavior of computer systems and

monitor their health. Each computer system generates system logs on the execution of the event; thus, an ample amount of records are available. Even so, log analysis is troublesome due to the size of the data. As stated in a systematic literature review [3], many researchers have used logs in log analysis, anomaly and failure detection, troubleshooting, and prediction research.

The failure detection using log data framework comprises six steps, such as i) Log collection: Logs are obtainable in raw and unstructured formats. Different systems generate various types of logs; therefore, different types of logs ought to be collected for investigation. ii) Log parsing: In this step, unstructured logs are refined to be converted into a structured format. The primary objective of log parsing is to excerpt log templates from raw system logs. Log parsing substitutes the variable part of the log with special characters and preserves only the constant part. iii) Structured logs: Results acquired from the parsing are stored in the .csv file format; this data is used for further processing. iv) Feature extraction: Log templates and the contents produced in the course of log parsing are preferred as features for encoding. v) Vector representation: Log templates and contents are converted into vector representation in order to furnish them as input to machine learning models. vi) Anomaly / Failure Detection: Eventually, excavated vectors are served to the machine learning or deep learning models to classify logs in accordance with the allocated log level. Logs are classified into different categories, which include "fail," "Fatal," "error," etc. levels. These categories demand attention as they indicate the abnormal behavior of the system. The stated log levels are allocated to the logging statements on executing any exception in the system. Thus, the administrator gets anomalous data to emphasize and can take remedial action accordingly.

As per the literature, machine learning [4] and deep learning [5] have popular techniques effectively applied to classify logs. This classification can save time on log analysis and assist system administrators in concentrating on doubtful log entries. System logs are a combination of text, numbers, and special symbols. The data is available in natural language format and cannot be directly used to build ML (Machine Learning) and DL (Deep Learning) models. Many researchers utilized various NLP techniques for embedding purposes in the existing literature. But considering the nature of the log data and challenges in handling system logs such as voluminous data, commonly used words, the occurrence of the same word with different meanings, etc., direct vector conversion is not significant. Thus, vectors are required to

generate based on the word's context. Therefore, it is necessary to follow the process of text data conversion to numerical vectors based on semantics.

Proposed feature extraction with semantic analysis conquers the challenges related to variation in log format and imbalanced data. The proposed systems comprehend the semantic analysis of log templates by practicing the BERT pre-trained model. The system employs the BERT to procreate sentence vectors, bearing in mind the log templates and contents acquired against log parsing. At last, machine learning techniques are employed to classify log entries contingent on earmarked levels.

The Contributions in this paper are summarized as follows.

1) The proposed system for classifying logs is based on analyzing the meaning of logs with the BERT model that has already been trained.

2) Different Infrastructures such as Apache, OpenStack, Windows, BGL, and Android logs are collected and parsed using the "Drain" parser to derive log templates.

3) Sentence embedding is done on the derived log templates to determine each entry's meaning.

4) Extracted features are provided to machine learning classifiers to analyze logs pertaining to levels. The main goal of the classification is to test the efficiency of the semantic analysis done by different NLP techniques.

The proposed system will significantly diminish manual errors by enabling automated and accurate solutions to failure prediction.

The paper has eight sections, including details: Section II discusses related work. Section III has the descriptive analysis of the datasets, including log data collection and preprocessing. Section IV includes NLP-based feature extraction techniques. Section V investigates the models and technical definitions of the methodology used to perform experimentations. Sections VI and VII emphasize the experimental setup, followed by derived results. Finally, the conclusion and future directions are stated in Section VIII.

## II. RELATED WORK

Failure prediction is a crucial aspect of IT infrastructure monitoring as it enables organizations to proactively detect and mitigate potential issues before they result in costly downtime or performance degradation. The system can identify patterns or anomalies that may indicate impending failures and take preventive measures to avoid or minimize the impact of such failures. System logs, which are records of events and activities generated by various components of an IT system, can be invaluable in failure detection and prediction in IT infrastructures. System logs capture essential real-time information about IT resources' behavior, performance, and status, such as servers, networks, applications, and databases. One of the primary uses of system logs in failure detection is to provide visibility into the operational state of IT systems. By monitoring system logs, IT teams can detect such anomalies early and take preventive actions to mitigate potential failures. System logs can also be

used in failure prediction by leveraging machine learning and statistical techniques.

Wang et al. [6] propose that system downtime can be reduced by identifying the reason for failure, making anomaly and failure detection, prediction, and root cause analysis. Despite being an emerging domain, automated log analysis is complicated due to the manual evaluation of system logs by administrators, who track simple words like "kill," "exception," "dead," "fail," etc., to investigate defects [3]. In order to address the challenges of unavailability, reliability, and performance in IT infrastructure, it is vital to study machines as they are, understanding what they do instead of what is expected [7]. Various rule-based and classification-based approaches [8][9], including machine learning [10][11] and deep learning [12][13] techniques, have been proposed for automated system log analysis. Moreover, supervised [14] and unsupervised [15] learning techniques applied to massive, unstructured system logs have gained significant attention in recent years, with a substantial research corpus of similar work.

Recently, NLP-based analysis has been introduced to understand the meaning of logs for log analysis in complex IT infrastructures [16]. Word2Vec has been applied by authors [17] to perform word embedding of log contents, followed by finding log sequences using TF-IDF. Unsupervised learning has been utilized for the extracted features, resulting in a 67.25% improved F1 score compared to LogCluster [18]. Researchers [19] have calculated polarity scores to identify abnormal behaviors in HPC systems with a 96% F-score. In the recent past, many researchers have been concentrating on the use of BERT [20] re-BERT [21] pre-trained model as an embedding technique and LSTM [22][23], Bi-LSTM [24][25] attention base mechanism for classification purpose.

## III. ILLUSTRATIVE ANALYSIS OF THE DATASET

### A. Dataset Collection

System logs are intended to be the primary source of information about the system; thus, the availability of a log dataset for research is a demanding obligation. Log data records every operational detail of each component of the IT infrastructure at run-time. The mishandling of such sensitive data may cause several issues. Therefore, system logs are not easily obtainable for research and experimentation. He, Zhu, He, & Lyu, in 2020 [26], collected sample logs and made them available on "loghub" [27] for study. An extra set of logs are produced in the labs and released for research determination. In the systematic literature review [3], we discussed details about availability of more datasets that are accessible for research purpose.

### B. Dataset Preprocessing with Log Parser

Systems logs are the "print" statements scripted by engineers under software development and documented in the course of the carrying out of affiliated operations. The logs are composed of a constant log header (id, state, timestamp, level, etc.) and a dynamic part (updates on operation execution). The primary purpose of log parsing is to transform unstructured logs toward structured data by extracting the constant part from logs called log templates. The sample log parsing

technique is shown in Fig. 1. Log message or content is "Component State Change: Component \042SCSI-WWID:01000010:6005-08b4-0001-00c6-0006-3000-003d-0000\042 is in the unavailable state (HWID=1973)" from which log template is extracted as "Component State Change: Component <\*> is in the unavailable state (HWID=<\*>)."

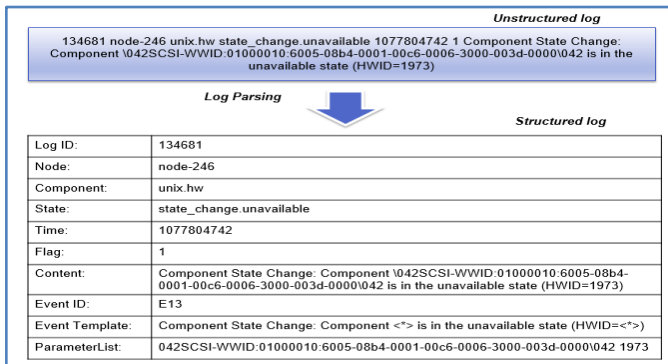


Fig. 1. Components of example HPC log.

Various researchers have discussed miscellaneous log parsers such as POP [28], Spell [29], SLCT [30], etc. Drain [31] parser has been adapted in this research work to parse log datasets. Drain elected for experimentation by examining execution time, availability, accuracy, and flexibility parameters. The drain parser employed the fixed-depth tree structure to perform and retrieve log templates. Table I presents the summary of findings on the performance of Drain on various types of logs. For the parsing, datasets are selected from multiple infrastructures, such as Apache as a server application, OpenStack as a cloud system, Windows as an operating system, BGL as a supercomputer, and Android as a mobile system. Table I contains the column number of log messages utilized for the parsing, the derived unique number of templates, and the maximum template length. Thus "Drain's" is a better parser for this research due to its parsing accuracy.

### C. Feature Extraction

System logs are a combination of text, numbers, and special symbols. Natural language data cannot be used directly to build ML (Machine Learning) and DL (Deep Learning) models. For this reason, it is imperative to follow the action of text data conversion to numerical vectors, known as vectorization or word embedding. The mined vectors can be employed to train different Machine learning and Deep learning models for classification, detection, and prediction purposes; in this way, word embedding is imitated for feature extraction.

At present, different Natural Language Processing (NLP) models are available for feature extraction in view of sentiment and semantic analysis. TF-IDF, polarity score, word2vec, and doc2vec work based on word frequency or position occurrence in the given text and analyze word-related sentiments. Whereas BERT, GPT2, and XL [16] function contingent on the semantics of words regarding the position and meaning of words accompanying them. The BERT model is pre-trained on massive datasets like Wikipedia and proposed by Google to be fine-tuned on a particular dataset. Pre-trained word embedding models are applied for vector representation of log templates and to strengthen the prediction of unobserved log entries. Moreover, BERT supports domain-specific semantic information and can address out-of-vocabulary (OOV) words in novel kinds of logs during run-time [32].

This experimentation focuses on doc2vec and BERT sentence embedding techniques to get vectors of log templates. Whereas TF-IDF is unsuitable in log datasets as the TF-IDF work on the weighting methods, and weights are assigned considering the frequency of occurrence of words. In the case of system logs, common words represent the different meanings of the log messages, and frequently occurring words are unnecessary. Thus, TF-IDF is unsuitable, even if it archives good classification accuracy. Fig. 2 renders the process of feature extraction. First, the unstructured log is processed toward a structured format; then, log templates are excavated with the Drain parser. Then the log template is preprocessed to expel special symbols and stop words; further steaming is performed. This cleaned data will be available for tokenization, followed by vectorization.

## IV. FEATURE EXTRACTION TECHNIQUES

### A. Doc2Vec

Doc2vec is a Natural Language Processing (NLP) technique for converting documents into vectors. Doc2vec's work is based on the conception of Word2vec. The direct encouragement for the development of doc2vec is to induce a vector illustration of a group of words collected together to be presented as a single unit, irrespective of the length of the document. The pivotal variance in the word and sentence representation is that words carry logical structure, but documents don't. Mikilov and Le [23] introduced an additional vector, Paragraph ID, along with the word2vec model to solve this issue. Thus, at the time of word vectors training, the document vector also gets trained, and eventually, the document is converted to numerical form. This model is the Distributed Memory version of the Paragraph Vector (PV-DM).

TABLE I. EXPERIMENTAL RESULTS OF DRAIN PARSER ON VARIOUS DATASETS

Dataset	Source Type	Size of Data	Number of log Messages	Number of Unique Template	Template Max Length	Parsing Accuracy
Apache	Server Application	4.90 MB	56,481	44	42	1
OpenStack	OpenStack infrastructure log	5.4 MB	207,820	7,221	104	0.73
Windows	Windows event log	267.465 MB	611,103	176	173	0.99
BGL	Supercomputer	708.76 MB	4,747,963	619	376	0.99
Android	Android framework log	25.7 MB	1,555,005	14,899	124	0.91

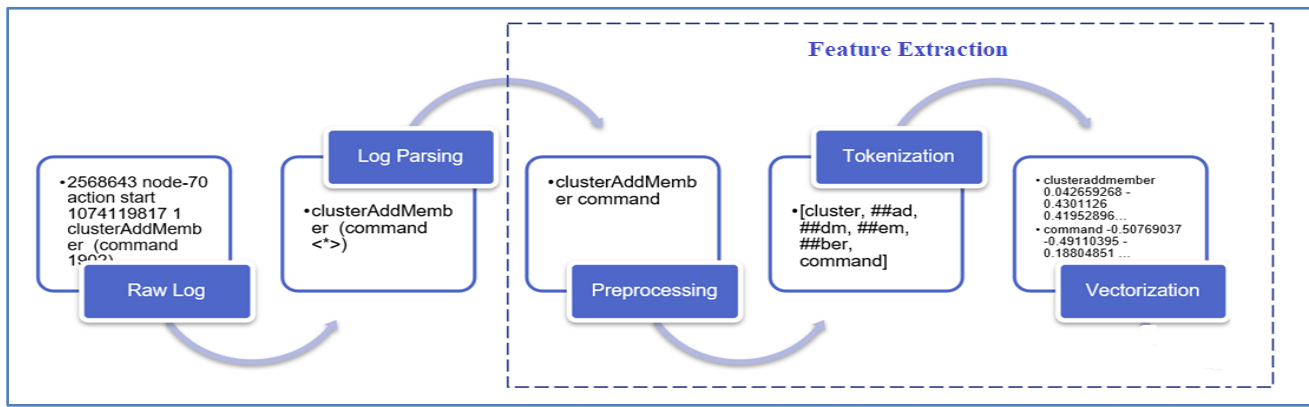


Fig. 2. Process of feature extraction.

To utilize the doc2vec model, the following steps need to be pursued. First, furnish the dataset, which is to be turned into vectors. A word vector is created for an individual word, and combining related word vectors creates a document vector for each document [33]. The softmax hidden layer is used to train the weights, and then all weights are set to find the sentence vector.

**B. Bidirectional Encoder Representations from Transformers (BERT)**

BERT models are the most acceptable preference for obtaining superior-quality language features from the offered text dataset. Furthermore, the model can be fine-tuned for specific tasks such as semantic analysis or question answering, relying on input datasets. BERT is a pre-trained language model that is directionally trained [34]. Devlin et al. demonstrated that a directionally trained language model could possess a more profound sense of language context and flow than single-direction language models [35].

The BERT pre-trained model outperforms word2vec as this approach assigns dynamic numerical vectors to each token, considering the context within which the word appears whereas in word2vec, each word has a fixed numerical vector allocated. Experimentation uses BERT to pull out features by generating word and sentence embedding vectors from log templates and contents. This research focuses on the feature extraction part of the BERT; thus, the remaining part is not considered for an explanation. Here, log templates and contents are elicited from the Drain parser and presented to the BERT model to extract the features. BERT is a pre-trained model taking input data in a specific format. BERT mainly adds an [SEP] as the split between consecutive sentences and

an [CLS] at the start of the sentence. The BERT model offers intrinsic tokenizing. The supplied input is spitted into multiple tokens considering the corpus records. Following that, the embedding layer creates an embedding vector for each token, which includes [CLS] and [SEP]. Log template data desires to be converted into torch tensors and called the BERT model to evoke embedding. The BERT PyTorch interface demands that the data be in torch tensors rather than Python lists. The bert-base-uncased model contains 13 layers (1 for input embedding and +12 for output embedding) of the transformer encoder and 768-hidden units of all transformers.

Every token has 13 independent vectors, each of length 768 but necessary to get separate vectors for every token or single vector presentation of the entire sentence. Individual vectors are calculated by adding the last four layers together. Furthermore, a 768-length vector is calculated for each sentence by taking the average of the second to the final hidden layer.

Table II presents a comparative analysis of Doc2Vec and BERT embedding techniques. This summarized view is bestowed in reference to the critical points observed during the study of Doc2Vec and BERT techniques. These techniques are compared using a type of embedding suitable for which kind of data and the pros-cons of the method. Doc2Vec works on static sentence embedding, whereas BERT considers the context of the words for embedding.

Thus, Doc2Vec is the appropriate choice in a problem where semantic relations between the words are essential. To extract contextual ties between words, BERT works very efficiently.

TABLE II. COMPARATIVE ANALYSIS OF WORD EMBEDDING TECHNIQUES / MODELS

Technique/Model	Embedding Type	Suitable for	Pros	Cons
Doc2Vec	Static Sentence Embedding	Semantic Relation Between Word	Generate a vector representation of a group of words collected to present as a single unit.	The co-occurrence matrix of sentences occupies plenty of memory for storage.
BERT	Contextualized Word Embedding	Contextual Relation Between Word	Capable of gaining context-sensitive bi-directional feature representation.	Fine-tuning and pre-training are inconsistent. Long training time due to the immense size of model files



## V. CLASSIFICATION MODEL

### A. Model Definition

Machine learning classifiers are essential tools for a wide range of applications. They have the potential to revolutionize many industries by automating tasks, improving accuracy, and providing new insights into complex systems. These classifiers work by learning patterns and relationships within a given dataset and then using that knowledge to classify new data into pre-defined categories or classes. In recent research, the authors explored using multiple classifiers to group logs based on log level. The working of machine learning classifiers can vary depending on the algorithm used. This study experimented on five different infrastructure logs using k-Nearest Neighbors, Linear Regression, Support Vector Machines, Naïve Bayes, Gradient Boosting Decision Trees, and Random Forest machine learning classifiers.

1) *K-Nearest Neighbors (KNN)*: IT is a machine learning classifier that can be used for regression and classification tasks. A non-parametric algorithm finds the K closest training examples (i.e., neighbors) to a new data point and uses their class labels to make a prediction [36].

2) *Linear regression*: Linear regression is a type of regression analysis that models the relationship between a dependent variable and one or more independent variables [37]. It is commonly used for predicting continuous values, such as sales revenue or stock prices.

3) *Support Vector Machines (SVMs)*: SVMs are supervised learning algorithms that can be used for classification or regression tasks [38]. SVMs try to find the optimal hyperplane that separates the different classes in the dataset.

4) *Naïve bayes*: Naïve Bayes is a probabilistic algorithm that can be used for classification tasks [39]. It is based on Bayes' theorem and assumes that the features in the data are independent of each other.

5) *Gradient boosting decision trees*: Gradient boosting is an ensemble learning technique that combines multiple decision trees to improve prediction accuracy. It involves training a series of decision trees in sequence, with each subsequent tree trying to correct the errors of the previous one [40].

6) *Random forests*: Random forests are also an ensemble learning technique that uses multiple decision trees to improve prediction accuracy [41]. However, unlike gradient boosting, random forests train each decision tree independently and then aggregate their predictions to make the final prediction.

### B. Evaluation Metrics

Classification of logs is based on the level earmarked for the log entry. In the different IT infrastructures, log entries hold numerous types of levels. Thus, a multi-class classification technique is favored to accomplish the classification. Generally, a multi-class classifier's performance is appraised by the Micro-F1 score and Macro-F1 Score [42]. Therefore, TP (True Positives), TN (True Negative), FP (False

Positives), and FN (False Negatives) values were collected from each category of level and further utilized to calculate micro precision, macro precision, micro recall, macro recall, and macro-F1.

For a provided log category  $i$ , outcomes are labeled as  $TP_i$ ,  $TN_i$ ,  $FP_i$ , and  $FN_i$ . Where  $TP_i$  represents the number of true positives in logs belonging to the  $i$  category.  $TN_i$  represents the true negative in logs belonging to the  $i$  category.  $FP_i$  represents false positives, and  $FN_i$  means false negatives in logs belonging to the  $i$  category.

Considering values of  $TP_i$ ,  $TN_i$ ,  $FP_i$ , and  $FN_i$ ,  $precision_i$  and  $recall_i$  are evaluated as:

$Precision_i$  can be calculated as the percentage of positively labeled predictions made out of all predictions under the  $i$  category of the level [43].

$$Precision_i = \frac{TP_i}{TP_i + FP_i} \quad (1)$$

The  $Recall_i$  can be calculated as the number of correct predicted results divided by applicable instances. Recall provides the number of accurately predicted results divided by all relevant samples [43].

$$Recall_i = \frac{TP_i}{TP_i + FN_i} \quad (2)$$

Macro-F1: Employed to compute the F1- score in the instance of multi-class settings. Macro-F1 is known as the macro-averaged F1 score and is calculated as simple arithmetic means of the F1 scores of each class [44].

$$Macro\ Average\ Precision = \frac{\sum_{k=1}^k Precision_k}{k} \quad (3)$$

$$Macro\ Average\ Recall = \frac{\sum_{k=1}^k Recall_k}{k} \quad (4)$$

$$Macro\ F1\ Score = 2 * \left( \frac{MacroAveragePrecision * MacroAverageRecall}{MacroAveragePrecision^{-1} + MacroAverageRecall^{-1}} \right) \quad (5)$$

Specificity is calculated on the negatives that are detected accurately. Specificity is also known as True Negative Rate (TNR), which denotes the classifier's ability to enter negative entries in the actual class [45]. In the case of logs, the system administrator can select a log level with correct specificity to proctor the anomalies or failures.

$$Specificity_i = \frac{TN_i}{TN_i + FP_i} \quad (6)$$

The metrics used to measure model performance are training and testing splits accuracy. Accuracy is the rate of the absolutely classified data to all the data [46].

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (7)$$

## VI. IMPLEMENTATION DETAILS

All models are implemented in Python and executed on the Symbiosis Institute of Technology (Pune, India) server. Various datasets such as Apache, OpenStack, Windows, BGL, and Android were utilized to conduct the experimentation. These datasets carry a vast number of log messages ranging

from around fifty-six thousand to 11 million (refer to Table III for dataset details). Because of the excellent server configuration made executing the BERT feature extraction technique and ML classifiers on a massive data size possible.

TABLE III. DATASET DESCRIPTION

Dataset	Description	Source Type	Period	Number of logs
Apache	Apache webserver error log	Server Application	263.9 days	56,481
OpenStack	OpenStack infrastructure log	Cloud System	NA.	207,820
Windows	Windows event log	Operating System	NA.	611,103
BGL	Blue Gene/L supercomputer log	Supercomputer	214.7 days	4,747,963
Android	Android framework log	Mobile System	NA.	1,555,005

The "Drain" parser is employed to parse the log messages into log templates. An environment was created to run the Drain parser by installing dependencies such as Python 2.7, Scipy, NumPy, sci-kit-learn, and pandas. The unstructured logs were converted into the structured format and preserved in the .csv file. The results of parsing using Drain are presented in Table I.

For feature extraction, we construct Doc2Vec and BERT sentence embedding models. Doc2Vec model was developed considering vector size 10, windows as 2, minimum count of records one, and assigned workers as 4. At the same time, the Bert-base-uncased model was employed to obtain sentence vectors of log templates and contents. Considering the time required for embedding and model training, optimizing the performance of the BERT pre-trained model was indispensable. According to [47] BERT model works effectively when max\_seq\_len is 25, pooling\_layer is set as 12, priority batch size is 16, and prefetch\_size is set as 10. The exact configuration was followed to improve the speed of the embedding process.

The classification models were trained over random training and testing data selection from the provided datasets. Records are selected using different seeds, as 70% and 80% of log entries as training data, and 30% and 20% remain as testing data. All classifiers were experimentally evaluated based on precision, recall, F1-score, specificity, and accuracy for each log level within our labeled dataset.

## VII. RESULTS

Table IV demonstrates the accuracy of classification models where BERT is utilized as an embedding technique to apprehend the meaning of log templates and contents. The K-

nearest neighbor model indicates lower accuracy among the seven implemented classifiers, whereas Random Forest offers higher classification accuracy for all datasets. As per the observation from Table IV, although the training and testing ratio changes yet there is an insignificant difference in the accuracy values.

Minimum accuracy was recorded as 81.47% for the BGL dataset using KNN, whereas 90.22% accuracy for the Apache dataset using the SVM model. The accuracy score greater than 90% is highlighted in Table IV. Higher accuracy was derived on an 80% training ratio for the Apache dataset using Linear Regression, SVM, and Random Forest and for the OpenStack dataset using Random Forest. Table IV observations show the KNN model returns lower accuracy, and the Random Forest model returns higher accuracy for almost all datasets. The difference between the minimum and maximum accuracy is 8.75%; thus, we can conclude that all implemented classification models have roughly comparable accuracy on Apache, OpenStack, Windows, BGL, and Android datasets. Based on this discussion, it is stated that semantic analysis using BERT helps classify various types of log records efficaciously. In addition, it is claimed that OpenStack and Android datasets are more suitable for the evaluation of the robustness of the classification model in the case of unseen log records. A more significant number of log templates are recorded for OpenStack and Android datasets in the parsing process (stated in Table I).

### A. Results on Apache Dataset

Fig. 3 presents a metaphorical evaluation of seven classifiers over the Apache webserver error log dataset, considering a 30% and 20% testing data ratio. Prior to the classification, features were extracted with the help of the BERT model. Random Forest achieves the highest precision (96.08%) among the seven techniques and carries an F1 score of 92.71% in both cases, considering the 30% and 20% testing data ratio. This demonstrates that Random Forest provides the best classification results on semantic analysis of log templates and contents of log records. KNN, LinearRegression Support Vector Machines, Gradient Boosting Decision Trees, and Random Forests obtain consistent precision values on the Apache dataset, although the training-to-testing data ratio varies. Gradient Boosting Decision Trees and Random Forests show high precision but a low recall rate compared to other models. It is ascertained that all implemented models achieve consistent results on the Apache dataset, which implies that the semantics of the Apache log template and contents are derived correctly; thus, models can understand and perform classification operations. Also, unique templates (44) are derived during parsing 56,481 log records (refer to Table I) with 100% accuracy. The observation revealed the importance of log parsing in the log-based failure detection process.

TABLE IV. CLASSIFICATION ACCURACY IN PERCENTAGE ON VARIOUS DATASETS CONSIDERING 30% AND 20% TESTING DATA USING BERT EMBEDDING TECHNIQUE

IT Infra-structure	Training Ratio	k-Nearest Neighbors	Linear Regression	Support Vector Machines	Naïve Bayes	Gradient Boosting Decision Trees	Random Forest
Apache	70%	86.36	88.04	88.54	87.88	88.69	89.69
	80%	86.95	<b>90.01</b>	<b>90.22</b>	89.46	89.13	89.65
OpenStack	70%	84.17	86.11	86.34	85.27	86.07	88.17
	80%	85.17	88.02	88.14	87.94	87.81	89.34
Windows	70%	82.11	84.36	84.36	83.99	84.39	84.45
	80%	83.35	86.77	86.77	85.23	85.73	85.39
BGL	70%	81.47	83.39	83.39	83.79	83.09	85.21
	80%	82.98	85.79	85.70	85.74	85.01	86.89
Android	70%	81.89	83.89	83.89	81.87	82.46	85.72
	80%	83.67	85.79	85.79	84.72	84.72	87.56



Fig. 3. Precision, recall, f1-score, and specificity in percentage on Apache datasets considering 70% and 80% of training data using BERT embedding technique.

**B. Results on OpenStack Dataset**

Fig. 4 presents a metaphorical evaluation of seven classifiers over the OpenStack infrastructure log dataset, considering a 70% and 80% training data ratio, respectively. Before the classification, features were extracted with the help of the BERT model. KNN, Linear Regression, Support Vector Machines, Naïve Bayes, Gradient Boosting Decision Trees, and Random Forests achieved more than 90% precision when experiments were conducted on 30% of testing records and 20% of testing records, respectively. The precision, recall, F1-Score, and specificity improved by increasing the training-to-testing ratio. Among the seven implemented classifiers, Random Forest has the highest precision (95.13%), recall (89.31%), and F1 Score (92.13%) over 80% of the training data. The OpenStack dataset is preferred to check the classification efficiency for unobserved log records as it records a higher number (7,221) of log templates in 207,820 total log entries (refer to Table I), 3.47% of the whole dataset. In contrast, other datasets retrieve less than 1% of log templates. More variations in the log template promote checking the capability of semantic analysis to extract rigorous meaning that imparts to accurate classification.

**C. Results on Windows Dataset**

Fig. 5 presents a metaphorical evaluation of seven classifiers over the Windows event log dataset, considering a 70% and 80% training data ratio. Before the classification, features were extracted with the help of the BERT model. K-Nearest Neighbors records minimum precision as 85.67% and maximum precision by Random Forest as 87.99%, which

means the difference in precision is significantly less for seven classification models. Although the precision, recall, and F1-Score values are less than 90%, they are consistent for all implemented classifiers. The Windows dataset results are decreasing compared to Apache and OpenStack datasets due to the size of the data and the number of unique templates. In the Windows dataset, 176 unique templates were extracted from 611,103 (refer to Table I) event records, which is only 0.02%. Here, unique templates are fewer, but the contents of the individual events fluctuate in compliance with the recorded message.



Fig. 4. Precision, recall, f1-score, and specificity in percentage on Openstack datasets considering 70% and 80% of training data using the BERT embedding technique.



Fig. 5. Precision, recall, f1-score, and specificity in percentage on Windows datasets considering 70% and 80% of training data using BERT embedding technique.

**D. Results on BGL Dataset**

Fig. 6 presents an illustrative evaluation of seven classifiers over the Blue Gene/L supercomputer log dataset, considering a 70% and 80% training data ratio. Before the classification, features were extracted with the help of the BERT model. KNN records minimum precision as 82.89% and maximum by Random Forest as 86.77%, which means the

difference in precision is significantly less for seven classification models. Although the precision, recall, and F1-Score values are less than 90%, they are consistent for all implemented classifiers. The BGL dataset results are decreasing compared to Apache and OpenStack due to the size of the data and the number of unique templates. In the Windows dataset, 619 unique templates were extracted from 4,747,963 (refer to Table I) log records, which is only 0.01%. Here unique templates are lesser, but the contents in the individual log fluctuate in compliance with the recorded message. According to observation, 1-2 % change in the precision, recall, and F1-Score values on different testing ratios, such as lower results recorded on the 30% testing ratio, whereas improved results by 1-2% recorded on 20% testing data.



Fig. 6. Precision, recall, f1-score, and specificity in percentage on BGL datasets considering 70% and 80% of training data using the BERT embedding technique.

#### E. Results on Android Dataset

Fig. 7 presents a metaphorical evaluation of seven classifiers over the Android framework log dataset, considering a 70% and 80% training data ratio. Before the classification, features were extracted with the help of the BERT model. KNN records the minimum precision as 78.34%. The difference in precision is significantly less for the seven classification models. The Android dataset results are decreasing compared to Apache and OpenStack due to the size of the data and the number of unique templates. In the Android dataset, 14,899 unique templates were extracted from 1,555,005 (refer to Table I) log records, which is only 0.09% of the whole dataset. Thus, the Android dataset is preferred to check the classification efficiency for unseen log records. More variations in the template help check the capability of semantic analysis to extract exact meaning that contributes to accurate classification. As a bottom line, it is stated that the greater the number of log records and the greater the number of unique templates, the more they help to train the model effectively.



Fig. 7. Precision, recall, f1-score, and specificity in percentage on Android datasets considering 70% and 80% of training data using the BERT embedding technique.

#### VIII. CONCLUSION AND FUTURE WORK

This paper describes an automatic and accurate classification of logs to facilitate system administrators during cause analysis of failures using system logs generated by various massive-scale IT infrastructures. The implemented models are able to understand the meaning of records and then classify them based on their level for log entries from multiple infrastructures such as Apache, OpenStack, Windows, BGL, and Android. The system admin can pay more attention to bizarre records and adopt remedial measures on the Anomalous records pointed out in the classification results,

The proposed system works efficiently on different types of log entries irrespective of changes in the format and imbalanced data. Thus, this work indicates how semantic analysis using BERT and classification using Linear Regression, Support Vector Machines, Naïve Bayes, Gradient Boosting Decision Trees, and Random Forests models furnish robust classification of new log entries. Considering the results and discussion points, K-Nearest Neighbors does not work well due to the imbalanced nature of log records. It is observed that, as compared with Doc2Vec, the semantic analysis achieved by the BERT pre-trained model is better while working with different classifiers. In addition, BERT influences the classification of any log record type with all classifiers and precisely processes the unseen or new log entries.

Experimentation using BERT as an embedding technique and machine learning models as classifiers derived precision, recall, F1 scores, and specificity in the range of 80% to 90%. In the extension to this work, we will try to improve the results to reduce false alerts with the help of applying deep learning techniques such as LSTM. Future work put forward the enforcement of LSTM models and propounding modified LSTM models to secure better results. Also, the system implemented with feature extraction and classification is semi-automated. In the future, the proposed system will be enhanced to implement a fully automated classification system to reduce human intervention.

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# Application of the Learning Set for the Detection of Jamming Attacks in 5G Mobile Networks

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**Abstract**—Jamming attacks represent a significant problem in 5G mobile networks, requiring an effective detection mechanism to ensure network security. This study focused on finding effective methods for detecting these attacks using machine learning techniques. The effectiveness of Ensemble Learning and the XGBOOST-Ensemble Learning combination was evaluated by comparing their performance to other existing approaches. To carry out this study, the WSN-DS database, widely used in attack detection, was used. The results obtained show that the hybrid method, XGBOOST-Ensemble Learning, outperforms other approaches, including those described in the literature, with an accuracy ranging from 99.46% to 99.72%. This underlines the effectiveness of this method for accurately detecting jamming attacks in 5G networks. By using advanced machine learning techniques, the present study helps strengthen the security of 5G mobile networks by providing a reliable mechanism to detect and prevent jamming attacks. These encouraging results also open avenues for future research to further improve the accuracy and effectiveness of attack detection in radiocommunication in general and specifically in 5G networks, thereby ensuring better protection for next-generation wireless communications.

**Keywords**—Jamming attacks; 5G mobile networks; ensemble learning; XGBOOST-ensemble learning; attack detection

## I. INTRODUCTION

Radiocommunication is defined, according to the International Telecommunication Union (ITU), as telecommunication carried out using radioelectric waves, that is to say, an electromagnetic wave that propagates in space without an artificial guide and whose frequency is by convention less than 3000 GHz [1]. The fields of application of this form of communication are numerous, including Wi-Fi, mobile, satellite, IoT networks, wireless sensors, high-altitude platforms, smart cities, smart grids, connected vehicles, etc. All these applications use propagation of the useful signal emitted in all directions, often in environments with multiple and sometimes complex obstacles, thus undergoing all kinds of disturbances, including intrusions by jamming for denial of service (DoS) and distributed denial of service (DDoS) [2]. Jamming attacks consist of intentionally transmitting a signal [3] that covers the frequencies used by the communication system to degrade the quality of the signal received by a communication device. Jamming signals can be relatively weak intentional electromagnetic interference (IEMI) [4] that degrades the performance of radio communication networks

without damaging them. With the proliferation of connected objects (IoT) and the convergence of networks, the number of devices used in everyday life and connected to the Internet by radio communication has increased considerably in recent years. According to statistics, this number has increased from 1 million in 1992 to more than 50 billion in 2020[5] globally. With this reality, telecommunications networks, particularly 5G mobile networks, have undergone significant transformations to adapt to this exponential growth of connected devices. Significant contributions include the evolution of the radio access network (RAN), the part of 5G that connects end-user devices. Architectures such as C-RAN, O-RAN, vRAN, etc., have been proposed to address these challenges. These new network architectures have improved the flexibility, capacity, and efficiency of 5G mobile networks. However, with this evolution, new security challenges have also emerged. Among these challenges, jamming attacks represent a significant problem that compromises network security. Despite the advantages offered by new network architectures, the security of C-RAN networks has been questioned due to their vulnerability [6] to malicious jamming attacks, especially regarding the use of radio resources. Even the most advanced C-RANs can be subject to all sorts of attacks on radio networks.

Different types of jamming attacks can be used against C-RAN, including random, reactive, deceptive, and constant jamming [7]. These attacks seriously threaten the proper functioning of C-RAN networks and can compromise the quality of services offered to end users.

In order to counter these jamming attacks, it is essential to put in place effective detection mechanisms. This study focuses on using machine learning techniques to detect these attacks in C-RAN networks. The effectiveness of Ensemble Learning and the XGBOOST-Ensemble Learning combination is specifically assessed, comparing their performance to other existing approaches.

By identifying and evaluating the different jamming attacks possible in C-RAN networks, our study aims to strengthen the security of these networks by proposing advanced detection mechanisms. These results will allow a better understanding of the characteristics of these attacks and the development of appropriate countermeasures to protect C-RAN networks from the harmful consequences of jamming attacks.

The issue of jamming attack detection in 5G mobile networks using machine learning (ML) techniques is addressed in this study. The approach developed here, uses a specific database (WSN-DS) to evaluate and compare the performance of different machine Learning algorithms. The goal is to determine the most efficient algorithm for detecting jamming attacks based on this data set. The present study has made the following contributions:

- The use of machine learning techniques, in particular ensemble learning and the XGBOOST-ensemble learning combination, to detect jamming attacks. This innovative approach leverages the capabilities of these advanced techniques to improve detection accuracy.

- Performance evaluation of ensemble learning and XGBOOST-ensemble learning in comparison with other existing approaches. This comparative evaluation highlights the superior effectiveness of the hybrid XGBOOST-Ensemble Learning method, which outperforms the other approaches studied and those described in the literature.

This paper is organized as follows. After the introduction, which sets out the problem addressed in this paper in Section I, Section II presents a literature review of previous work on intrusion detection attacks and methods (ML-IDS) in radio communications, particularly in 5G. The ML-IDS methodology adopted in this work (EL-IDS) is formulated and presented in Section III. The results obtained are presented in Section IV and discussed in Section V. Finally, Section VI focuses on the research objective and draws conclusions from this study.

## II. RELATED WORK

The new generation of wireless communication networks, the fifth generation (5G), guarantees a high transmission rate and low latency and maintains good connectivity between heterogeneous mobile devices. 5G cellular networks provide the key infrastructure to deliver emerging services. Security anomaly detection is increasingly important in protecting systems from malicious attacks. Several authors have conducted interference studies in the 5G network. F Wu et al. studied a mixed digital interference (MNI) recognition approach based on convolutional neural networks (CNN) [8]. The results of this work showed that the accuracy could reach 97% or more for different signal-to-noise ratios and fading channels. M. Usama et al. proposed a technique stimulated by recent advances in deep learning to exploit the rich information hidden in large volumes of data and tackle resource allocation problems [9]. Mughaid et al. built a simulator for NOMA and applied a drop attack to extract a dataset from the simulation model. The accuracy of detecting drop attacks using data extracted after applying ML algorithms is 95.7% for LR. Furthermore, their methodology for detecting wireless cyberattacks in 5G networks is based on applying ML and DL techniques such as Decision Trees, KNN, Multi-class Decision Jungle, Multi-class Decision Forest, and Multi-class Neural Networks. The proposed work is implemented and tested using a complete set of reference data on Wi-Fi networks [10]. The experiments yielded 99% accuracy for the KNN algorithm and 93% for DF and the neural network. L. Xiao et al. investigated MEC systems' attack patterns, focusing on mobile offloading

and caching procedures. In this article, they propose security solutions that apply Reinforcement Learning (RL) techniques to provide secure offload to edge nodes against jamming attacks; also, lightweight authentication and secure collaborative caching schemes have been designed to protect data confidentiality[11]. The results of these reinforcement learning-based methods for mobile edge caching are relevant. Y. Wang et al. presented an anonymous jamming detection model for 5G and beyond based on critical signal parameters collected from the radio access network and core network protocol stacks on a test bench. 5G trial. The results of their approach give supervised instantaneous detection models an area under the curve (AUC) between 0.964 and 1 compared to time-based long-term memory models (LSTM), which reach an AUC between 0.923 and 1 [12]. Jamming and intrusion detection remain 5G's most important research areas of maintaining the trustworthiness of use cases and preventing user experience degradation by avoiding a severe infrastructure failure or a denial of service in critical applications within the company. Similarly, Marouane Hachimi et al. proposed machine learning-based intrusion detection in the 5G C-RAN network to enhance security [5]. Their approach was to classify the types of jamming attacks within a 5G network. Their experiment gave an attack classification accuracy of 94.51% with a false negative rate of 7.84%.

The work presented above indicates that the studies carried out by these authors have focused on interference recognition in Wi-Fi networks using Machine Learning and Deep Learning models.

Furthermore, these studies highlight the use of Machine Learning and Deep Learning algorithms for interference classification, but have not delved into comparative studies that evaluate the performance of different interference classification models in Wi-Fi networks. The present study uses Machine Learning techniques, in particular Ensemble Learning (Random Forest, KNN, Naïve Bayes, Logistic Regression) and the XGBOOST-Ensemble Learning combination (XGBOOST-Random Forest, XGBOOST-KNN XGBOOST-Naïve Bayes, XGBOOST-Logistic Regression) to detect interference attacks in the 5G network. It compares the performance of different interference identification techniques, to highlight their impact on the accuracy of interference classification. The use of these different approaches provides a better understanding of Ensemble-Learning classification methods and the XGBOOST-Ensemble Learning combination, highlighting the strengths and weaknesses of each technique in detecting interference in the 5G network.

## III. MATERIAL AND METHOD

### A. Material

The database used for our study is the WSN-DS: a data set for intrusion detection systems in wireless sensor networks. It contains 374,661 simple connection vectors, each including 23 characteristics, and is labeled as normal or attack. The specific attack types are scattered into different attack categories, namely constant jamming, random jamming, deceptive jamming, and reactive jamming, in addition to the normal case (without attack).

The experiments used Python programming on a DELL desktop computer with an Intel(R) Core i7-10700 CPU clocked at 2.90 GHz, 32 GB of RAM, and a card NVIDIA Quadro P400 graphics.

### B. Deployment Architecture

Fig. 1 presents the architecture. It divides base stations into Radio Remote Heads (RRH) and the Baseband Unit (BBU). RRH is the unit that provides the interface to the fiber and performs the digital processing, digital-to-analog conversion.

The traditional C-RAN architecture is based on Mobile Cloud Computing (MCC) principles with centralized BBUs in remote data centers. Resources provided to mobile users are typically located at the end of a long chain of nodes and across a mobile backhaul that can be congested at any time. However, more and more applications today operate almost in real time with requirements for very short transmission times. Thus, the performance of C-RAN systems is highly dependent on the physical proximity between mobile users and cloud servers.

The objective of this architecture is to concede the calculation and the storage to the H-RRHs near the mobile user to increase the processing capacity of the mobile terminals and allow the unloading of the greedy tasks in resources. All the added resources from the Cloud-RRH.

In addition, using cloud containers instead of virtual machines (VMs) at the RRH cloud level saves performance and processing time. A container is a collection of self-contained components ready to be deployed, and it can include libraries to be able to run the applications. Unlike VMs, multiple containers can share the same host operating system with its libraries and binaries. The containers are much lighter, translating into faster launch and easier migration from one machine to another.

Despite these proposals for attractive solutions introduced in this new C-RAN architecture, the radio interface remains a significant challenge in the face of jamming attacks using radio resources. For experimental results, a specialized dataset for Wireless Sensor Networks (WSN) was analyzed to classify jamming attacks; WSN-DS can have normal or malicious network traffic.

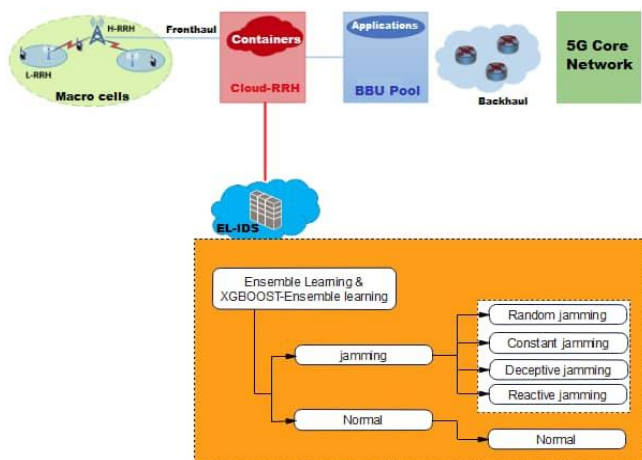


Fig. 1. Deployment architecture of EL-IDS in the CRAN – CRRH environment).

### C. Learning Algorithms

The choice of the appropriate Learning algorithm [13] is crucial for the performance of a prediction model. In the present study, we opted for the use of Learning ensembles composed of the following algorithms: Random Forest, KNN, Naïve Bayes, Logistic Regression and XGBOOST. Each classification algorithm has its advantages and disadvantages, and we decided to combine them with XGBOOST for feature extraction to improve the performance of our classification model. When the data is insufficient, the learning set can use bootstrapping to train various classifiers using the different data samples, and also if the data is too large to train a single classifier then it is possible to partition the data into subsets for training purposes.

1) *KNN (K Nearest Neighbor)*: The nearest neighbor (KNN) method [14] is a popular classification method in data mining and statistics due to its simplicity of implementation and significant performance in classification. However, traditional KNN methods cannot assign a fixed k value (even if set by experts) to all tested samples. Previous solutions assign different k values to different test samples by cross-validation, but they are usually very time-consuming [15]. The KNN method has been widely used in data mining and machine learning applications due to its simplicity of implementation and remarkable performance.

2) *Naive bayes*: Naïve Bayes is one of the most popular data mining algorithms. Its effectiveness relies on the attribute independence assumption, although this may be violated in many real-world datasets. Many efforts have been made to mitigate this assumption, among which feature selection is a critical approach [16].

The naive Bayes classifier has surprised machine learning researchers by performing well on various learning problems. The researchers sought to overcome the main weakness of naive Bayes attribute independence and improve the algorithm's performance [17]. The naive Bayes classifier simplifies learning by assuming that features are class-independent. Although independence is generally a bad assumption, naive Bayes often compete with more sophisticated classifiers in practice.

3) *Logistic regression*: Logistic regression is used to obtain the odds ratio in the presence of more than one explanatory variable. The procedure is similar to multiple linear regression, except that the response variable is binomial. The result is the impact of each variable on the odds ratio of the observed event. The main advantage is avoiding confounding effects by analyzing the association of all variables [18]. It is an algorithm based on a statistical model allowing the study of the relations between a set of qualitative variables,  $X_i$ , and a qualitative variable  $Y$ . It uses a generalized linear model on a logistic function as a link function. The probability of predicting an event with the logistic regression model is established or not from the optimization of the regression coefficients, and its result continuously varies between 0 and 1.

4) *Random forest*: Random forest is a supervised learning algorithm used for classification and regression. It combines multiple decision trees to produce more accurate predictions. Random forest is useful for datasets with categorical or continuous variables and can handle missing data. The RF algorithm randomly divides the data set into training data (in-bag) for training and validation data (out-of-bag) for testing. The level of learning and 2/3 of the data set is devoted to training data and 1/3 to validation data. Subsequently, many decision trees are randomly created using "bootstrap samples" from the dataset. The branching of each tree is determined by randomly selected predictors at node points [19].

5) *XGBOOST*: XGBOOST is an improved model of the Gradient Boost algorithm. This machine Learning algorithm solves common business problems while relying on a minimum amount of resources [20]. Extreme gradient boosting is a method that is used to reduce the number of errors in predictive data analysis. XGBOOST is an assembly of decision trees (weak learners) that predict residuals and correct errors of previous decision trees. The particularity of this algorithm lies in the decision tree used. It is a recently introduced machine learning algorithm, which has proven to be very powerful in modeling complex processes in other research areas.

#### D. Methods

The methodology used in this study is based on several well-defined steps, thus providing a solid and rigorous approach to achieving our objectives. The most advanced intrusion detection techniques are studied to enable the security system monitoring the network to analyze traffic in order to discover actions that disrupt network confidentiality, integrity and availability.

Here is a detailed description of these steps:

- Step 1 : Data preprocessing

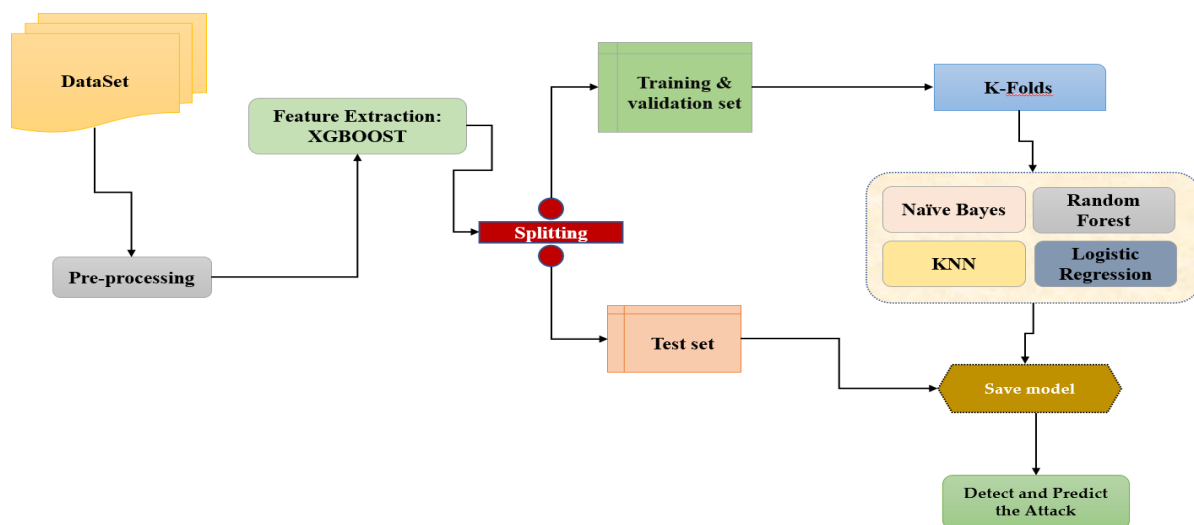


Fig. 2. Illustration of our methodology.

In this first stage, data were pre-processed to prepare them for subsequent analysis. Two distinct groups of data are created: the independent variables and the dependent variable. The "Type of attack" column is designated as the dependent variable in our dataset. The transformation of this categorical variable into a numerical value to facilitate analysis is carried out.

- Step 2 : Feature extraction

In this step, the XGBOOST algorithm is used to extract the characteristics of the independent variables. This advanced method enables us to highlight patterns and significant information in the data. Next, our data are divided into three parts: training, validation and testing. This division enables us to measure the effectiveness of the model on separate data sets and ensure its generalizability.

- Step 3 : Training with cross-validation

In this crucial step, the model was trained using cross-validation with algorithms. This approach makes it possible to test different algorithms and select the best performing one for classifying instruction types, the specific task. The training and validation sets are used to adjust the model parameters and evaluate its performance.

- Step 4 : Testing and evaluation

The test phase is essential for evaluating the quality of our model and detecting attacks. The test dataset used is independent of the training and validation datasets, to assess the model's actual performance. The results obtained are carefully examined and compared with known attacks to measure the model's effectiveness in detecting attacks.

Following this well-structured methodology, an in-depth study is carried out on attack detection, pre-processing the data, extracting relevant features, training the model by cross-validation and rigorously evaluating its performance.

Fig. 2 below summarizes the methodology adopted:

### E. Evaluation Metrics

To evaluate the results of this study, several measures were used. Efficiency (MCC). The differential equations are: accuracy, precision, recall, F1 score and Matthew's correlation coefficient. The differential equations are as follows:

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN} \quad (1)$$

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

$$Recall = \frac{TP}{TP + FN} \quad (3)$$

$$F1\ score = 2 * \frac{Precision * Recall}{Precision + Recall} \quad (4)$$

$$MCC = \frac{TP * TN - FP * FN}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}} \quad (5)$$

$$MSE = \frac{1}{n} \sum_{i=1}^n (Y_i - \hat{Y}_i)^2 \quad (6)$$

The Receiver Operating Characteristic (ROC) curve is a graph that shows the performance of a binary classification model. It describes the rate of true positives (sensitivity) as a function of the rate of false positives at different classification thresholds. An ideal ROC curve is approximately in the upper left corner of the graph, denoting high sensitivity and specificity.

The confusion matrix is a table that summarizes the results of the predictions of a classification model. It evaluates the model's predictions with the actual values from the dataset and classifies them into four categories: true positives, true negatives, false positives, and false negatives. The confusion matrix is used to compare a model's precision, recall, specificity, and overall accuracy.

### IV. RESULTS

The results are structured into two main parts: ensemble learning and XGBOOST Ensemble Learning.

The results of the machine learning models and XGBOOST-Ensemble learning have been presented separately. The machine learning models of the XGBOOST-Ensemble Learning combination outperform the machine learning models of ensemble learning, with a maximum accuracy of 99.72%.

### V. DISCUSSION

#### A. Case of Ensemble Learning

The Table I presents the metrics results:

The Random Forest model presents exceptional performances on all the criteria evaluated. It achieves high precision, a high F1 score, and high recall, all at 99.68%. The very low MSE of 0.007 indicates that the model predictions are close to the actual values. Moreover, the MCC of 98.18% indicates a robust correlation between the predictions and the actual observations. The execution time is reasonable at 356.15 ms.

The KNN model also performs well, although slightly lower than the Random Forest. Measurements of precision, F1 score, and recall are around 98%. The MSE of 0.063 indicates a slight average error of the predictions compared to the actual values. The execution time is longer at 1730.48 ms, which can be a drawback if efficiency is an important criterion.

The Naïve Bayes model has lower performance than the two previous models. Although precision and F1 score are reasonable at 88.10%, recall is relatively low at 84.83%. The high MSE of 0.358 indicates a more significant error of predictions against actual values compared to previous models. The MCC of 48.35% suggests a moderate correlation between predictions and actual observations. However, the execution time is very fast at only 2.62 ms.

The logistic regression model performs lower than other models. Precision and F1 scores sit at 86.24%, while recall is slightly higher at 88.21%. The high MSE of 0.511 indicates a significant prediction error compared to the actual values. The low MCC of 14.76% suggests a weak correlation between predictions and actual observations. Execution time is moderately fast at 185.65 ms.

The Random Forest model is the best among the four evaluated models regarding overall performance, with outstanding results on all measures. The KNN also shows good performance, although lower. Naïve Bayes models and logistic regression show relatively weaker performance, with more significant errors and less strong correlation between predictions and actual observations. Fig. 3 presents the histogram representing the performance of the models.

The Fig. 4 represents the ROC curve and the confusion matrix of the best model, namely the Random Forest.

TABLE I. CASE OF ENSEMBLE LEARNING METRICS RESULTS

Models	Accuracy (%)	Time(ms)	Precision (%)	F1 score (%)	MSE	Recall (%)	MCC (%)
Random Forest	99.68	356.15	99.68	99.68	0.007	99.68	98.18
KNN	98.23	1730.48	98.21	98.21	0.063	98.23	89.72
Naïve Bayes	84.83	2.62	88.10	88.10	0.358	84.83	48.35
Logistic Regression	88.21	185.65	86.24	86.24	0.511	88.21	14.76

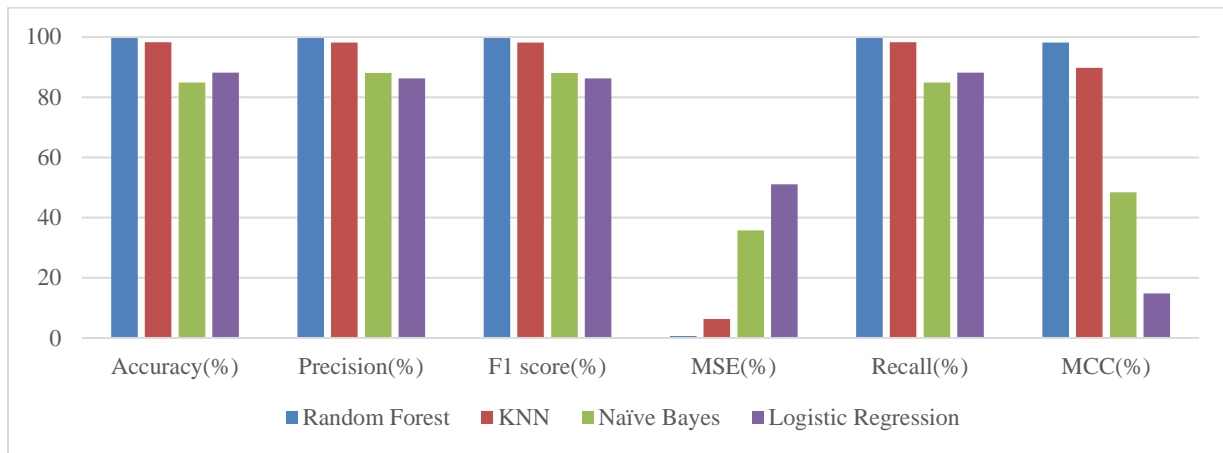


Fig. 3. Model performance histogram of case of ensemble learning.

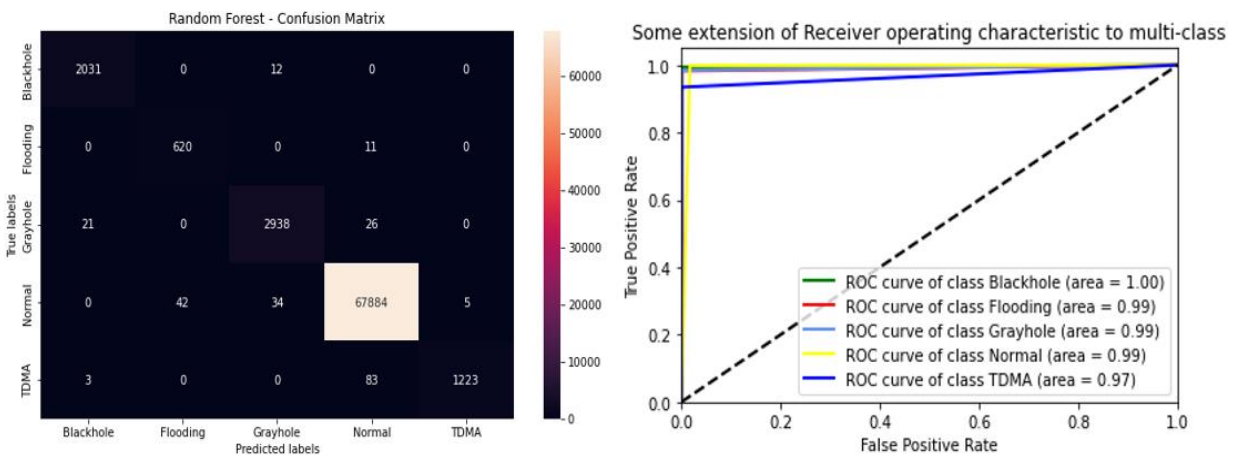


Fig. 4. ROC curve and confusion matrix of Random Forest.

**B. Case of XGBOOST- Ensemble Learning**

All of the models presented in Table II have high levels of accuracy, with scores ranging between 99.46% and 99.72%. This performance demonstrates their ability to classify the vast majority of samples accurately.

The execution time varies depending on the classification methods used. The XGBOOST-Naïve Bayes model is the fastest, with an execution time of only 1.369 milliseconds, while the XGBOOST-Random Forest model is the slowest, requiring 606.06 milliseconds. The other two models fall between these extremes regarding execution time. It is essential to consider these differences based on your specific application needs.

All models have an accuracy ranging from 99.46% to 99.72%, demonstrating their ability to classify most positive samples accurately. These models are, therefore, effective in avoiding false positives.

The F1 score, which combines precision and recall, presents high values for all models, ranging between 99.46% and 99.72%. This indicates a good balance between accuracy and the ability to recall positive samples.

The low MSE (Mean Squared Error) values obtained here indicate a low error in the predictions made. However, it should be noted that their interpretation may be limited in the context of classification.

Recall measures the ability of models to detect true positives among all truly positive samples. All models exhibit high recall values ranging from 99.46% to 99.72%, demonstrating their ability to identify positive samples.

The Matthews Correlation Coefficient (MCC) is a measure that considers the four categories of classification results. All models obtain high values of MCC, ranging from 96.98% to 98.41%, indicating a strong correlation between predictions and actual observations.

In conclusion, the models' performances based on XGBOOST and the other algorithms are globally compelling. The histogram represents the performance of these models visually.

Fig. 5 presents the histogram representing the performance of the models.

The ROC curve and the confusion matrix of the best model, namely the XGBOOST-Logistics Regression, are represented by the Fig. 6.



TABLE II. CASE OF XGBOOST-ENSEMBLE LEARNING METRICS RESULTS

Models	Accuracy (%)	Time(ms)	Precision (%)	F1 score (%)	MSE	Recall (%)	MCC (%)
XGBOOST-Random Forest	99.69	606.06	99.69	99.69	0.0066	99.69	98.25
XGBOOST-KNN	99.69	25.708	99.69	99.69	0.0064	99.69	98.26
XGBOOST-Naïve Bayes	99.46	1.369	99.47	99.47	0.0092	99.46	96.98
<b>XGBOOST-Logistic Regression</b>	<b>99.72</b>	<b>83.806</b>	<b>99.72</b>	<b>99.72</b>	<b>0.006</b>	<b>99.72</b>	<b>98.41</b>

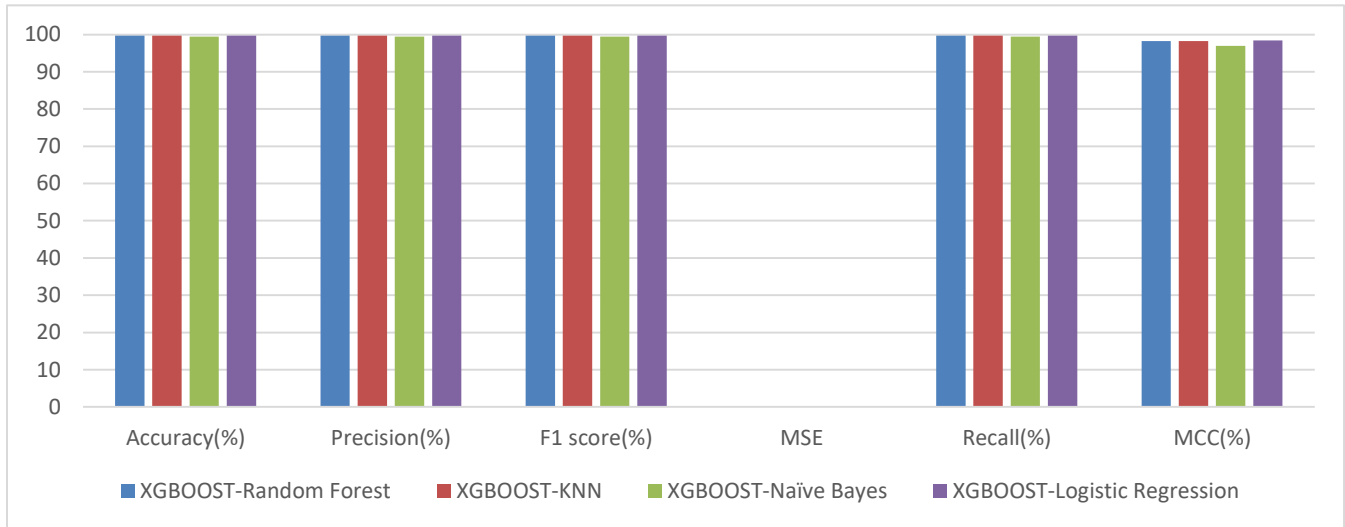


Fig. 5. Model performance histogram of case of XGBOOST- ensemble learning.

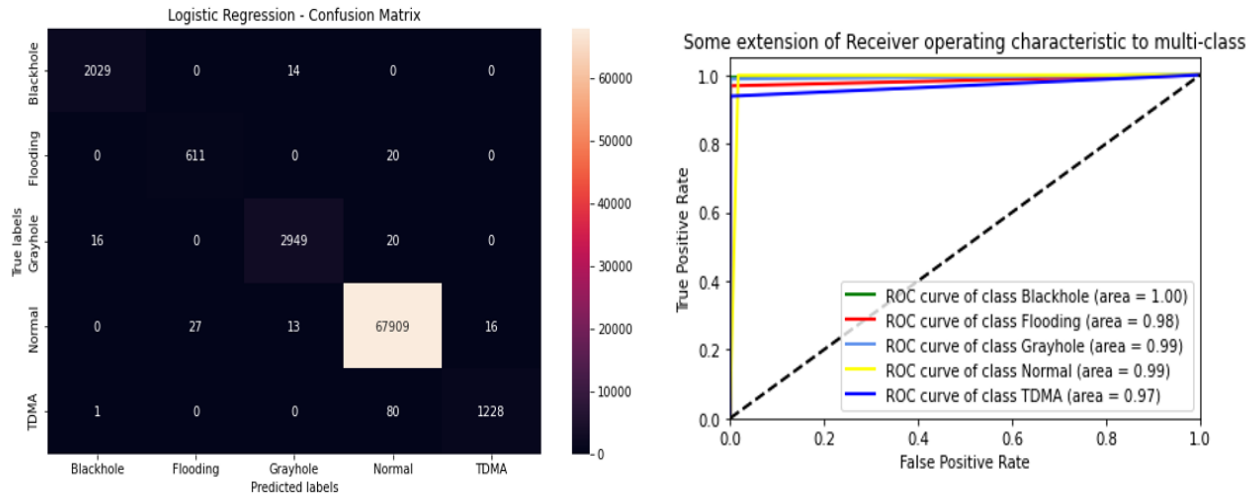


Fig. 6. ROC curve and confusion matrix of XGBOOST- ensemble learning.

C. Comparison with Existing Methods

The results of our experiments exceeded those of the state of the art. Table III shows the results. These results are also represented by the histogram, as shown in Fig. 7.

Fig. 7 shows the histogram comparing the results with those of the state of the art. A comparison was made between the proposed system and the methods used by other researchers in the field of intrusion detection in wireless sensor networks. The results showed that our system outperforms other authors' methods in the two approaches we performed.

TABLE III. COMPARISON WITH EXISTING RESULTS

Method	Accuracy (%)
Marouane Hachimi et al[16]	94,51%
Singh, N et al [17]	98,29%
Shaimaa Ahmed et al[18]	97,9%
<b>Our method of scenario1</b>	<b>99,68%</b>
<b>Our method of scenario2</b>	<b>99,72%</b>

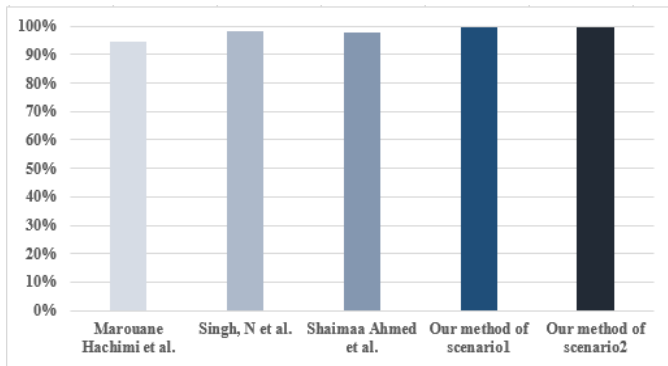


Fig. 7. Histogram of best scores of experiments.

In the first case, using the ensemble learning approach with the Random Forest algorithm, our system achieved an accuracy rate of 99.68%. This means that our method detected intrusions with high accuracy, surpassing the results obtained by other researchers. In the second case, using the XGBOOST-Logistic Regression approach as part of the Learning Ensemble, our system achieved an even higher accuracy rate of 99.72%. This remarkable performance highlights the effectiveness of our method of detecting intrusions in wireless sensor networks accurately.

These results demonstrate the superiority of our system compared to existing methods in terms of intrusion detection accuracy. The approach developed in this paper, based on advanced machine learning techniques, offers remarkable performance, strengthening the security of wireless sensor networks and guaranteeing more effective protection against intrusions.

Importantly, these results also demonstrate the importance of continued research in this area, as they pave the way for future improvements and new approaches for even more accurate detection of intrusions in wireless sensor networks.

## VI. CONCLUSION

In conclusion, the present study has demonstrated that the use of machine learning techniques, in particular ensemble learning and the XGBOOST-Ensemble Learning combination, is promising for the detection of attacks in 5G networks. The results show that the hybrid method, XGBOOST-Ensemble Learning, outperforms all other approaches, including those described in the literature, with an accuracy between 99.46% and 99.72%. These results confirm the effectiveness of ensemble learning in detecting attacks in 5G networks. This study represents a significant advance in the detection of attacks in 5G networks using machine learning techniques. The promising results pave the way for further research and continuous improvements in 5G network security, helping to ensure the reliability and protection of next-generation wireless communications. Future works will explore other attack detection methods based on statistical analysis approaches, such as operational approach models. This will enable us to improve detection accuracy and develop more robust defense systems against attacks in 5G networks. Another avenue would be to integrate real-time detection techniques to enable a rapid

and proactive response to potential attacks, thereby strengthening the security of 5G networks.

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# Hybrid Global Structure Model for Unraveling Influential Nodes in Complex Networks

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**Abstract**—In graph analytics, the identification of influential nodes in real-world networks plays a crucial role in understanding network dynamics and enabling various applications. However, traditional centrality metrics often fall short in capturing the interplay between local and global network information. To address this limitation, the Global Structure Model (GSM) and its improved version (IGSM) have been proposed. Nonetheless, these models still lack an adequate representation of path length. This research aims to enhance existing approaches by developing a hybrid model called H-GSM. The H-GSM algorithm integrates the GSM framework with local and global centrality measurements, specifically Degree Centrality (DC) and K-Shell Centrality (KS). By incorporating these additional measures, the H-GSM model strives to improve the accuracy of identifying influential nodes in complex networks. To evaluate the effectiveness of the H-GSM model, real-world datasets are employed, and comparative analyses are conducted against existing techniques. The results demonstrate that the H-GSM model outperforms these techniques, showcasing its enhanced performance in identifying influential nodes. As future research directions, it is proposed to explore different combinations of index styles and centrality measures within the H-GSM framework.

**Keywords**—Centrality indices; combination; hybrid; global structure model; influential nodes

## I. INTRODUCTION

In the captivating world of graph analytics, identifying significant nodes is critical, providing invaluable insights into the structure and behavior of many real-world networks. Networks with considerable sways, such as social networks, biological networks, and information networks, are characterized by nodes that operate as hubs or influencers, shaping the behavior of the entire network. Understanding and locating these significant nodes improves our understanding of network dynamics and offers possibilities for applications such as targeted marketing, recommendation systems, and vulnerability analyses [1], [2].

Centrality measurements are the preferred metric in network analysis for evaluating the relevance and influence of individual nodes or edges. DC [3], betweenness centrality (BC)[4], closeness centrality (CC)[5], and PageRank (PR) [6] are metrics that have been created to identify nodes that play essential roles depending on a variety of parameters. These traditional metrics primarily focus on local or global network information [7], [8], frequently failing to capture the delicate

interplay between the two. Local influence measurements, such as DC and CC, focus on a node's close connections and proximity to other nodes, elucidating its impact on information or resource flow within a narrow network section[9]–[11]. Global impact metrics, on the other hand, such as BC and PR, take into account the more extensive network structure and the importance of nodes to which a specific node is connected. These metrics excel at identifying nodes that serve as bridges between distinct network groups or enhance network connectivity across the board. These global measures are limited since they are computationally expensive and do not function well in the absence of a complete network structure [9], [12]–[14]. Evaluating local and global influence is critical to have a complete sense of node relevance. Nodes strongly influenced at both scales will likely hold critical positions within the network's complicated structure. They could impact immediate network behavior while altering its overall structure and dynamics.

Ullah's[15] Global Structure Model (GSM) provides a framework for ranking nodes in a network based on their local and global significance. This model uses the K-shell value to assess individual influence while considering neighboring node K-shell values and including path length to determine the global effect. It is worth noting, however, that the GSM falls short of adequately capturing the impact of path length, allowing the opportunity for further improvement. To remedy this issue, an improvement of GSM (IGSM) [16] has been made, which uses DC as its primary parameter rather than KS. Despite these advancements, precisely assessing the value of individual nodes within complex networks remains a substantial problem, emphasizing the need for ongoing study and developing novel ways to acquire more profound insights into network topologies.

This study continues our prior efforts in [17] and [18]. We successfully identified indices based on their similarity, demonstrating the improved performance obtained by combining indices from different network topologies, particularly when incorporating local and global centrality metrics. Next, we enhanced our findings by integrating the GSM with local and global centrality measurements by proposing a new hybrid model (H-GSM). Based on these findings, the current study intends to improve the algorithm using DC and KS framework.

The primary contribution of this study lies in the creation and evaluation of the H-GSM framework. The H-GSM framework combines the GSM with the comprehensive analysis provided by DC and KS, resulting in an improved ability to identify influential nodes. Notably, this integration enables the capturing of the intricate relationship between local and global network information, which is often overlooked by conventional centrality metrics. The findings of this study offer valuable insights for further exploration of different combinations of index styles and centrality measures, thereby advancing the understanding and application of network analysis methodologies.

## II. PRELIMINARIES

GSM and IGSM consider the node's self-influence and global influence, except that GSM believes in KS-decomposition, while IGSM is the improvement that applied DC. The formula is expressed as follows:

$$GSM(i) = SI(i) \times GI(i) = e^{-\frac{KS(i)}{n}} \times \sum_{i \neq j} \frac{KS(j)}{d_{ij}} \quad (1)$$

$$IGSM(i) = improved\_SI(i) \times improved\_GI(i) = e^{-\frac{DC(i)}{n}} \times \sum_{i \neq j} \frac{DC(j)}{d_{ij}^{ceil(\log_2(aver\_degree))}} \quad (2)$$

where  $KS(i)$  refers to the K-shell decomposition value of node  $i$ ,  $DC(i)$  refers to the degree value of a node, and  $d_{ij}$  refers to the path length between node  $i$  and node  $j$ .

These methods have grown in popularity because they are straightforward and enable researchers to quickly collect node values and use them in massive networks, broadening the scope of their potential applications. However, determining each node's significance within a network accurately presents a significant barrier for both the K-shell decomposition and the DC techniques. There need to be more levels in the K-shell decomposition method, which causes many nodes to be assigned to the same level [12], [19]. While DC only considers edge information, it ignores other essential elements like the structure of the entire network [20]. As a result, it might be challenging to accurately distinguish each node's relevance in large-scale networks where many nodes may have identical DC values. DC needs to recognize the significance of position data within the network. Due to their distinct placements or responsibilities in tying together various network regions, nodes with the same DC value may have differing degrees of influence. Alternative approaches that consider additional network properties and the impact of location information are needed to get over these constraints and develop a more thorough knowledge of node influence.

In this study, a hybrid approach of global structural model is proposed. It is suggested that the overall structure of the network is influenced by each node's capacity to impact itself. Because of this, the self-influence participant is essential to global influence. The following is how our suggested method is expressed:

$$H - GSM(i) = hSI(i) \times hGI(i) = e^{-\frac{DC(i)+KS(i)}{n}} \times \sum_{i \neq j} \frac{e^{-\frac{DC(i)+KS(i)}{n}}}{d_{ij}^{ceil(\log_2(aver\_hSI))}} \quad (3)$$

Fig. 1 is a sample network of 7 nodes and 10 edges, showing each node's classification from the KS-Decomposition. Using node 3 as an example, the overall steps for calculating H-GSM is shown.

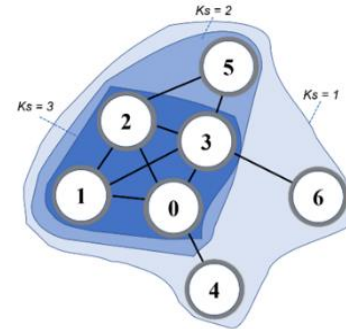


Fig. 1. Sample network.

Step 1: Determine KS and DC values.

$$DC(3) = 5 \quad KS(3) = 3$$

Step 2: Calculate hybrid self-influence (hSI).

$$\begin{aligned} hSI(3) &= e^{-\left[\frac{DC(3)+KS(3)}{n}\right]} \\ &= e^{-\left[\frac{5+3}{7}\right]} \\ &= 3.1357 \end{aligned}$$

Step 3: Calculate hybrid global influence (iGI).

$$\begin{aligned} hGI(3) &= \sum_{i \neq j} \frac{hSI(j)}{d_{ij}^{ceil(\log_2(aver\_hSI))}} \\ &= \frac{2.7183}{1^{ceil(\log_2(2.1944))}} + \frac{2.3564}{1^{ceil(\log_2(2.1944))}} + \frac{2.7182}{1^{ceil(\log_2(2.1944))}} \\ &\quad + \frac{1.3307}{2^{ceil(\log_2(2.1944))}} + \frac{1.7708}{1^{ceil(\log_2(2.1944))}} + \frac{1.3307}{1^{ceil(\log_2(2.1944))}} \\ &= 10.9777 \end{aligned}$$

Step 4: Calculate node influence of H-GSM.

$$\begin{aligned} H-GSM(3) &= hSI(3) \times hGI(3) \\ &= 3.1357 \times 10.9777 \\ &= 34.4228 \end{aligned}$$

Table I presents the rankings of centrality indices of different methods. Notably, the H-GSM metric consistently assigns rankings to nodes, distinguishing it from other centrality indices. The methodology is expanded through experimentation to conduct a comprehensive analysis of a more complex network.

TABLE II. RANKING OF NODES OF THE SAMPLE NETWORK

Rank	DC	BC	CC	PR	GSM	IGSM	H-GSM
1	3	3	3	3	3	3	3
2	1, 2	1	1, 2	0	1, 2	2	2
3	0	2	0	2	0	1	0
4	5	0, 4, 5, 6	5	1	5	0	1
5	4, 6		6	5	6	5	5
6			4	4	4	6	6
7				6		4	4

### III. METHODOLOGY

#### A. Datasets

This investigation utilized nine distinct real-world datasets, each featuring varying network sizes and unweighted attributes, to conduct further analyses. Table II presents information regarding the intricacies and classification of the network. The networks are available for download from KONECT (<http://konect.cc/networks/>) and NETWORK (<http://networkrepository.com/>). The variables  $n$ ,  $m$ ,  $k$ , and  $K_{max}$  are utilized to describe the characteristics of a network. Specifically,  $n$  represents the number of nodes,  $m$  represents the number of edges,  $k$  represents the average degree of the network, and  $K_{max}$  represents the highest degree present in the network.

TABLE III. DETAILS ON EXPERIMENTED NETWORK

Network	Type	$n$	$m$	$\langle k \rangle$	$K_{max}$
Karate	Social	34	78	4.588	17
Netscience1	Co-authorship	379	914	4.82	34
Router	Networking	2113	6632	6.128	38

#### B. Experimental Environment

The experiment setup is performed on a system with configuration on Windows 11 platform 64-bit system; the machine hardware configuration is an Intel® Core i7-8550U CPU @ 2.4 Hz processor, 24 GB of RAM; and Python-Visual Studio Code 1.56.2 is used for programming.

Regarding the proposed model analysis, the model is subjected to testing and validation procedures to ensure its capacity to represent each node's relative significance accurately. The proposed model is assessed through the implementation of the following procedures:

#### C. SIR Model

The Susceptible-Infected-Recovered (SIR) model is well-known for investigating each node's spreading dynamics. We will employ this section to quantify the performance of H-GSM and other benchmark centralities. All seed nodes are vulnerable for the first time. The seed node is likely to infect its nearest and next-nearest neighbor nodes (in the susceptible state) at each time step, and each node (the infected node) has a chance of recovering. This procedure was continued until no further infected nodes were discovered. Finally, all nodes gathered are used to simulate the actual node impact.  $S(t)$ ,  $I(t)$ , and  $R(t)$  represent the number of nodes in the susceptible, infected, and recovered states, respectively. Each loop represents a time step,  $t$ , and  $F(t)$  returns the total number of infected and recovered nodes at time  $t$ , which can be used to assess the influence of the original infected node. The infected

nodes will recover at step  $t$  with a probability of  $\rho$ . When no infected nodes remain, the propagation process is complete. Identical operations are performed for each node in each network using 100 distinct SIR model iterations.

#### D. Comprehensive Cumulative Distribution Function

The comprehensive cumulative distribution function (CCDF) is a commonly utilized tool in network analysis to compare and analyze centrality measures. The CCDF facilitates examining the distribution of centrality values across network nodes. By comparing the CCDFs of various centrality measures, scholars can evaluate how these measures capture distinct facets of node significance and how they order nodes based on centrality. This comparative analysis offers valuable insights into the network's attributes and actions. The value of the CCDF at a given rank,  $r$  in a ranking list is obtained by summing the probabilities of all the ranks greater than  $r$ . The mathematical expression for the CCDF can be represented as:

$$CCDF(r) = 1 - \frac{\sum_{i=1}^r n_i}{n} \quad (5)$$

where  $n$  is the total number of network nodes and  $\sum_{i=1}^r n_i$  refers to the number of numerical rankings less than or equal to  $r$  in the ranking list.

Through the graphical representation of the CCDF, it is possible to visually inspect the extreme values of the distribution, which correspond to nodes exhibiting elevated levels of centrality. This data can aid in identifying the most critical nodes within the network. A more pronounced slope of the centrality line in a CCDF plot indicates a higher degree of concentration of nodes with high centrality. In contrast, a less steep line suggests a more equitable distribution of centrality values among the nodes within the network.

#### E. Kendall's $\tau$ Correlation Coefficients

Kendall's  $\tau$ -correlation coefficient is used to evaluate the consistency between two rankings or order of things, making it a valuable tool for comparing centrality indexes. Each centrality indices rank nodes based on their importance or centrality in a network. We may measure how well the ranks provided by different indices agree by comparing them using Kendall. Using Kendall, we may assess the degree of agreement or concordance between the levels of nodes obtained by various centrality measures. Suppose two centrality indices give similar rankings (i.e., nodes ranked highly by one index are also ranked highly by the other). The Kendall coefficient will be high, suggesting a strong positive association. If the ranks differ significantly, the Kendall tau coefficient will be low, indicating a weak connection or disagreement between the indices. We may use Kendall to statistically analyze the consistency or divergence of multiple centrality measures and acquire insights into how well they capture similar or dissimilar characteristics of node importance in a network. The formula is as follows:



$$\tau(X, Y) = \frac{2(C - D)}{n(n - 1)} \quad (6)$$

where C and D are the numbers of concordant pairs and discordant pairs, respectively.

#### IV. RESULTS AND DISCUSSIONS

Fig. 2 shows how the distribution of nodes on those three networks over time, changed for various centrality indices for the top-10 node rank. A distinct line represents each centrality index. The analysis of centrality indices reveals that H-GSM exhibits consistently higher F(t) values than other metrics. This implies they exhibit a higher degree of efficacy in disseminating the pathogen. They show unique modes of distribution. The H-GSM protocol demonstrates a comparatively gradual rise in its initial phase, a diminished apex, and a protracted duration of sustained levels. GSM-based approaches exhibit higher F(t) values than conventional centrality metrics like DC, BC, CC, and PR. According to the Karate dataset, the disease is less likely to spread effectively. Incorporating iterative and incremental elements within H-GSM enhances its capacity to propagate the pandemic. This illustrates the importance of integrating multiple components and iterative procedures in models of epidemic propagation.

The utilization of standard deviation (SD) values furnishes insights into the degree of variability exhibited by the performance of individual centrality measures. Successive display of the standard deviation values for DC, BC, CC, PR, GSM, IGSM, and H-GSM is observed. Smaller standard deviation values suggest more significant levels of consistency and stability in behavior, while larger standard deviation values indicate increased levels of unpredictability. Upon examination of the graph, it is evident that H-GSM networks exhibiting a greater quantity of nodes demonstrate a decreased standard deviation compared to networks with fewer nodes.

The CCDF plot in Fig. 3 compares various centrality indices when network nodes are eliminated. The findings indicate that the metrics above exhibit varied characteristics and levels of susceptibility toward removing nodes. By examining the diminishing patterns of the curves, one can gain insight into the unique features of each method. A linear curve devoid of inflection points implies that each node is categorized with a distinct value. At the same time, a more pronounced descent indicates a more significant number of nodes being allocated to the same rank. The swift reductions observed in DC and BC highlight their noteworthy susceptibility and impact on the broader network connectivity and dissemination of information. The data suggest that CC experiences a gradual decrease, implying a comparatively less significant influence on the overall structure of the network. The decline in PR is relatively slower, indicating a less severe impact on the network's connectivity. The slower declination of GSM, IGSM, and H-GSM results in moderate sensitivities when nodes are removed. The comparative analysis of the three approaches across the three networks reveals that H-GSM effectively discerns the impact of individual nodes.

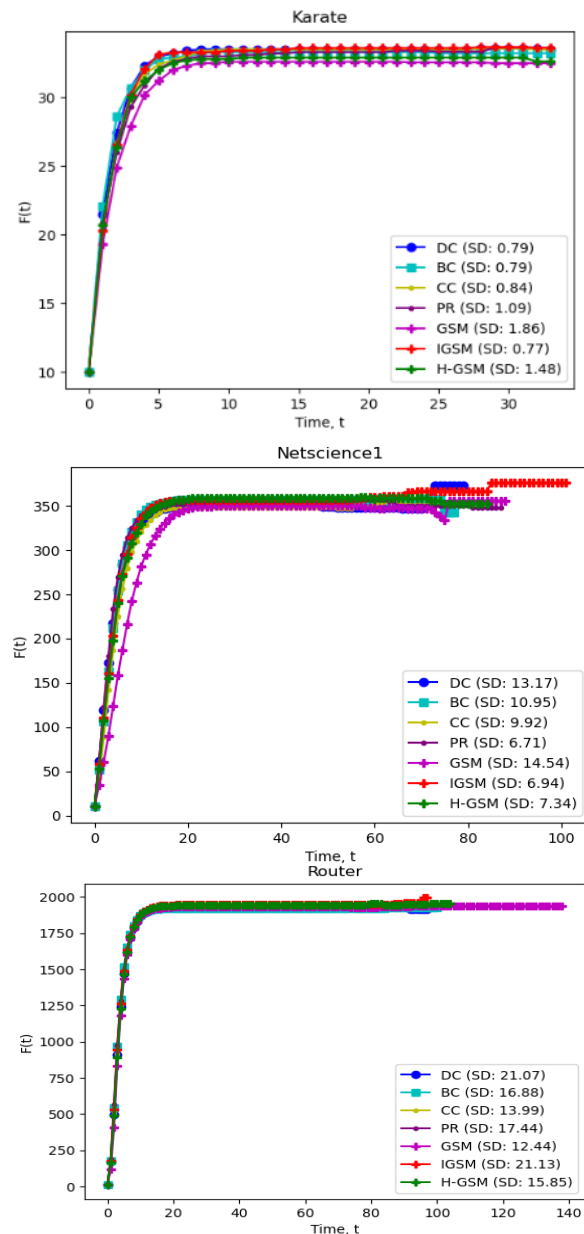
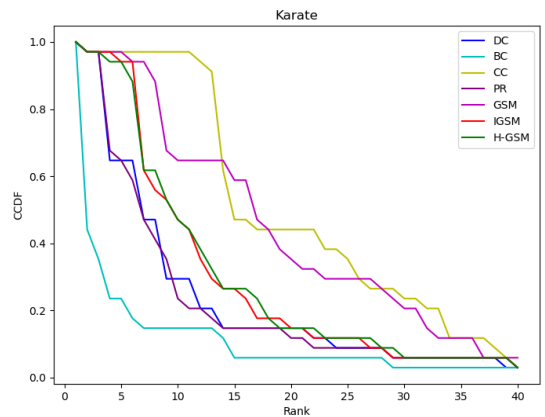


Fig. 2. Propagation influence of top-10 ranking effect.



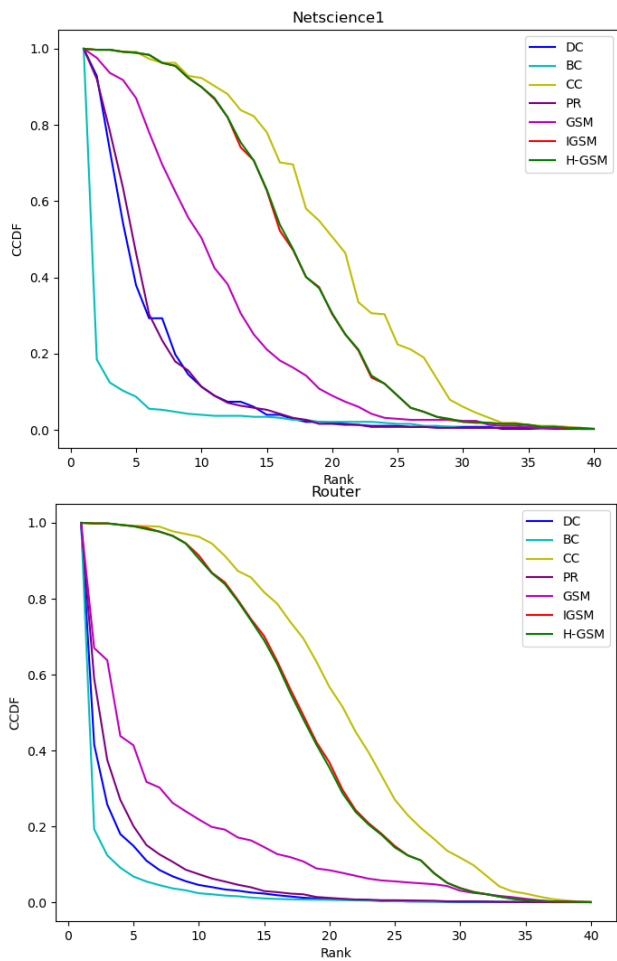


Fig. 3. CCDF diagram of ranking results of each method.

Kendall's model with SIR was employed to assess the impact of nodes in various networks and verify the H-GSM's suitability and efficacy. Fig. 4 displays Kendall's values of the H-GSM algorithm and others under consideration. As evidenced by the data, H-GSM outperforms other methods regarding Kendall values. This indicates that H-GSM exhibits superior performance across diverse networks featuring varying node sizes.

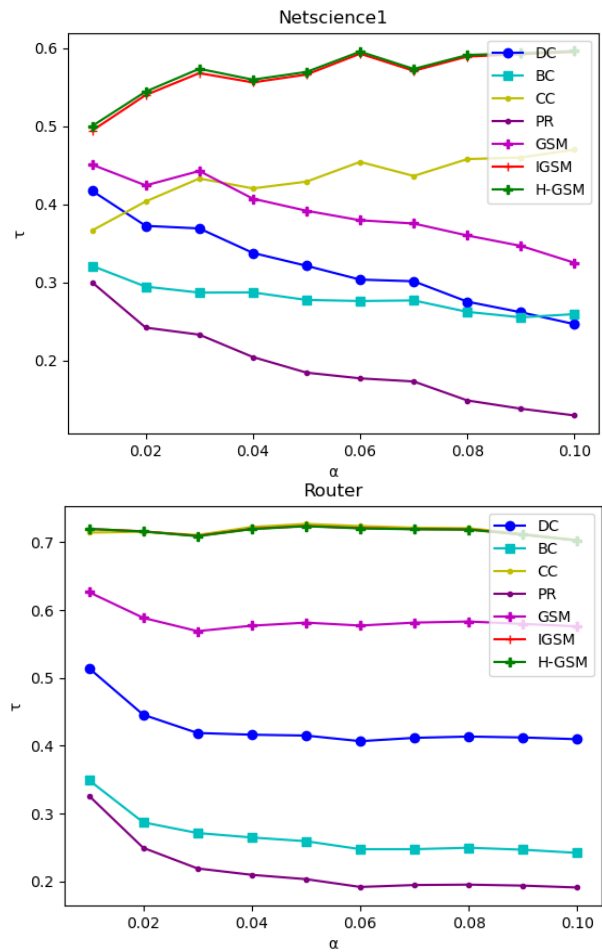
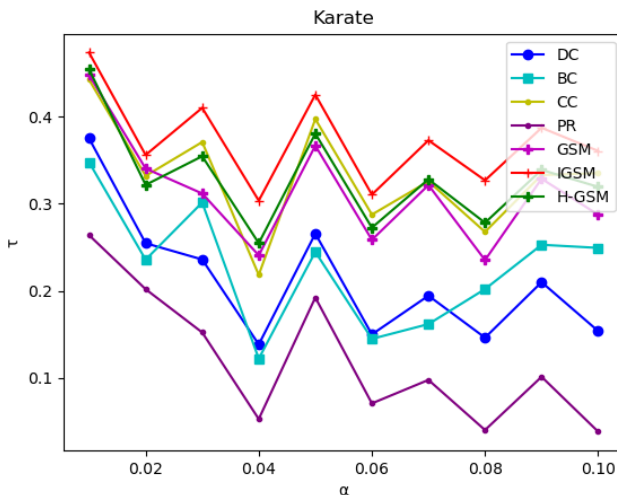


Fig. 4. Kendall coefficients between different propagation probabilities with the SIR model.

To conduct a more comprehensive examination of the propagation phenomenon of H-GSM, we analyzed the dissemination influence of nodes ranked in the SIR model. Value of  $\beta=0.1$  was chosen, while  $\alpha$  was varied between 0.01 and 0.1. This decision was made due to the potential for propagation across the entire network when larger alpha values are utilized. Tables III, IV, and V display the nodes ranked in the top ten for the Karate, Netscience1, and Router networks. It was observed that a significant proportion of the nodes that ranked within the top 10 of H-GSM were also present in other algorithms. Thus, the validity of the proposed H-GSM has been confirmed.

This study aimed to compare the efficacy of the proposed H-GSM with that of GSM in terms of node spreading. Consequently, in H-GSM and GSM, solely different nodes are considered seed nodes to analyze the propagation effect. A mean value of 100 rotations is calculated. In the illustrated instance presented in Fig. 5, it was observed that the impact of node 26, which is present in H-GSM, surpasses that of node 7 in GSM. The results indicate that our proposed H-GSM model exhibits a superior infection effect than the original GSM model. The findings are consistent across other networks, as depicted in Fig. 6 and 7.

TABLE IV. TOP-10 RANKING NODES OF THE KARATE NETWORK

Rank	DC	BC	CC	PR	GSM	IGSM	H-GSM
1	0	0	33	33	33	33	33
2	0	33	2	0	0	0	0
3	27	27	33	27	2	27	27
4	2	2	26	2	27	2	2
5	1	26	27	1	1	1	1
6	26	8	8	26	8	26	3
7	3	1	13	3	13	8	8
8	13	13	16	18	3	13	13
9	18	16	1	8	25	3	26
10	8	5	3	13	7	16	25

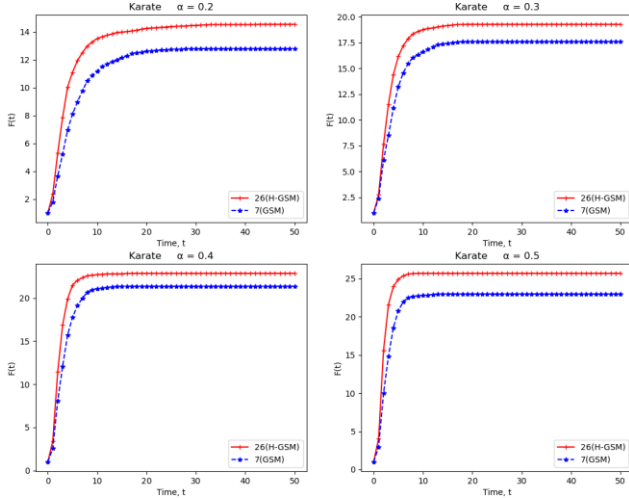


Fig. 5. Node propagation effect of Karate network.

TABLE V. TOP-10 RANKING NODES OF THE NETSCIENCE1

Rank	DC	BC	CC	PR	GSM	IGSM	H-GSM
1	3	58	58	58	4	58	3
2	4	106	119	3	3	4	4
3	58	189	106	4	5	3	58
4	5	119	44	119	13	106	5
5	72	72	187	72	14	119	119
6	219	4	107	5	28	44	13
7	119	44	4	106	29	107	44
8	13	187	6	142	16	5	106
9	142	6	130	219	15	187	107
10	106	178	135	53	119	189	219

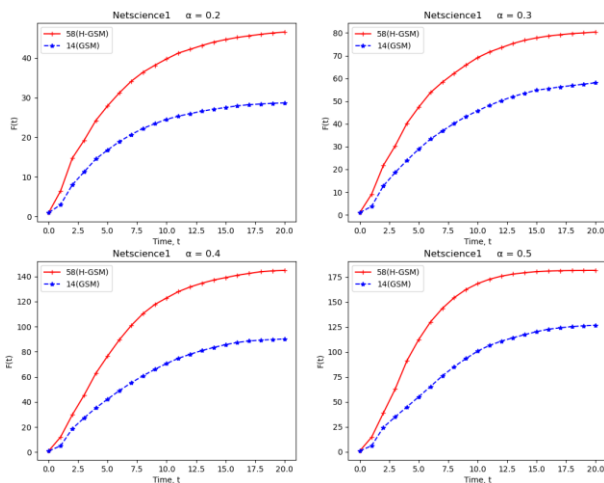


Fig. 6. Node propagation effect of Netscience1 network.

TABLE VI. TOP-10 RANKING NODES OF THE ROUTER NETWORK

Rank	DC	BC	CC	PR	GSM	IGSM	H-GSM
1	100	2	2	100	89	100	100
2	139	0	100	139	384	139	139
3	350	100	89	62	350	2	350
4	62	139	139	0	356	89	89
5	48	159	0	99	369	0	384
6	242	508	242	159	279	242	0
7	113	99	384	350	381	99	135
8	135	350	426	2	185	62	48
9	0	62	99	242	367	384	2
10	89	179	216	310	100	350	356

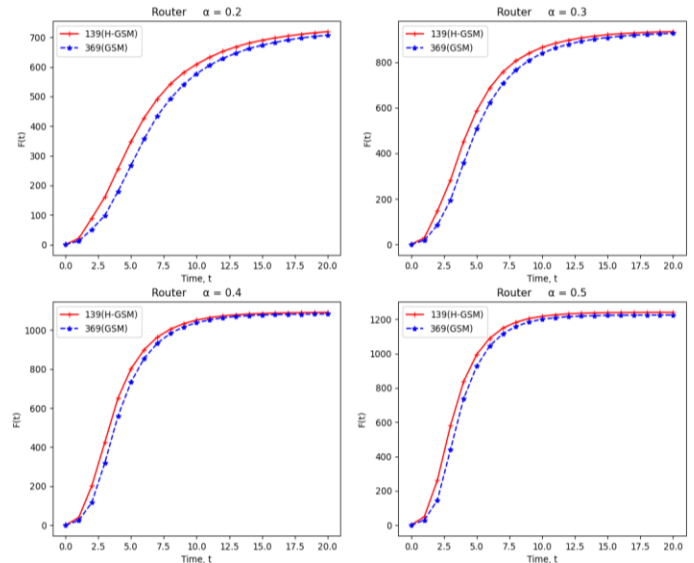


Fig. 7. Node propagation effect of Router network.

## V. CONCLUSIONS

In conclusion, this study addresses the challenge of identifying influential nodes in complex networks. Despite the existing methodologies, node identification remains a significant concern for researchers. To overcome this challenge, a new algorithm called H-GSM is proposed, which integrates degree and k-shell centrality measures. By incorporating both local and global centrality metrics, the H-GSM model improves upon the existing GSM model, effectively capturing the network's intricate influences. To evaluate the effectiveness of the H-GSM model, experiments are conducted on three different complex networks with varying sizes. The model's performance is assessed by examining its spreading ability using the SIR model and comparing various centrality metrics using Kendall's tau correlation coefficient. The experimental results demonstrate that the H-GSM algorithm outperforms established benchmarks in accurately identifying influential nodes. In future research, further enhancements of the algorithm's performance outcomes are planned by exploring different combinations of index styles and centrality measures. These investigations will contribute to advancing the understanding and application of network analysis techniques. Overall, the H-GSM algorithm presented in this study offers a promising approach for unraveling influential nodes in complex networks and holds potential for future advancements in the field.

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# Multi-Granularity Tooth Analysis via Faster Region-Convolutional Neural Networks for Effective Tooth Detection and Classification

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**Abstract**—In image classification, multi-granularity refers to the ability to classify images with different levels of detail or resolution. This is a challenging task because the distinction between subcategories is often minimal, needing a high level of visual detail and precise representation of the features specific to each class. In dental informatics, and more specifically tooth classification poses many challenges due to overlapping teeth, varying sizes, shapes, and illumination levels. To address these issues, this paper considers various data granularity levels since a deeper level of details can be acquired with increased granularity. Three tooth granularity levels are considered in this study named Two Classes Granularity Level (2CGL), Four Classes Granularity Level (4CGL), and Seven Classes Granularity Level (7CGL) to analyze the performance of teeth detection and classification at multi-granularity levels in Granular Intra-Oral Image (GIOI) dataset. Subsequently, a Faster Region-Convolutional Neural Network (FR-CNN) based on three ResNet models is proposed for teeth detection and classification at multi-granularity levels from the GIOI dataset. The FR-CNN-ResNet models exploit the effect of the tooth classification granularity technique to empower the models with accurate features that lead to improved model performance. The results indicate a remarkable detection effect in investigating the granularity effect on the FR-CNN-ResNet model's performance. The FR-CNN-ResNet-50 model achieved 0.94 mAP for 2CGL, 0.74 mAP for 4CGL, and 0.69 mAP for 7CGL, respectively. The findings demonstrated that multi-granularity enables flexible and nuanced analysis of visual data, which can be useful in a wide range of applications.

**Keywords**—Dental informatics; intra-oral image; deep learning; faster region-convolutional neural network; classification; granularity level; tooth detection

## I. INTRODUCTION

As living standards improve and dental health awareness increases, a growing number of individuals are pursuing dental treatments (such as orthodontics, dental implants, and restoration) as a means to maintain a healthy lifestyle [1]. According to the WHO Global Oral Health Status Report (2022), almost 3.5 billion people worldwide are affected by oral illnesses [2]. In underdeveloped nations, the lack of oral hygiene knowledge, limited access to dental care facilities, and high cost of treatment contribute to untreated dental issues,

resulting in severe consequences for individuals in these regions [3].

Extensive research has been conducted to explore Deep learning-based object detection methods for dental disease diagnosis in various dental models including radiographic images, CBCT images, and intra-oral images [4] [5].

Radiographs and periodontal images are widely used as objective diagnostic tools for tooth disease diagnosing. This includes bitewing, periapical, and panoramic images. Despite their widespread use these images are known to have limitations. For example, they are likely to contain tooth ghost images, low resolution and contrast, overlaps, angulation, magnification, and other artifactual information which are sources of unwanted features and noise [6]. Alternatively, CBCT is employed for their high-quality three-dimensional volumetric information which addresses the issue of distortion and superimposition of bony and dental structures [7]. However, automatic segmentation using CBCT poses certain difficulties, such as noisy images, unclear edges, presence of a human skull [8].

Recently, intra-oral dental images are used for tooth disease diagnosis. They provide valuable insights into a patient's oral health status and help in formulating treatment plans [9]. This approach (i) does not necessitate specialized equipment for data acquisition, (ii) offer rich features despite small image size, and (iii) consequently requires low computational cost for image processing and object detection tasks. However, the identification and detection of individual teeth in these images present some challenges such as partial occlusion, overlapping, and varying illumination [10] [11]. Another issue is unavailability of comprehensive intra-oral image datasets.

Deep learning (DL) has emerged as a powerful approach for overcoming the challenges in the dentistry domain, capable of autonomously extracting high-level and discriminative characteristics from a given dataset [12]. Convolutional neural networks (CNNs) have achieved significant appeal among DL approaches due to their well-established multilayer structure. CNN-based techniques for dental image processing have demonstrated outstanding performance in a variety of clinical tasks, most notably tooth detection and classification/

numbering across many dental imaging modalities, including cone-beam computed tomography (CBCT) [13] and radiography images [14]. However, the classification of tooth types in intra-oral dental images is a challenging task due to the complex and diverse structures found in these images [15]. These images have rich geometrical structure which makes it difficult to learn the discriminative features among the tooth classes. Despite some common morphological characteristics for distinguishing tooth type between individuals, there exist great variances in surface appearance with the same type of tooth [11]. Additionally, teeth classification in intra-oral images is demanding due to the inhomogeneous texture or color distribution of teeth. For example, even if the images represented the same incisor type, there are often strong differences in the directionality, granularity, or color tone of teeth. These variations make it challenging to classify the teeth accurately. Hence analysis of dental images using deep learning models has caught the attention of many researchers [16].

To overcome the aforementioned challenges, we hypothesize that the discriminative local detailed information of intra-oral images is naturally hidden in various granularity patches of the images. Multi-granularity in image classification is useful for applications such as object recognition, where objects may be present at different scales or levels of complexity. By classifying objects at multiple levels of granularity, it is possible to accurately identify objects of different sizes or shapes, which can be useful for tasks such as autonomous navigation or robotic manipulation. Thus, the underlying research work examines the effect of granularity in tooth detection and classification using intra-oral images. The multiple levels of granularity are used to specify the structural levels of the tooth. The granularity level changes based on the three tooth groups considered in this study. The Granular Intra-Oral Image (GIOI) dataset consists of three granular levels named Two Classes Granularity Level (2CGL) of the upper and lower jaw, Four Classes of Granularity Level (4CGL) of incisor, canine, premolar, and molar, and Seven Classes Granularity Level (7CGL) is used for tooth classification.

The following are the main contributions of this study:

- Modeling of faster region-convolutional neural network (FRCNN) based on three types of ResNet models for multi-granularity levels teeth classification from intra-oral images.
- Analysis of teeth detection and classification at multi-granularity levels via FRCNN.

The rest of the paper is divided into the following sections. Section II summarizes the previous research on tooth detection and classification, and granularity level classification. Section III offers the proposed methodology. The experimental findings are presented and discussed in Section IV. Section V analyses the effect of granularity levels on the tooth classification task. Section VI provides the conclusion of the research work and suggests opportunities for further study.

## II. RELATED WORK

The core of this research work is to analyze teeth detection and classification at multi-granularity levels via FRCNN from Granular Intra-Oral Image (GIOI) dataset. Therefore, to get a better understanding of the existing research work, this section presents a review of related work on the topic of (i) tooth classification using deep learning models including Faster R-CNN, AlexNet, and VGG; and (ii) the effect of multi-granularity on classification accuracy.

### A. Tooth Classification using Deep Learning Models

In the context of deep learning, this study used Convolutional Neural Network (CNN). A CNN is a type of Artificial Neural Network (ANN) that is commonly used in Deep learning for image, text, object recognition, and classification. CNNs have been widely used in computer vision tasks such as object detection, face recognition, and image segmentation [17]. They have also been applied in other domains, such as natural language processing and dentistry.

In an automated diagnostic procedure, classifying teeth is a crucial task. Researchers have examined the classification task using a small sample of tooth periapical pictures; one such study was carried out by Zhang et al. [18] employed a cascade network structure for the automated identification of 32 teeth positions. Their approach utilized multiple CNNs as the fundamental modules and achieved an F1-Score, precision, and recall of 80.4, 80.3, and 80.6, respectively. Oktay [19] introduced a CNN-based method for tooth detection in dental panoramic X-ray images. The approach accurately determines the potential positions of three tooth types (incisors, premolars, and molars), achieving a remarkable accuracy level of over 0.92. Similarly to this, Miki et al. [13] used 52 CBCT images to categorize teeth into seven types based on their location. AlexNet was employed as the CNN structure in this study, and it achieved a classification accuracy of 88.8%. In research on automated detection and labeling of 2D teeth, Zhang et al. [18] and Chen et al. [20] used CNN to identify teeth in periapical radiographs, and experimental findings indicated that their precision rates were 95% and 90% respectively. These findings ensured the importance of deep learning models such as AlexNet [13] [19] and VGG [18] in achieving accurate and efficient detection for automated dental charting and proper surgical and treatment planning.

Another model based on GoogleNet, a fully convolutional network (FCN) was proposed to detect teeth by Muramatsu et al. [21]. The classification of teeth by type (i.e., incisors, canines, premolars, and molar) and tooth condition was performed using a ResNet-50-based pre-trained network. Görürgöz et al. [22] applied transfer learning with a pre-trained GoogLeNet Inception v3 CNN and developed an algorithm consisting of jaw classification, region detection, and final classification models. The proposed algorithm achieved an F1 score, precision, and sensitivity of 0.8720, 0.7812, and 0.9867, respectively. These findings demonstrate the potential of CNN algorithms for efficient and precise tooth detection and numbering in dental imaging, which could lead to more reliable diagnoses and treatments.



These studies show that CNN models are trained on a large dataset of dental images, where each image is labeled with the coordinates or bounding boxes representing the location of each tooth. CNN learns to recognize patterns and features that differentiate teeth from the background and other structures in the image [23]. It's important to note that different studies proposed specific modifications or variations of CNN architectures to optimize tooth detection and classification performance such as AlexNet, Faster R-CNN, GoogLeNet, RCNN, and ResNet.

Tooth detection and classification using Faster R-CNN (Faster Region-based Convolutional Neural Network) [24] is an area of research that focuses on automating the process of identifying and categorizing teeth in dental images. The effectiveness of Faster R-CNN in tooth numbering and identifying dental cavities on oral radiographs was studied by Tuzoff et al. [25]. They used the Faster R-CNN architecture for teeth detection using 1,352 adult panoramic radiographs. A two-stage system was proposed, in which faster R-CNN is used to detect the teeth followed by a VGG-16 network to identify and number. Nonetheless, the study encountered misclassification errors resulting from similarities between adjacent teeth. Chen et al. [20] suggested employing Faster R-CNN for tooth detection and recognition in dental periapical films. The test dataset demonstrated precision and recall values of over 90%. However, the study faced challenges due to complications such as missing teeth and root canal treatments in the images from regular clinical work. Mahdi et al. [26] presented an automatic teeth recognition model that leverages the Faster R-CNN technique based on the residual network. This model represents a significant step forward in dental image analysis, achieving impressive results with high mean Average Precision (mAP) scores of 0.974 and 0.981 for ResNet-50 and ResNet-101, respectively. In a similar vein, Bilgir et al. [27] developed a Faster R-CNN model that automated tooth numbering over a dataset of 2,482 panoramic radiographs with a precision of 0.96. Estai et al. [28] proposed a three-step method for automatically detecting and counting teeth in digital orthopantomography (OPG) pictures. They used U-Net, Faster R-CNN, and VGG-16 CNN models. The results showed that it had a high recall and precision score of 0.99 for tooth detection and 0.98 for tooth numbering, indicating its potential importance in general dentistry and forensic medicine applications.

It is concluded that Faster R-CNN is sensitive to objects with missing features i.e., broken tooth [20], overlapping [29], occlusion [25], blur, and noise [30]. These issues distort the fine details of the tooth [26] [31]. This leads to low classification accuracy [32] and limits the model's generalization ability on other imaging modalities or dental issues [13]. Despite these issues, there are various advantages to using Faster R-CNN for tooth identification and classification tasks. It enables exact tooth localization in dental pictures while effectively handling size and aspect ratio variations [33]. Research has shown that Faster R-CNN accurately identifies the position of teeth with a high IOU value [20]. The model exhibits significant potential in dental image processing tasks, assisting in dental diagnosis, treatment

planning, and various other applications within the dental field [34].

### B. Effect of Multi-Granularity on Classification Tasks

The ability to analyze or portray data at numerous levels of detail or abstraction is referred to as multi-granularity. Multi-granularity is important for a range of applications since it provides for more nuanced and flexible data processing. It has been the focus of recent studies in fields such as scene classification [35], land change detection [36], and brain image analysis [37]. This section reviews relevant research on the role of granularity in various classification problems.

Several researchers have recently investigated the use of multi-granularity in medical image classification, employing a range of approaches and techniques. Within these investigations, Wu et al. [38] focused their research on lung nodule classification. Their study evaluated a novel approach using a publicly available lung nodule dataset, and the results demonstrated that employing the multi-granularity approach resulted in enhanced classification accuracy. In addition, Wang et al. [39] provided a unique method for producing generalized visual representations for medical images using multi-granularity cross-modal alignment. To assess the effectiveness of their approach, they used a variety of medical imaging datasets, including chest X-rays and mammograms. The results showed that the proposed model outperformed existing methods in a variety of classification and retrieval tasks, highlighting the effectiveness of multi-granularity cross-modal alignment in acquiring comprehensive visual representations for medical images. Wang et al. [36] suggested a multi-granularity framework for extracting latent ontologies from remote sensing datasets, which they tested in six different scenarios. The results showed that combining three granularity levels produced the best results, with the second level of granularity providing the highest accuracy. On the other hand, the third level of granularity exhibited comparatively lower accuracy. Furthermore, the study highlighted that fine-scale cropping increased classification accuracy whereas excessive cropping degraded performance. Additionally, Zuo et al. [40] presented an innovative method for fine-grained crop disease classification that combines multi-granularity feature aggregation with self-attention and spatial reasoning to improve accuracy. The evaluation outcomes showcase the effectiveness of incorporating multi-granularity feature aggregation, self-attention, and spatial reasoning in the field of fine-grained crop disease classification.

In the past few years, significant progress has been made in deep learning-based image classification and object re-identification. For instance, Ouyang et al. [41] introduced a hybrid methodology that merges a CNN with a modified capsule network for remote sensing image classification. Their model incorporated spatial-spectral attention and multi-granularity features, allowing it to effectively capture precise spatial and spectral information. Likewise, Tu et al. [42] introduced the Multi-granularity Mutual Learning Network (MMNet) for object re-identification. The MMNet integrates multiple modules to effectively learn distinctive features across varying visual granularities. By capturing diverse discriminative local features from multiple granularities, the MMNet demonstrated superior performance compared to

previous approaches. Wu et al. [43] presented a CNN-based image classification approach that takes advantage of multi-granularity features. The fundamental goal of this research is to incorporate the concept of hierarchical structure categorization and to investigate the incorporation of granularity computing theory in deep learning. The experimental findings revealed the enhanced model's usefulness, with higher image classification accuracy and superior generalization capabilities. Chen et al. [44] investigated the impact of label granularity on CNN classification performance. Experiments on several datasets revealed that training with fine-grained labels improved the accuracy of classifying coarse-grained classes, in contrast to training with coarse-grained labels. According to their research, while training a CNN for natural images, using fine-grained labels outperforms using coarse-grained labels from the same dataset. The utilization of fine-grained labels enables the network to learn more intricate and specific features. Zhu et al. [45] introduced a novel methodology for few-shot learning that incorporates multi-granularity techniques. The proposed approach was tested on many few-shot learning datasets, including CIFAR-FS and mini-ImageNet. The outcomes substantiated the efficacy of multi-granularity episodic contrastive learning in the context of few-shot learning.

The presented review identifies that granularity level classification leads to improvement in computational efficiency, adaptation capability (even if shallow models and the small dataset is used), and extracting fine-grained feature [43]. Additionally, the multi-granularity technique is less prone to overfitting when compared to deep networks and offers better generalization and increased classification accuracy [46] [44] [43]. However, despite these benefits, granular-level classification studies in the domain of tooth classification are seldom seen and its relevance in this domain needs to be explored.

### III. PROPOSED METHODOLOGY

This section introduces the methodology used to achieve the main aim of this study which is to analyze the effect of teeth detection and classification at multi-granularity levels using FRCNN. The overview of the proposed method to detect teeth at multi-granularity levels using FRCNN is presented in Fig. 1. The detection pipelines as shown in Fig. 1 perform four essential steps: data collection, data pre-processing, modeling detection, and finally providing results and discussion.

The following subsections will provide the details of data collection and pre-processing criteria including inclusion and exclusion criteria, ground truth marking scheme and consequent labeling procedure, and identification and implementation of label-preserving data augmentation methods. Additionally, the proposed CNN model and model evaluation will be introduced:

#### A. Dataset Preparation

A significant challenge in the advancement and practical adoption of DL models lies in acquiring adequately large, curated, and representative training data, along with expert annotations. In this section, the fundamental steps for preparing a dental imaging dataset for addressing the issue of

tooth classification in Intra-Oral imaging using deep learning models are described.

1) *Data acquisition:* With the absence of a publicly available dataset, this study proposes the GIOI dataset that offers three teeth classification granularity levels as shown in Fig. 2, i.e., Two Classes of Granularity Level (2CGL) of maxilla and mandible; Four Classes of Granularity Level (4CGL) of incisor, canine, premolar, and molar; and Seven Classes Granularity Level (7CGL) of teeth numbering. In the proposed GIOI dataset development phase, the Advanced Medical and Dental Institute at University Sains Malaysia (USM) and University Technology PETRONAS (UTP) have collaborated to develop the GIOI dataset. These images represent subjects from different age groups and genders. The images are also captured at different distances and illumination levels to present rich feature diversity.

2) *Data Pre-Processing:* The first stage in pre-processing was to filter the dataset by setting the inclusion and exclusion criteria. The images were visually analyzed, and the images containing gum or cavity diseases are extracted. Additionally, images having missing teeth or wisdom teeth are also excluded. Table I and Table II display the inclusion and exclusion criteria that were used for the data pre-processing.

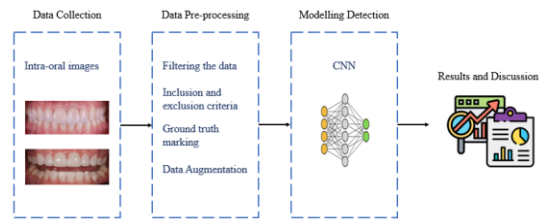


Fig. 1. Overview of the proposed tooth detection model.

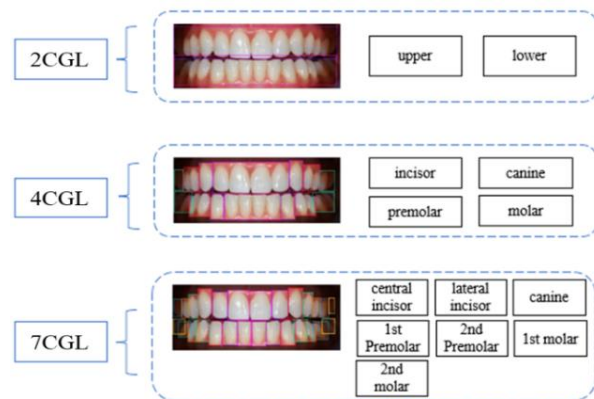


Fig. 2. Teeth classification granularity levels in the GIOI.

TABLE I. INCLUSION CRITERIA

Inclusion Criteria
Adults between 18-50 ages were included.
Both male and female.
Stained teeth.
Different orientations (left, right, upper, lower).
The gap between teeth.

TABLE II. EXCLUSION CRITERIA

Exclusion Criteria
Crowded tooth.
Wisdom tooth.
Missing and broken tooth.
Tongue.
The tooth has braces.
Teeth have gum or cavity diseases.

The GIOI dataset contained 550 images and seven-tooth classes (Central Incisor, Lateral Incisor, Canine, 1st Premolar, 2nd Premolar, 1st molar, 2nd molar). The current study used the ISO standard tooth numbering system to identify each tooth with a unique label [7]. The VGG Image Annotator (VIA) [47] web application has been used for annotating and labeling the training set samples. VIA is an open-source software that allows human annotators to define and describe regions in an image.

3) *Data augmentation*: the data set contained unequal samples, that is, the number of different types of samples was different. To enhance the dataset, data augmentation was used as an option [48]. Data augmentation effectively expands the dataset size and quality. The effectiveness of data augmentation for dental image augmentation was assessed by including image mixing, geometric transformation, transforms, and kernel filters [49]. As a result, 2,260 augmented images were acquired for training. Table III contains the specifics of this assessment.

TABLE III. DATA AUGMENTATION METHODS FOR DENTAL IMAGES

Type of Augmentation	Post Augmentation Observation	Label Preservation	Selection Status
Vertical flip	Tooth visual attributes do not remain intact.	No	Rejected
Horizontal flip	Tooth visual attributes remain intact.	Yes	Selected
ChannelShuffle	Resulting in an image that is not a true representative of a real-world scenario.	No	Rejected
Brightness and contrast	Introduces a wide range of illuminations.	Yes	Selected
Noise injection	Improves the model's generalization ability	Yes	Selected
Cropping	This may result in the loss of distinguishable tooth features	No	Rejected
Motion blur	Simulates the possible sudden motion of the optical sensor/subject in a real-world scenario.	Yes	Selected
RandomGridShuffle	Tooth visual attributes do not remain intact.	No	Rejected
Histogram equalization	Improves the image's contrast level.	Yes	Selected
image compression	This keeps the resolution of an image	Yes	Selected

**B. Model Architecture**

In this paper, the Faster R-CNN architecture is supported by three types of ResNet [50] network: ResNet-50, ResNet-101, and ResNet-152 as backbone models. Fig. 3 shows the FR-CNN-ResNet model. The first phase of the model includes

the backbone models that generate the feature map. The second phase is the region proposal network (RPN), for identifying areas of an input image that most likely contain a region of interest. The last phase includes the detection network. The RPN generates region proposals (bounding boxes) for potential objects in an image, while the detection network classifies the proposals and refines their bounding boxes. The RPN is a fully convolutional network that is trained to predict objectness scores and bounding box offsets at each position in an image. It uses a sliding window approach to generate region proposals, which are then passed to the detection network. When the RPN generates a set of candidate regions, each region is represented by a fixed-size feature map, which can be of different sizes depending on the size of the input image and the region proposal. However, the detection network that processes these regions requires a fixed-size input to apply convolutional layers.

ROI (Region of Interest) pooling addresses this discrepancy by dividing the fixed-size feature map for each region proposal into a fixed number of equally sized sub-windows and then applying a max pooling operation to each sub-window to produce a fixed-size output. The output of the ROI pooling operation is a feature map of fixed size that can be fed into the detection network. The detection network in Faster R-CNN is based on the Fast R-CNN [51] architecture, which consists of two main components: a convolutional feature extractor and a set of fully connected layers for object classification and bounding box regression. It takes the region proposals generated by the region proposal network (RPN) as input and produces the final object detection results.

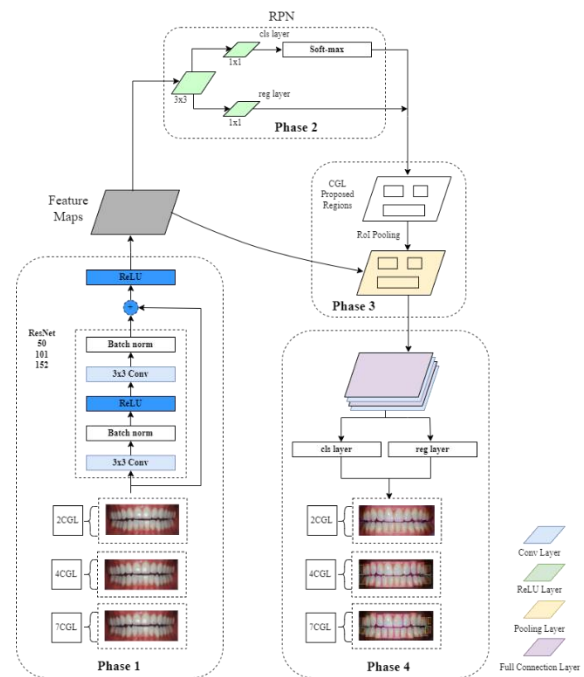


Fig. 3. FR-CNN-ResNet model.

The main activities of the FR-CNN-ResNet algorithm are presented in the following nine steps:

Step 1: The system fed the images to the backbone ResNet50, ResNet101, or ResNet101 models.

Step 2: The backbone models extract the features from the images.

Step 3: The RPN takes the feature maps as input and generates a set of object proposals, which are regions in the image that are likely to contain objects.

Step 4: The proposed regions generated by the RPN in Step 3 are passed through ROI pooling, which divides the fixed-size feature map for each region proposal into a fixed number of equally sized sub-windows.

Step 5: The detection network takes the fixed-size feature maps generated in Step 4 by the ROI pooling layer as input and produces the final object detection results.

Step 6: The final output is obtained by applying non-maximum suppression to remove duplicate predictions and keep only the most confident detections.

### C. Model Evaluation and Performance Measures

Average Precision (AP) [50] is a popular evaluation metric for object detection tasks that measures the accuracy of the predicted object bounding boxes. AP is calculated based on a precision-recall curve that summarizes the trade-off between precision and recalls for different object detection thresholds. The average precision value is computed for recall values ranging from 0 to 1.

Precision [51] is a performance metric used in object detection to measure the proportion of correct positive detections out of all the positive detections made by the network. Precision measures how accurate the algorithm is in detecting objects. The given equation was used to calculate precision:

$$Precision = \frac{True\ Positive}{True\ Positive + False\ Positive} \quad (1)$$

Recall [50] is a performance metric used in object detection to measure the proportion of actual positive detections out of all the positive instances present in the dataset. In other words, recall measures how well the algorithm can detect all the objects present in the image. The following equation used for recall calculation:

$$Recall = \frac{True\ Positive}{True\ Positive + False\ Negative} \quad (2)$$

The F1 score is a performance metric used in object detection that combines precision and recalls into a single score. The F1 score provides a balanced view of the network's accuracy by considering both the number of correct detections and the number of missed detections. It is defined by the following equation:

$$F1\ score = \frac{2 \times (precision \times recall)}{(precision + recall)} \quad (3)$$

## IV. RESULTS AND DISCUSSION

The presented study evaluates the effect of granularity on tooth detection and classification using FR-CNN-ResNet models. The GIOI dataset, consisting of three teeth classification granularity levels, is considered in testing the proposed FR-CNN-ResNet model. The total number of epochs was set as 100 for all different backbone ResNet models. The

batch size for all Faster R-CNN backbone models was set as 2. In addition, two learning rate values were used, i.e., 0.001 and 0.0001. This section presents the experimental results for all three classification granularity levels separately.

### A. Case 1: Two Classes Granularity Level (2CGL)

1) The two classes' granularity level (2CGL) consists of two tooth classes i.e.: upper and lower. A total of 2,260 images containing 2078 upper and 1956 lower were used to train the models in seven different experiments. A total of 107 images are used to test the models. It has been identified that the lower learning rate during training of Faster RCNN variants resulted in lower mean average precision during the testing of all such models. This indicates the unsuitability of a smaller learning rate for 2CGL tooth classification. For all F-RCNN variants, the optimal accuracy was achieved using a constant learning rate of 0.001.

As depicted in Fig. 4, the highest average precision of 0.95 and 0.93 for the upper and lower tooth, respectively, is achieved by the FR-CNN-ResNet-50. With FR-CNN-ResNet-101, the average precision for upper and lower teeth is observed to be the lowest among all types of FR-CNN models. With a deeper backbone, i.e., ResNet-152, no significant improvement is observed by the FR-CNN-ResNet-152 model in the average precision of target classes. This performance indicates that at 2CGL, the FR-CNN-ResNet-50 model is the best choice. Similarly, the highest mAP of 0.94 was achieved by FR-CNN-ResNet-50. The lowest mAP of 0.742 is yielded by the FR-CNN-ResNet-101 model trained on a lower learning rate. This confirms that a lower learning rate and deeper backbones are not optimal for optimal classification at the 2CGL level.

The model exhibited FR-CNN-ResNet-50 achieves a competitive and high mAP of 0.94. As presented in Table IV, the model also exhibited perfect or near-to-perfect recalls for upper and lower teeth classification results. Additionally, the best F1 scores for upper and lower teeth classification are equal to 0.96 and 0.94 for the FR-CNN-ResNet-50 model. This performance indicates that this model for 2CGL is ideal as it is trained quickly and generates very competitive results compared to other models.

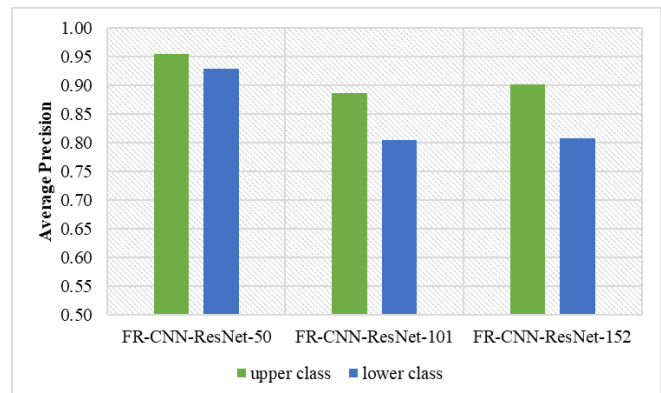


Fig. 4. 2CGL average precision comparison of the models.



TABLE IV. 2CGL AVERAGE PRECISION, RECALL, AND F1 SCORES FOR EACH MODEL

2CGL Classes	AP			Recall			F1-Score		
	FR-CNN-ResNet-50	FR-CNN-ResNet-101	FR-CNN-ResNet-152	FR-CNN-ResNet-50	FR-CNN-ResNet-101	FR-CNN-ResNet-152	FR-CNN-ResNet-50	FR-CNN-ResNet-101	FR-CNN-ResNet-152
Upper	<b>0.95</b>	0.89	0.90	0.97	0.92	0.93	<b>0.96</b>	0.90	0.92
Lower	<b>0.93</b>	0.81	0.81	0.96	0.85	0.86	<b>0.94</b>	0.83	0.83

Overall, the average precision of upper teeth remains higher as compared to lower teeth. This can be attributed to labeling precision as naturally lower teeth are occluded by upper teeth. For this reason, the bounded boxes for upper teeth are more precise as compared to lower teeth as it contains some part of upper teeth. FR-CNN-ResNet is generally good at detecting large objects because it uses region proposals to identify potential object locations and then applies a classifier to each region proposal to determine the presence and location of an object. The RPN in FR-CNN-ResNet generates region proposals by sliding a small network over the convolutional feature map output by the backbone network. The size of the sliding window is fixed, and the stride can be adjusted to control the region proposal density. Because of this mechanism, FR-CNN-ResNet can effectively detect large objects but may struggle with detecting small objects due to the limitations of the region proposal mechanism.

B. Case 2: Four Classes Granularity Level (4CGL)

1) This section presents the results of the granular level two (4CGL) classification, which consists of four classes, i.e., Incisor, Canine, Premolar, and Molar. A total of 2,260 images containing 4091 incisors, 8138 canines, 7940 premolars, and 6564 molars were used to train the models in seven different experiments and 107 images were used for testing. Within FR-CNN-ResNet models, the learning rate again played an important role. With a lower learning rate, i.e., 0.0001, mAP remained low, as compared to the mAP of the model trained with a higher learning rate of 0.001.

As presented in Fig. 5, the highest average precision (AP) of 0.849 is produced by the FR-CNN-ResNet-50 model for the incisor tooth class, followed by the Canine, Premolar, and Molar tooth class which achieved an AP of 0.82, 0.73 and 0.58 respectively. The following factors contribute to higher average precision for incisor class, (i) no occlusion, (ii) large size, and (iii) high illumination. As discussed in Table V, the FR-CNN-ResNet-50 model also has the highest recall and F1 values for all classes. This result also concludes that FR-CNN-ResNet-50 is less sensitive to occlusion, object size, and low illumination.

As shown in Table V, the highest mAP of 0.74 was observed by FR-CNN-ResNet-50. The other models are significantly behind where FR-CNN-ResNet-101 and FR-CNN-ResNet-152 achieved mAP of 0.71 and 0.63, respectively. This result indicates that for 4CGL, FR-CNN-ResNet-50 is the best model among the three for teeth classification and detection.

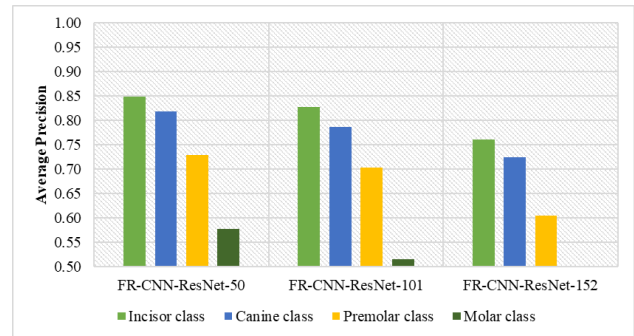


Fig. 5. 4CGL average precision comparison of the models.

TABLE V. 4CGL AVERAGE PRECISION, RECALL, AND F1 SCORES FOR EACH MODEL

4CGL Classes	AP			Recall			F1		
	FR-CNN-ResNet-50	FR-CNN-ResNet-101	FR-CNN-ResNet-152	FR-CNN-ResNet-50	FR-CNN-ResNet-101	FR-CNN-ResNet-152	FR-CNN-ResNet-50	FR-CNN-ResNet-101	FR-CNN-ResNet-152
Incisor	<b>0.85</b>	0.8	0.7	<b>0.88</b>	0.8	0.8	<b>0.87</b>	0.8	0.7
Canine	<b>0.82</b>	0.7	0.7	<b>0.86</b>	0.8	0.7	<b>0.84</b>	0.8	0.7
Premolar	<b>0.74</b>	0.7	0.6	<b>0.78</b>	0.7	0.6	<b>0.75</b>	0.7	0.6
Molar	<b>0.58</b>	0.5	0.4	<b>0.66</b>	0.5	0.5	<b>0.63</b>	0.5	0.4

These results conclude that by using a pre-trained ResNet-50 as the backbone network, the Faster R-CNN model can leverage the high-level features learned by ResNet-50 to accurately classify medical images. Moreover, the ResNet-50 architecture has a deep network structure that allows it to learn complex features in medical images, including subtle differences between images that may be indicative of different conditions or diseases. This makes it particularly effective in medical image classification tasks where subtle differences can be critical in diagnosing a disease. However, the choice of backbone architecture depends on the specific task and dataset, and other backbones such as ResNet-101 or ResNet-152 may perform better in some scenarios.

C. Case 3: Seven Classes Granularity Level (7CGL)

This section presents the results of the Seven Classes Granularity Level (7CGL) classification, which consists of seven classes, i.e., Central Incisor, Lateral Incisor, Canine, 1st Premolar, 2nd Premolar, 1st molar, and 2nd molar. This level of granularity creates three major issues, (i) objects with low illumination conditions, (ii) large variation in object size, and (iii) class imbalance. A total of 2,260 images were used to train the models in seven different experiments, and 107 images were used for testing. Within FR-CNN models, the learning rate again played an important role. With a lower learning rate, i.e., 0.0001, mAP remained low, compared to the mAP of the model trained on a higher learning rate of 0.001.

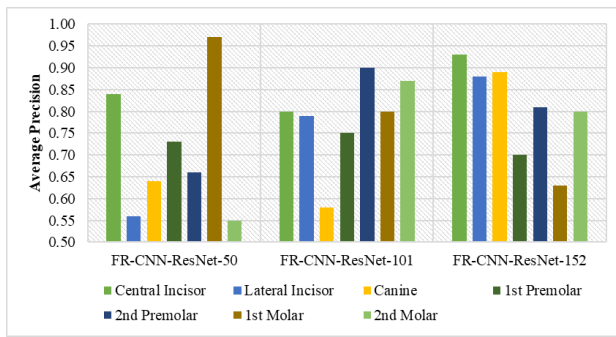


Fig. 6. 7CGL average precision comparison of the models.

A comparative performance analysis is presented in Fig. 6 which highlights that the performance of all models decreases as the target tooth is further away from the central position. However, in all performance measures, FR-CNN-ResNet-50 remains the best-performing model.

As presented in Table VI, the average precision for all models gradually decreased as tooth location moved from front to behind. Overall, FR-CNN-ResNet-101 yielded the lowest average precision score, while FR-CNN-ResNet-50 again emerged as the top-performing model. FR-CNN-ResNet-50 recall values also remained high for the central incisor and lateral incisor. The model produced a perfect recall value. Considering the F1 scores of all three models, it is again evident that at the 7CGL level, FR-CNN-ResNet-50 has the

TABLE VI. 7CGL AVERAGE PRECISION, RECALL, AND F1 SCORES FOR EACH MODEL

7CGL Classes	AP			Recall			F1-Score		
	FR-CNN-ResNet-50	FR-CNN-ResNet-101	FR-CNN-ResNet-152	FR-CNN-ResNet-50	FR-CNN-ResNet-101	FR-CNN-ResNet-152	FR-CNN-ResNet-50	FR-CNN-ResNet-101	FR-CNN-ResNet-152
Central Incisor	<b>0.84</b>	0.77	0.82	<b>0.87</b>	0.83	0.85	<b>0.85</b>	0.80	0.84
Lateral Incisor	0.81	0.73	0.76	0.86	0.81	0.82	0.84	0.77	0.79
Canine	0.80	0.72	0.76	0.85	0.79	0.81	0.82	0.75	0.78
1 <sup>st</sup> Premolar	0.72	0.59	0.65	0.79	0.69	0.73	0.75	0.63	0.69
2 <sup>nd</sup> Premolar	0.64	0.39	0.51	0.73	0.54	0.62	0.68	0.45	0.56
1 <sup>st</sup> Molar	0.57	0.36	0.45	0.69	0.47	0.57	0.63	0.41	0.50
2 <sup>nd</sup> Molar	<b>0.49</b>	0.30	0.38	0.61	0.42	0.50	0.54	0.35	0.43

#### V. ANALYSIS OF THE EFFECT OF GRANULARITY LEVELS ON TOOTH CLASSIFICATION TASK

In this study, three different models of FR-CNN ResNet were implemented for three granularity level cases named 2CGL, 4CGL, and 7CGL to demonstrate the influence of using different granularities in tooth classification. For all FR-CNN variants, the optimal performance is achieved using a constant learning rate of 0.001. Within the FR-CNN-ResNet models, the learning rate played an important role in which, with a lower learning rate, i.e., 0.0001, mAP remained low, as compared to the mAP of models trained on a higher learning rate of 0.001. This result confirms that a lower learning rate and deeper backbones are not optimal for classification at 2CGL, 4CGL, and 7CGL cases.

For an individual granularity level, the first granularity level achieves the best classification accuracy while the third is

the least accurate. The best improvement can be observed in the 2CGL with the FR-CNN-ResNet-50 model, where the mAP result is 0.94 better than FR-CNN-ResNet-101, which achieved the lowest mAP of 0.85. And FR-CNN-ResNet-50 model remained significantly higher than other models in 4CGL, which achieved an mAP of 0.74. For 7CGL, the performance of all models decreases as the target tooth is further away from the central position. Overall, FR-CNN-ResNet-101 yielded the lowest average precision score, while FR-CNN-ResNet-50 again emerged as the top-performing model by achieving an mAP of 0.69.

highest F1 scores for all seven classes. However, the model's performance significantly decreased for smaller and occluded teeth such as 2nd Premolar, 1st Molar, and 2nd Molar.

Overall mAP of FR-CNN-ResNet-50 remained highest at 0.69, followed by FR-CNN ResNet-101 and FR-CNN ResNet-50 with mAP of 0.55 and 0.62, respectively. One possible reason for the low mAP of FRCNN can be attributed to its limitation with detecting small objects, especially if large objects surround them, as the region proposal network may overlook.

FR-CNN-ResNet, like many object detection models, can struggle to detect small objects as the size of the RPN anchors, which are the pre-defined boxes used to search for objects in an image, may be too large relative to the size of the small objects being searched for. This means that the RPN may fail to generate proposals that accurately localize small objects. In the case of occluded objects, the RPN may still generate proposals that partially or completely overlap with the occluded object, allowing the CNN to classify and localize the object within the proposal. However, the accuracy of object detection for occluded objects may still be affected by the extent of occlusion and the quality of the proposals generated by the RPN. In the case of objects with low illumination, the features extracted from the image may be less informative due to reduced contrast and detail in the image. This can make it more difficult for the model to distinguish the object from the background or other objects in the scene.

These results indicate that with the largest granularity level as shown in 2CGL and 4CGL, the tooth structure and the tooth features are clear. Therefore, FR-CNN-ResNet has the strong ability to exploit features such as shape and texture features. The following factors contribute to higher average precision



for 2CGL and 4CGL, (i) no occlusion, (ii) large size, and (iii) high illumination. As the level of drowsiness becomes more detailed in 7CGL, it becomes increasingly difficult to achieve a high level of precision in detecting and classifying teeth due to the intricate structure of teeth [52] [53]. Furthermore, it is difficult for FR-CNN-ResNet to identify objects from low-resolution images as the features extracted from the image may be less informative due to reduced contrast and detail in the image [53]. This can make it more difficult for the model to distinguish the object from the background or other objects in the scene [21]. FR-CNN-ResNet can learn and recognize features of objects even when they are partially occluded, due to the use of shared convolutional layers that extract features from different parts of the image [54] [55]. However, the accuracy of object detection for occluded objects may still be affected by the extent of occlusion and the quality of the proposals generated by the RPN [54].

## VI. CONCLUSION

The automatic detection and classification of teeth in intra-oral dental images are crucial for medical treatment and forensic identification. However, due to the complexity of the problem and limitations in the size of available data, this task remains challenging. To overcome such challenges, this paper investigates the intriguing problem that how granularity impacts the performance of CNN-based object detection and classification models. A Faster Region-Convolutional Neural Network based on ResNet models is proposed for teeth detection and classification at multi-granularity levels from the GIOI dataset. Three different ResNet backbones, i.e., ResNet-50, Res-Net101, and ResNet-152 were evaluated. The evaluation results showed that the proposed FR-CNN-ResNet model is appropriate for teeth classification at three granular levels named, 2CGL, 4CGL, and 7CGL. Additionally, it was revealed that the FR-CNN-ResNet-50 performed better than the FR-CNN-ResNet-101 and FR-CNN-ResNet-152 at each of the three granular levels, where the FR-CNN-ResNet-50 achieved mAP of 0.94, 0.74 and 0.69 at 2CGL, 4CGL, and 7CGL respectively. Overall, it is concluded that multi-granular approaches in intra-oral dental image analysis have the potential to capture significant details and improve the accuracy of automated detection and classification tasks, which can aid in medical treatment and forensic identification.

As a practical implementation, the integration of Faster R-CNN with additional networks will extend its capabilities beyond tooth detection and numbering. It will enable predictions regarding the presence of various dental conditions, including orthodontic issues, tooth fillings, and the overall assessment of dental health to facilitate the patient and dentist.

This study has two known limitations which will be addressed in future work. Firstly, for deep learning methods, large-curated datasets will be used to further improve the performance parameters. Secondly, only a few cases of the 3rd molar tooth class were identified during the dataset generation procedure, thus resulting in removing the 3rd molar class. Further in the future, a yolo-based model will be proposed to preserve topological information and the precise spatial location of pixels for each tooth.

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# A Hybrid Approach for Underwater Image Enhancement using CNN and GAN

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**Abstract**—Underwater image-capturing technology has advanced over the years, and varieties of artificial intelligence-based applications have been developed on digital and synthetic images. The low-quality and low-resolution underwater images are challenging factors for use in existing image processing in computer vision applications. Degraded or low-quality photos are common issues in the underwater imaging process due to natural factors like low illumination and scattering. The recent techniques use deep learning architectures like CNN, GAN, or other models for image enhancement. Although adversarial-based architectures provide good perceptual quality, they performed worse in quantitative tests compared with convolutional-based networks. A hybrid technique is proposed in this paper that blends both designs to gain advantages of the CNN and GAN architectures. The generator component produces or makes images, which contributes to the creation of a sizable training set. The EUVP dataset is used for experimentation for model training and testing. The PSNR score was observed to measure the visual quality of the resultant images produced by models. The proposed system was able to provide an improved image with a higher PSNR score and SSIM score with state-of-the-art methods.

**Keywords**—Convolutional neural network (CNN); generative adversarial networks (GAN); enhancing underwater visual perception (EUVP); underwater images; image enhancement; computer vision; artificial intelligence

## I. INTRODUCTION

Underwater imaging involves capturing images of objects and creatures that can only be seen underwater using specialized tools and procedures. For research projects, studies of various aquatic animals, and other undersea items, the ocean floor is always a fascinating subject. Fish and marine mammals are popular subjects for photographers, but they also look for coral reefs, underwater cave networks, underwater landscapes, crustaceans, seaweeds, and so on. When researchers need to look at objects on the seabed over time, underwater photography is highly helpful. Numerous aquatic animals can be found below the surface of the water and are harmed by the disposal of plastics and other garbage. Ocean exploration [1] and mapping will help to close knowledge gaps in areas such as tectonics, maritime hazards, etc. Enhancing scientific understanding of the deep sea will aid in managing and utilizing ocean resources sustainably.

When light travels through water, it degrades the image in ways that are not seen in typical airborne photos. Normal images are frequently of high quality; therefore image enhancement is rarely necessary. However, the quality is quite

poor for underwater photos because of the way light scatters in the water, which makes image processing challenging. The quality of images recently received more attention due to it being a crucial component of image processing. Image enhancement [2] is the process of enhancing the image quality while preserving all the information thereby producing results that are better suited for display or to prepare images for additional analysis in a variety of computer vision applications, such as object detection, image classification, scene understanding, and many other things. Underexposure, overexposure, low contrast, backlit images, improper colour balance, and out-of-focus subjects are some of the challenges [3] faced by underwater images. Other challenges in underwater imaging can be categorized as the need for adequate resolution and appropriate illumination conditions in order to provide high-quality images. The clarity of underwater images is crucial for many scientific and engineering uses in the ocean, including marine biology research and ocean rescue as well. Light of different wavelengths is absorbed in an underwater environment [4] at different rates, producing distinct colour casts. Light scattering [4] also reduces contrast and softens visual details. A lot of features hidden under the water can be shown by boosting an image's resolution, which can then be used by underwater researchers to enhance marine technology without endangering aquatic life. Therefore, techniques for underwater picture rectification are needed for both computer applications and scientific research. Both optical and acoustic technologies are employed to gather underwater data.

Contrarily, image processing offers a practical means of obtaining high-quality low-cost photos and videos. In the last ten years, the improvement and restoration of images from deep learning continued to attract attention. For a range of technical and scientific tasks, clear underwater photographs and recordings can offer vital information about the undersea habitat. However, the impacts of quality depletion, particularly the effects of bouncing back at vast distances, usually severely harm raw underwater photos and films [5]. The main causes of emerging problems are water's selective absorption and dispersion of light, in addition to the usage of synthetic illumination in deep water. The poor contrast and brightness, colour variations, hazy features, and uneven bright spot of the damaged underwater photos limit their practical applicability.

More focus has been placed on underwater image enhancement techniques as a crucial processing step. Due to the challenges in taking underwater images, their high cost, and the low quality problems brought on by low illumination

and light scattering under the water, a robust image improvement model would be extremely helpful in underwater research. These enhanced images can be applied to further tasks like segmentation, object detection, and others. Image Enhancement methods span the spectrum from the conventional, such as histogram equalization [6] and physical model-based methods [7], to the data-driven, such as convolutional neural networks [8] and generative adversarial networks [9].

Over the past few decades, deep learning techniques [10,11] have developed quickly and are now often utilized in a wide range of computer vision and image processing tasks. A way to utilize generative networks is image enhancement or super-resolution. Likewise CNNs outperforms traditional image enhancement because they search for patterns in the data that is provided. Convolutional layers are used to stack them and create intangible concepts. Comparing the state-of-the-art techniques, it is evident that adversarial networks place a greater emphasis on enhancing the visual quality of the photos. Convolutional networks, however, provide accurate quantitative results.

This study examines the shortcomings of current image enhancement techniques and suggests a hybrid solution for improving underwater images. The most recent image enhancement methods are examined in order to raise the photos' perceptual and quantitative quality. In order to obtain the favorable aspects of both models, two state-of-the-art methods are combined. To improve the poor-quality images, the proposed model is developed utilizing deep convolutional neural networks [12] and generative adversarial networks [13]. The underlying problem consists of increasing perceptual quality [14] and better performance in quantitative tests as well.

The concept of underwater imaging, its importance, challenges, and the premise of this paper are briefly discussed in Section I. The significant background information from related works is briefly introduced in Section II. The main portion of this study is introduced in Section III. The algorithm suggested in this paper was tested and describes the results of those tests and conducts an unbiased analysis of the algorithm's performance in Section IV. A summary and analysis of this paper's findings are provided in Section V.

## II. RELATED WORKS

Multiple techniques exist for improving and saving underwater photographs. Various techniques make use of physical models, while others don't. The Jaffe-McGlamery model [15] provides a precise physical representation for underwater imaging. Between the underwater photographs and the recovered images in a physical model, the model forges a link. By calculating the light's penetration and determining the ambient light of the surrounding underwater environment, one can produce reconstructed underwater images. Heng-Hua Chang [16] suggested a resilient single underwater image restoration system for enhancing graphic quality. Sheezan [17] described a restoration method for underwater pictures that prioritizes aesthetic quality. A red-channel method was suggested by Galdran [18] to correct underneath images.

Preprocessing underwater monocular vision with an improved DCP technique was presented by Tang et al. [19].

The traditional model-free technique focuses on changing the pixels of underwater photos, offering a more direct way to improve underwater photography than physical model-based improvement and rebuilding. Examples of techniques include white balance, gamma correction, histogram equalization, wavelet modification, and the Retinex algorithm. In order to produce thorough, high-quality photographs, experts typically utilize multiple techniques because underwater photography can degrade in a variety of ways. Examples include the blending of histogram equalization and wavelet transformation, the blending of wavelet transformation, white balance, and histogram equalization, and the blending of histogram equalization, white balance, and gamma correction.

New techniques for image processing have emerged as a result of the development of artificial intelligence (AI) over the preceding ten years. Neural networks (NN) and support vector machines (SVM) are good examples. Deep learning is used to improve photographs, notably image dehazing [20], as discussed by Jisnu, K & Meena, Gaurav. A network of deep neural networks was implemented by Li et al. [21] to de-scatter the underwater image. The use of a deep convolutional neural network (CNN) has been recommended by Perez et al. [22] to dehaze underwater shots. Deep CNN was implemented by Wang et al. [23] to color-correct and eliminate haze from underwater photographs. Cao et al. [24] exhibited clear latent deep CNN underwater reconstruction images.

Ground truth for underwater images can be challenging, so the typical deep learning framework can only be used to train models using ground truth from unique underwater images. The use of GAN by Fabbri et al. [25] improved the aesthetic appeal of aquatic scenes. Using an unsupervised GAN, Li et al. [26] described real-time underwater photo colour correction. A generative adversarial model with cycle consistency was employed by Li et al. The output of underwater photography will be fed into a neural network to build CNN models. The use of GAN to enhance the visual appeal of underwater photos was introduced by the author [25].

In order to increase underwater image quality from the perspectives of colour balance and dehazing, CNN is employed in the study. Despite the fact that it has been shown that GAN is mostly successful in reducing colour variance in underwater photographs. The clarity of underwater photographs can be increased by using a complete eliminating hazing model, which reduces the cumulative mistakes that arise from measuring background illumination and light transmission individually when a standard recovery model is applied. The employment of CNN in the single device eliminating hazing model, GAN colour adjusting, the improvement of ground truth, and the use of the blending technique for improving contrast are a few of the highlights.

The recommended picture improvement technique is tested on a large number of underwater photos from EUVP dataset [27], and some of the results are presented.

### III. PROPOSED METHOD

When compared to GAN-based models, CNN models are more concerned with improving numerical parameters while GAN-based models are more interested in the perceived quality of the improved images. Although the deep learning-based method for underwater image enhancement has made good progress, there is still much potential for development, particularly in the method's qualitative and quantitative capabilities. In order to address those issues, the paper suggests a hybrid strategy; thereby, performed an experiment combining GAN and CNN as a hybrid technique to get an enhanced image with better quantitative value and perceptual quality. We attempted the hybrid approach in two different ways. Initially, CNN and GAN were two parallel systems combined with concatenation. But because the two models must be trained independently, there was a large time commitment. The two models were afterward tested in a pipeline. The basic flow diagram of the system is discussed in the below section and briefly explains how the system works from the normal CNN and GAN to a hybrid architecture in which the input images are passed through both to get an enhanced image. This project will make use of the EUVP dataset [27], which will provide a detailed look.

#### A. Architecture of the Proposed System

Fig. 1 shows the hybrid system requires both CNN and GAN connected in a pipeline. The input image is passed through the pipeline architecture, thereby obtaining an enhanced image. The restored images are created with the help of the animation class of matplotlib. In the GAN architecture,

both the generator and the discriminator work together. The generator tries to produce better images after each epoch of the training and the discriminator acts like a binary classifier to detect real or fake images. In the CNN architecture, the input images pass through the layers and obtain the features of the input image. And these outputs of both GAN and CNN combined to get the resultant enhanced image. The loss function is attempted to be minimized by the generator and maximized by the discriminator as in a min-max game.

#### B. Dataset

1) *EUVP dataset*: The EUVP (Enhancing Underwater Visual Perception) dataset[27] offers multiple sets of paired and unpaired image examples of low and acceptable visual clarity in order to facilitate the supervised training of underwater picture enhancement algorithms. Table I shows the paired image details from the dataset[27] and Fig. 2 gives few examples of the paired images. In Table II, the details of the unpaired images are depicted and Fig. 3 shows some sample images from the unpaired set of the dataset[27].

TABLE I. PAIRED IMAGE DETAILS DATASET FROM EUVP DATASET[27]

Dataset Name	Training Pairs	Validation	Total Images
Underwater Dark	5550	570	11670
Underwater ImageNet	3700	1270	8670
Underwater Scenes	2185	130	4500

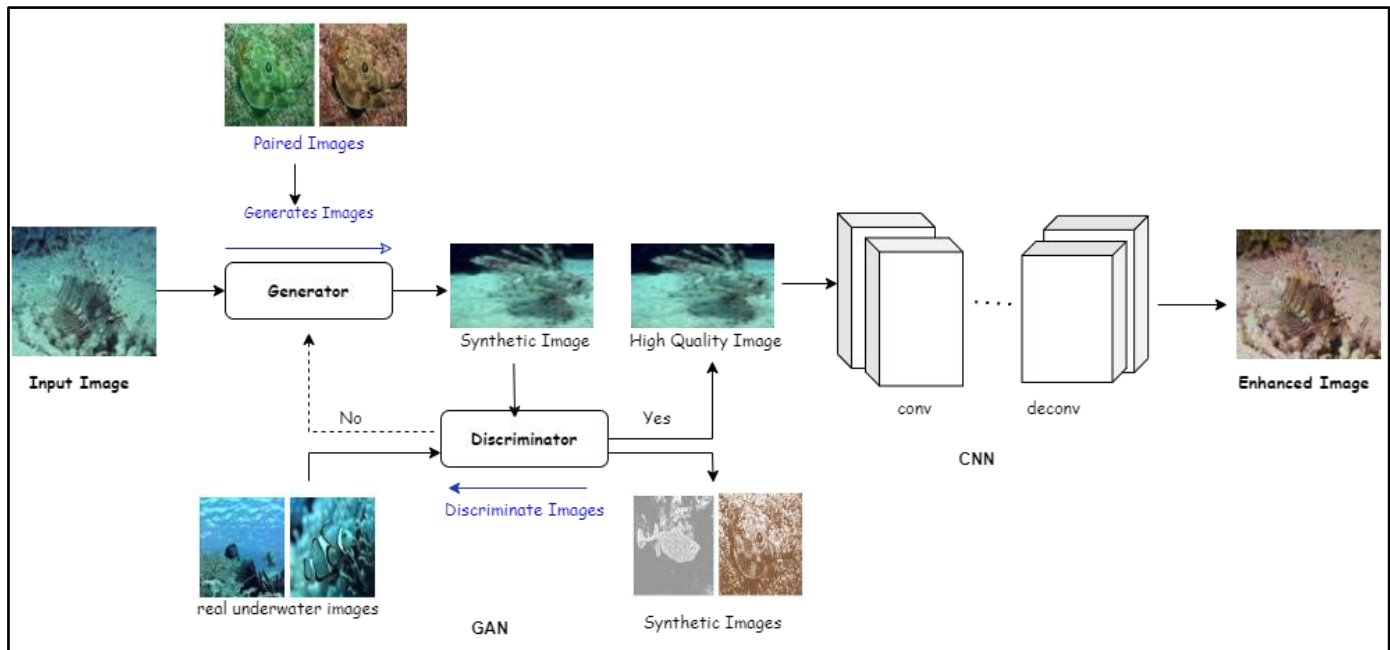


Fig. 1. Implementation flow using the suggested system, from raw input image to improved image





Fig. 2. Samples of the paired images from the EUVP dataset[27].

TABLE II. UNPAIRED IMAGE DETAILS DATASET FROM EUVP DATASET [27]

Poor Quality	Good Quality	Validation	Total Images
3195	3140	330	6665



Fig. 3. Samples of the unpaired images from the EUVP dataset [27].

### C. Platform and Specifications

The studies were carried out using a Google Colab Pro cloud-based subscription. 24GB CPU RAM and 16GB VRAM of the Tesla V100 GPU were used. We also ran some local tests on NVIDIA RTX 3060 GPUs with 6GB VRAM and 16GB CPU RAM. The complete application was written in the Python 3.7 programming language using the Pytorch module. To validate the project and see how it is advancing the state-of-the-art models used numerous experiments that were carried out.

## IV. RESULTS AND INFERENCE

Section IV explains many experiments carried out while the application was being developed and how measurements are utilized which are compared using results from other models. In this chapter, various screenshots of the findings are shown. Finally, all comparisons are shown in tabular style with the results of the baseline model.

### A. Metrics For Evaluation

1) *Peak signal-to-noise ratio (PSNR)*: The peak signal-to-noise ratio (PSNR) is used to interpret the image[28]. The signal-to-noise ratio is a term used in engineering to convey the association between a signal's maximum power and the power of corrupting noise that reduces the accuracy of its representation. Due to the fact that many signals have a broad dynamic range, PSNR is frequently expressed as a logarithmic value employing the decibel scale. PSNR is widely used to gauge the quality of reconstruction for lossy-compressed images and movies.

$$PSNR = 20\log_{10}(MAX/(MSE)^{1/2}) \quad (1)$$

where MAX is the highest pixel value that the image can contain and MSE is Mean Squared Error.

2) *Structural Similarity Index (SSIM)*: The Structural Similarity Index (SSIM)[28], a perceptual metric, quantifies the extent to which imagery is lost due to problems with data transmission or other processing steps like data encoding. The Structural SIMilarity (SSIM) index is a tool for calculating how similar two images are. On the assumption that the other image is thought to be of ideal quality, the SSIM index can be used to assess the quality of one of the images being compared.

$$SSIM(x,y) = ((2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)) / ((\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)) \quad (2)$$

where,  $\mu_x$  is the pixel sample mean of  $x$ ,  $\mu_y$  is the pixel sample mean of  $y$ ,  $\sigma_x^2$  is the variance of  $x$ ,  $\sigma_y^2$  is the variance of  $y$ ,  $\sigma_{xy}$  is the covariance of  $x$  and  $y$ ,  $c_1 = (k_1L)^2$ ,  $c_2 = (k_2L)^2$  are two variables to stabilize the division with weak denominator and  $L$  is the dynamic range of the pixel values,  $k_1 = 0.1$  and  $k_2 = 0.3$  by default.

3) *Loss function*: The first description of the typical GAN loss function [29], often known as the min-max loss, was made in a 2014 article titled "Generative Adversarial Networks" by Ian Goodfellow et al. The resulting value is enhanced by the discriminator, while it is diminished by the generator. This explanation of the defeat seemed to work well when viewed as a min-max game. In reality, it saturates the generator, which means that if it falls behind the discriminator during training, it commonly stops.

$$E_x[\log(D(x))] + E_z[\log(1-D(G(z)))] \quad (3)$$

Discriminator loss and Generator loss are two additional categories that can be tailored to the Standard GAN loss function.

Generator Loss:

$$\nabla\theta_g(1/m)\sum_{i=1}^m \log(1-D(G(z^{(i)}))) \quad (4)$$

Discriminator Loss:

$$\nabla\theta_d(1/m)\sum_{i=1}^m [\log D(x^{(i)}) + \log(1-D(G(z^{(i)})))] \quad (5)$$

In this function:

$D(x)$  is the discriminator's estimate of the probability that real data instance  $x$  is real,  $E_x$  is the expected value over all real data instances,  $G(z)$  is the generator's output when given noise  $z$ ,  $D(G(z))$  is the discriminator's estimate of the probability that a fake instance is real,  $E_z$  is the expected value over all random inputs to the generator (in effect, the expected value over all generated fake instances  $G(z)$ ).

### B. Experiments and Results

The Underwater\_dark set from the EUVP dataset, which contains 5550 pairs of photos for training as two sets, is used to train the suggested model. One group includes low-resolution (or grey) photographs, while the other has upgraded (or coloured) images. For every pair, both sets share the same filenames. Another 570 images were used for validation. As a

total, we have used 11,670 images from the dataset [27] for the experimentation and implementation. The degraded photos that were utilized for training are shown in Fig. 4. And Fig. 5 explains the generator and discriminator loss obtained while training. It is evident from Table III that the suggested hybrid technique performs better than the current models. The results demonstrate that, in comparison to our hybrid approach, the current models do not provide good quantitative results. The suggested approach produced better quantitative results with increased visual quality, as seen in Fig. 6 and Fig. 7. The outcomes of our hybrid technique are displayed in Fig. 6 by comparison with the input test image and the ground truth. The findings of the suggested approach are also compared to those of the current methods in Fig. 7 where our hybrid method makes a distinct quality difference.

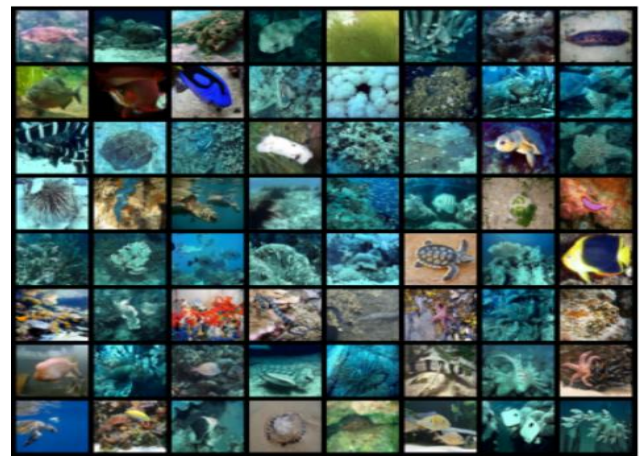


Fig. 4. Different training images from the EUVP dataset.

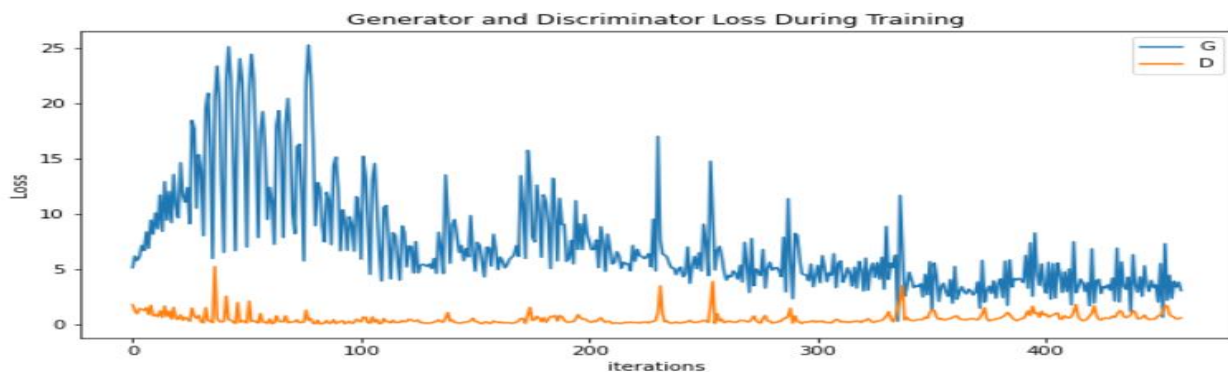


Fig. 5. The graph for generator and discriminator loss during training.

TABLE III. PSNR AND SSIM SCORES OF FIVE DIFFERENT IMAGES

Input Image	CNN		GAN		Hybrid Method	
	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM
(a)	<b>14.46</b>	0.4575	16.89	0.3635	18.96	0.4365
(b)	14.27	0.4532	17.36	0.4152	18.59	0.4712
(c)	12.78	<b>0.5012</b>	<b>18.64</b>	<b>0.7958</b>	19.44	0.8862
(d)	11.52	0.3589	15.48	0.5433	20.36	0.8578
(e)	11.33	0.2985	16.52	0.4056	<b>20.67</b>	<b>0.9558</b>







Fig. 6. The results obtained from the hybrid architecture (from left: test image, ground truth, and prediction on test image).

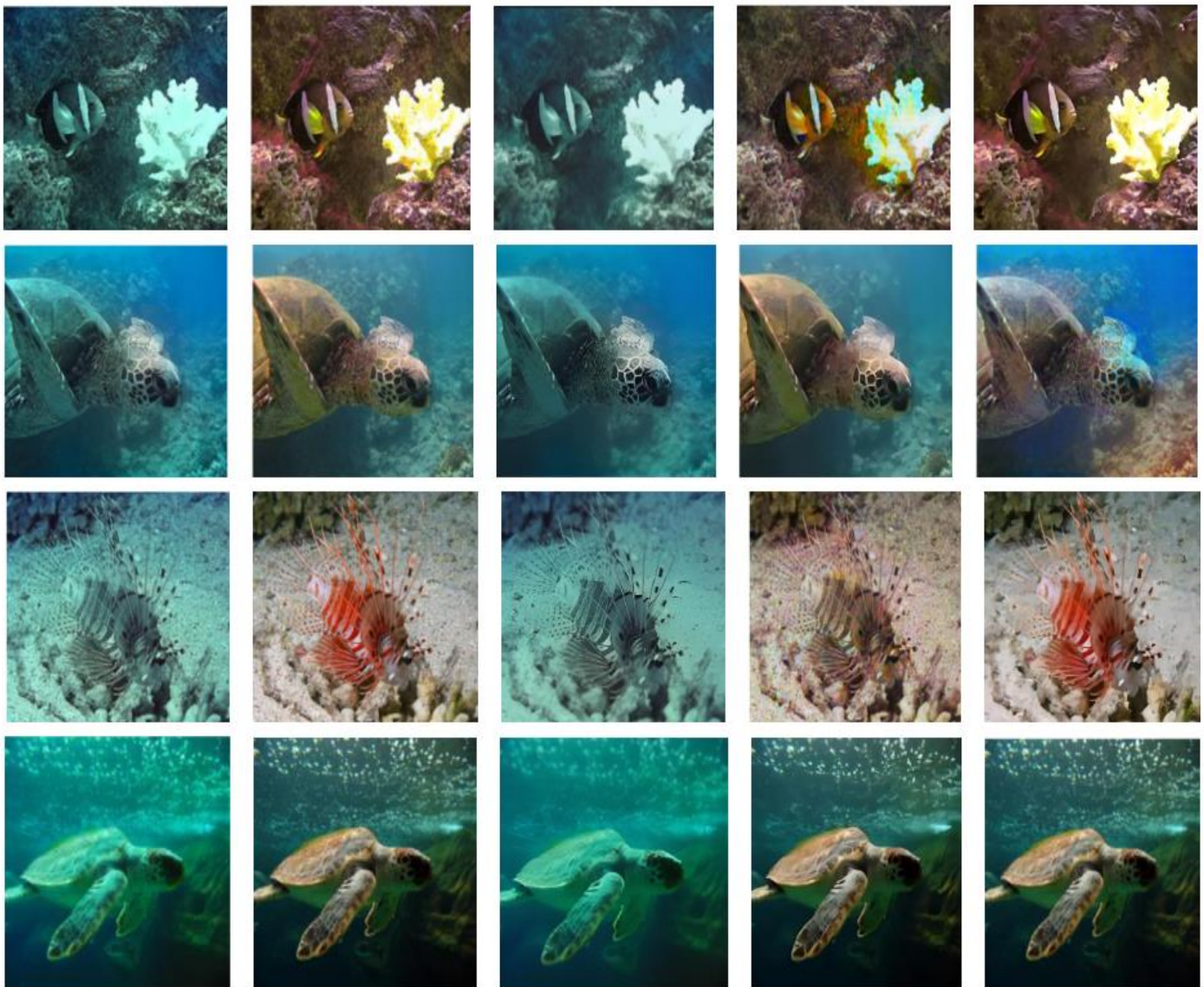


Fig. 7. The results obtained from the different models (from left: test image, ground truth, CNN result, GAN result, and hybrid model result).

## V. CONCLUSION AND FUTURE SCOPE

Due to the visual characteristics of light in water, an image acquired underwater degrades. However, traditional forms are insufficient for accurate reconstruction due to the deterioration of the observed image. We suggested a hybrid method for enhancing underwater descriptions in this research. The hybrid technique is with CNN and GAN, which produces better results. According to experimental data, the suggested technique outperforms the standard procedures when combined in visual and quantitative evaluation. The proposed model can improve the detailed information of the image by enhancing it, according to comparisons made between it and enhancement algorithms recently proposed. Although this method is best suited for enhancing images with fluctuating lighting levels, it has significant limitations when it comes to effectively restoring the details of extended exposure areas. However, augmentation restricts the local dark region when the lighting is too unbalanced, calling for further research. Another issue with the current system is we need to train a lot of data. This could take up a lot of time and space and be very complex in training. We performed various experiments and recorded the results for the proposed architecture.

As a future enhancement, the upgraded images can be taken as the input and can perform image segmentation and object detection as well to create an awareness about the pollution under the water and thereby help the aquatic lives to get a better life.

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# End-to-End Real-time Architecture for Fraud Detection in Online Digital Transactions

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**Abstract**—The banking sector is witnessing a fierce concurrence characterized by changing business models, new entrants such as FinTechs, and new customer behaviors. Financial institutions try to adapt to this trend and invent new ways and channels to reach and interact with their customers. While banks are opening their services to avoid missing this shift, they become naturally exposed to fraud attempts through their digital banking platforms. Therefore, fraud prevention and detection are considered must-have capabilities. Detecting fraud at an optimal time requires developing and deploying scalable learning systems capable of ingesting and analyzing vast volumes of streaming records. Current improvements in data analytics algorithms and the advent of open-source technologies for big data processing and storage bring up novel avenues for fraud identification. In this article, we provide a real-time architecture for detecting transactional fraud via behavioral analysis that incorporates big data analysis techniques such as Spark, Kafka, and h2o with an unsupervised machine learning (ML) algorithm named Isolation Forest. The results of experiments on a significant dataset of digital transactions indicate that this architecture is robust, effective, and reliable across a large set of transactions yielding 99% of accuracy, and a precision of 87%.

**Keywords**—Online fraud; big data analytics; fraud detection; behavior analysis; isolation forest

## I. INTRODUCTION

Digital transaction fraud happens when an entity gains illegal entry to a banking account and utilizes it to make online transactions. Fraud detection techniques seek to exploit two fundamental limits that fraudsters experience while committing online transaction theft. First, most fraud techniques are susceptible to restricted time limits since consumers and banks block account access immediately with fraud discovery. Therefore, fraudsters are needed to hit the credit limit on the account in a brief amount of time, and as a result, their act is revealed in the shape of suspicious transactions over these shorter periods. In addition, the second type of restraint is created by the variety of digital transactions exposed by financial institutions and the variety of customer behaviors and awareness regarding fraud threats throughout these channels. Fortunately, monitoring measures applied from the financial institutions' side added to device security measures used from the customer's side may impede, in many cases, fraud attempts. Such impediments push fraudsters to target a small niche of customers that don't frequently interact through digital channels or aren't aware of security measures [1] that should be applied. As a result of this condition, fraudulent transactions are made at a few specific accounts that vary from the area set of customers to which the requirements above are applied.

Conventional methods for detecting system fraud are rule-based [2] [3]. Although rule-based solutions help prevent many fraudulent transactions, they remain static and don't adapt to fraud trends changes even when humans adjust continuously. As a result, machine learning-based algorithms have emerged as a non-deterministic approach employed for digital payment fraud detection in recent years. This area of study, however, has received little attention in the literature. Many of the solutions that have been examined propose a technique based on intelligent field knowledge features or make a fundamental assumption about transaction chronology [4]. To conduct a digital payment transaction, a fraudster should first login into the banking system. The payment and login are two separate processes that must be performed within this sequence. Anyway, this simple procedure follows a typical series of events. Although the bulk of fraud efforts are more complicated, the utmost existing systems focus on records from the most contemporary transactions, depending on hand-engineered characteristics that will presumably identify broad connections.

The target of this study is real-time fraud detection in digital banking. In this context, a fraud detection scheme aims to determine the risk within each item as in kind of fraud likelihood in real-time. The bank may then opt to authorize the transaction, refuse it, or demand a specific type of authentication on the consumer after completing it. To tackle this issue, we present a real-time architecture for detecting transactional fraud through behavioral analysis, which combines big data analysis tools (Kafka, Spark, and h2o) with the Isolation Forest algorithm to see suspicious transactions and provide excellent detection performance. The experimental findings are provided to confirm the efficacy of our strategy.

Concisely, the following are the foremost contributions of the present research:

- 1) Establishing an advanced fraud detection architecture for digital transactions by combining an unsupervised learner with big data analytics kits for real-time detection and training time reduction, enabling it to identify fraud in a typical online transaction context,
- 2) Using efficient feature engineering methods on the raw data. This involves producing aggregate features based on transaction frequency and isolating complex characteristics including the transaction's date to month, day, location, and so on. Because of the variety of features, our model can detect patterns that individuals or primitive machine learning algorithms cannot,



- 3) Applying the isolation forest model for identifying suspicious transactions,
- 4) Extensive evaluations have been carried out to assess the efficacy of the suggested architecture.

Our suggested architecture outperforms crucial benchmarks on online transaction fraud data encompassing over a hundred million transactions in a thorough experimental examination. More precisely, we show how our method can be used to meet strict operating time limitations while still maximizing prediction performance requirements relevant.

The remnant of this article is structured as following: in the second part, we present a review of the online transactions' fraud detection literature. Section III presents the research summary. Section IV offers the Isolation Forest learner. Section V describes our suggested architecture for online fraud transaction detection. And Section VI outlines the end-to-end data pipeline and the dataset used and explains the findings. Further Section VII discusses our results providing comparison with state-of-the-art studies. Finally, Section VIII concludes the work with suggestions for further research.

## II. FRAUD DETECTION TECHNIQUES FOR ONLINE TRANSACTIONS

World banking services and industries have been subjected to massive e-frauds, which have resulted in the overturning of whole organizations, enormous investment losses, and considerable litigation expenditures. As a result, companies and scientific studies have shown a keen interest in detecting online fraud. This section examines various significant study topics relevant to our work.

### A. Outline of Extant Banking Fraud Recognition Methods and their Drawbacks

For many years, the general strategy in the cybersecurity business has been to prevent hypothetically fraudulent transactions by enforcing a set of strict criteria. A fraudulent identification rule-based system is designed to detect only elevated abusive transactions [4] [5]. This strategy efficiently reduces scam attempts and provides clients with a wisdom of security by uncovering well-known fraud trends. Nonetheless, rule-based detecting fraud technologies have shown in the arena that they are unable to go on with the gradually complex strategies used by cheats to jeopardize important properties: Cybercriminals may readily counteract a set of predetermined levels [6], [7] and fixed criteria are useless for identifying developing risks and adapting to previously undisclosed fraudulent transactions.

The miss of information to examine is another significant drawback of rule-based detecting systems more inventive the fraudulent strategy, the less the info you will get in examined trades [8]. This dearth of information might indicate that valuable data are not being gathered and saved, that data is available although lacking crucial points [7], or that data cannot relate to particular other info.

Many methods have been created and tried over time to increase the efficacy of rule-based detection strategies. However, recent trends indicate that deploying analytics

regularly on a flexible data architecture and reliable machine learning algorithms might yield promising outcomes.

### B. On Machine Learning-based e-Banking Fraud Detection

Recently, machine learning Fraud Detection has risen to prominence [9] [10] [11] [12]. Because of its more accurate findings, the anti-fraud domain is shifting from rule-based fraud identification to ML fraud detection. We present here some online fraud detection studies.

By using supervised machine learning methods, [13] have wanted to construct a transactional fraud detection algorithm capable of efficiently classifying an online transaction as illegitimate or legitimate. A credit-card fraud classifier was created utilizing three supervised machine-learning (ML) algorithms. SVM, LR (logistic regression), and neural networks are among these methods. All the classifiers attain about the same classification accuracy. The results show that the support vector machine beats the others.

Along with this, two algorithms, namely XGBoost, and Fully Connected Neural Network (FCNN), whose AUC merits may reach 0.912 and 0.969 correspondingly, have been developed by [14]. In the meantime, they have developed an interactive method for identifying online transaction fraud relying on the XGBoost model to evaluate submitted transaction data autonomously and provide customers with fraud detection findings. On the other side, to increase detection performance and quicken the convergence of identification, [15] has suggested an online transactional fraud detection approach using unbalanced data relying on the semantic integration of two unsupervised learners such as an artificial bee colony model and k-means. In the suggested method, ABC functions as a secondary classification level to handle the k-means classifier's inability to investigate the real bunches since it is susceptible to the beginning circumstance. The experiment results showed up to 100% True positive and less than 2% False Positive. In the same context [16] have offered a tailored alert model for detecting fraud in online transactions by mining a set of instances in each customer's regular transaction log. The suggested methodology segmented every consumer's log into transactions extracted a collection of chronological sequence arrangements and used it to identify if a novel transaction is malicious. The entering transaction is separated within many windows, and an alert is raised if the typical behaviors are not discovered in the subsequent windows. According to the experimental outcomes, the suggested approach beats the rule-based paradigm and the Markov chain method.

Moreover, FinDeepBehaviorCluster has been proposed by [17]. They have used temporal attention-based Bi-LSTM to determine sequential embed and handled click data in real-time as an event sequence to exploit the behavior sequence data. Handmade features reflecting domain expertise are produced to improve the system's interpretability. By integrating the two sorts of traits, a hybrid behavior interpretation has been created. Then, to group transactions with similar behavior, a pHDBSCAN (i.e., GPU-powered HDBSCAN) is used. The results show that FinDeepBehaviorCluster successfully detects lacking suspicious transactions having excellent business value. By merging machine learning with big data analytics



tools, [18] have presented a robust method for detecting fraud in online-based transactions. To notice whether electronic transfer behaviors are aberrant, the big data of internet-based e-transactions, which includes (credit card details data and trading), is first refined in the transaction pre-processing stage module, and then transferred to a rule-based specialist system module, which would be achieved with Spark streaming and divvied up platform Kafka. The regular records from the expert system module are then applied in the machine learning fraud prevention module to execute behavioral analysis via DT (Decision Tree), CNN, and SVM algorithms. The findings exhibit that the proposed strategy produces satisfactory results. Also, to identify Internet financial fraud, [8] have proposed a sophisticated and scattered Big Data approach. They have used Hadoop and Spark GraphX to identify and express every vertex's topologic feature in a dense lowly-dimensional vector using the graph embedding technique Node2Vec. The suggested approach seeks to anticipate the dataset's spurious entries. The findings indicate that the proposed strategy enhances the precision and accuracy of Online fraudulent transaction detection systems. In that same vein [19] have created a real-time scam detection for credit cards system utilizing big data technologies such as Microsoft Azure. The

given outcomes are pretty accurate by applying a variety of ML learners, such as Extreme Random Trees and Stochastic Gradient Descent.

Recently, the isolation forest learner has been applied in online banking transactions fraud detection, given its reputation as one of the most powerful algorithms. In fact, [20] have examined two unsupervised learners for CCFD i.e. credit card fraud detection (isolation forest (IForest) and local outlier factor (LOF)). When comparing precision and recalls for the two models, the findings show that Isolation Forest beats the local outlier factor. Additionally, the fraud detection percentage is about 0.27, whereas the LOF (local outlier factor) discovery rate is barely 0.02. The accuracy of the Isolation Forest is 0.99774 higher than that of the local outlier factor. Similarly, the IForest and LOF techniques were employed by [21] to detect fraudulent credit card transactions. The experiments provide good results.

All the studies discussed here are fascinating and revolve around fraud detection in large data circumstances. They offer trustworthy and promising prediction algorithms for preventing fraud. We present the comparison of all these models in the Table I.

TABLE I. PREVIOUS FINDINGS FOR OTHER STUDIES

Paper	Used dataset	Techniques used	Performance	Limits
[13]	Credit card dataset	SVM, LR, and neural networks	The support vector machine beats the others	The precision of the ANN is around twelve percent less than that of both of the models
[14]	Online transactions	XGBoost, and Fully Connected Neural Network (FCNN)	XGBoost reaches 0.912 and FCNN 0.969	The system can't identify malicious transactions in real-time as they occur
[15]	Online transactions	artificial bee colony model and k-means	Results showed up to 100% True positive and less than 2% False Positive	Quadratic Discriminant Analysis give the fewer accuracy
[16]	Online transactions	Tailored alert model for detecting fraud in online transactions	The suggested approach beats the rule-based paradigm and the Markov chain method.	The suggested methodology detects fraud by using regular patterns; however, it will only identify scams when individuals display considerably different trading habits than typical.
[17]	real-world e-commerce transaction data	temporal attention-based Bi-LSTM, pHDBSCAN	Results show that the proposed method successfully detects lacking suspicious transactions having excellent business value.	Unable to identify low frequency of fraudulent transaction
[18]	internet-based e-transactions (credit card details data and trading)	Spark streaming and Kafka. DT, support vector machine, and CNN	The findings show that the proposed strategy produces satisfactory results.	The outcomes need to be improved
[8]	Credit card dataset	Spark GraphX, Hadoop, and graph embedding technique Node2Vec	The findings indicate that the proposed strategy enhances the precision and accuracy of Online fraudulent transaction detection systems.	The suggested model will be enhanced to successfully learn the newly generated features, resulting in better identification of fraud.
[19]	Credit card dataset	Microsoft Azure, Extreme Random Trees, and Stochastic Gradient Descent.	Good accuracy	Does not handle the class imbalance problem
[20]	Credit card dataset	IForest and LOF	The findings show that Isolation Forest beats the local outlier factor within 0.99774 of accuracy. The fraud detection percentage is about 0.27, whereas the LOF discovery rate is scarcely 0.02.	The LOF learner yield low performance
[21]	Credit card dataset	IForest and LOF	The experiments provide good results.	LOF give the worst results

The upcoming section will highlight the comparative study of this literature reviewed methods for online fraud detection and present the motivations of our paper.

### III. SUMMARY AND MOTIVATIONS

Based on our literature review analysis in the previous section, we noticed that researchers have proposed several machine Learning approaches particularly supervised ones involving SVM, LR, DT, and NB algorithms, for detecting online transaction fraud. The majority of the approaches examined have shown to be beneficial in the process; nonetheless, due to changes in the fraudster's behavioral patterns, real-time fraud detection is always difficult, and algorithms fail to give better accuracy.

As the outcomes reveal, systems for detecting fraud that utilize SVM and LR offer good accuracy yet suffer from considerable overhead when handling huge datasets. Additionally, because the fraudulent act is shifting, these learners are just assisting in learning current trends in fraud. From another viewpoint, ANN, decision tree, and NB provide moderate accuracy and mid-scope at the expense of high prices.

Another limitation of these related studies is that most of them establish a profile of regular cases and then detect anything that does not fall within the usual profile as an abnormality; leading to misclassification, a high false positive rate, and also, they are not adept at handling real-time detection. In contrast with that, IForest segregates observations by picking a property and then erratically determining a splitting point between the selected property's maximum and minimum values [22]. The amount of splits required to isolate a trial equals the path length from the root node to the ending node [23]; by giving high fraud detection accuracy over large datasets, with the least false positive rates.

This study suggests a new end-to-end real-time architecture for online transaction fraud detection based on isolation forest learners. Combining the advantages of big data analytics tools and the unsupervised isolation forest with the aim to overcome the existing approaches' limitations and dealing with real-time detection and prevention of digital transactions while minimizing false positive rate, and false alarms, regulating latency in addition to speed, and dependability.

### IV. ISOLATION FOREST

Isolation Forest is defined as an unsupervised ML learner. It employs a similar technique as the (RF) Random Forest algorithm and is based on the notion of decision trees. Rather than using the typical properties of data points, the isolation forest algorithm's basic idea and approach are to detect abnormalities — for example, fraudulent transactions [24] [25].

Isolation forest outperforms other techniques in anomaly detection algorithms due to several advantages. First, it requires tiny samples from considerable datasets to generate an anomaly detection algorithm, making it rapid and robust. Secondly, no examples of abnormalities in the training sample are required. Furthermore, the tree depth serves as the foundation for its distance threshold for detecting anomalies independent of the sample dimensionality scale. It may

function as both a supervised and unsupervised learner, and its goal is for irregularities to be less frequent than everyday observations and to differ from their values.

To build the IForest (Isolation Forest), determine the amount of (Itrees) isolation trees within the forest. Next, for every isolation tree, the following procedures are taken [26] [27]:

- Select  $n$  instances at random from the training dataset.
- Pick an attribute at random to divide on.
- At random, select a separated value from a uniformly distributed covering the minimum to the most significant rate of the feature set in Step 2.

Assuming a dataset has  $n$  instances,  $h(x)$  is the route length as  $x$ . The average path length  $c(n)$  is afterward used to normalize the value of the path length  $h(x)$ . As Itrees have the same shape as the BStree (Binary Search Tree), the following equation is used to obtain the value of  $c(n)$ , where  $H(i)$  is the harmonical number that may be obtained via [28] [29] :

$$c(n) = 2H(n - 1) - \frac{2(n-1)}{n} \quad (1)$$

The abnormality score within each data point  $x$  in a database with  $n$  occurrences is obtained by using the following:

$$s(x, n) = 2^{-\frac{E(h(x))}{c(n)}} \quad (2)$$

with  $(E(h(x)))$  is the mean of  $h(x)$  across a set of Itrees).

The nearer a data point's anomaly score is near 1, the more likely that data point is an outlier. On the other hand, the records point is more probable to be regular if the abnormality count is near zero.

### V. END-TO-END FRAUD DETECTION SOLUTION ARCHITECTURE

This section proposes a real-time scalable architecture for preventing and detecting fraud in online transactions using big data analytics algorithms to improve the capacity to manage highly complex online transaction fraud instances. In this part, we will present a fraud detection pipeline as a sequence of steps applied to every transaction to mitigate the risk of fraud occurrence. This pipeline will consequently drive the suggested architecture and the technology stack used for its implementation.

#### A. Fraud Detection Pipeline

Let's say the banking account provider receives an authorization request for a transaction. Initially, the Online Detecting Fraud system captures the transaction data and its context in real-time. To prevent fraud, deterministic rules are positioned as barriers that should be imperatively checked before effectively executing the transaction. Given that these rules are implemented as part of the transaction, criteria such as low latency should be a real concern. Therefore, enforcing these rules must be performed in milliseconds. Otherwise, the customers will notice a significant delay while interacting with the bank application. Once these barriers are overcome, the customer transaction is executed. Next, we move forward with

fraud detection using more sophisticated and non-deterministic data analytics techniques.

At this stage, the goal is to detect suspicious transactions based on customers' past interactions with the bank's application. To see these transactions, customer data would be processed in real-time and fed to a pre-trained isolation forest model. This model makes predictions and produces suspicious transactions with an associated score. Transactions with a score over a predefined threshold would be displayed in a fraud monitoring application for human supervisors who will investigate customer behavior to confirm or reject those cases. The transaction monitoring agents might perform some curative actions and notify account holders of the occurrence of these high fraud-risk transactions by "mobile app alerts, e-mail or SMS." The fraudulent instances observed by the transaction monitoring and customer care departments are gathered, and the associated transactions in the database are tagged as suspicious. To sum up, any customer transaction will go through the pipeline below in Fig. 1:



Fig. 1. Customer transaction pipeline.

Each of the presented steps has different prerequisites to balance user experience and prevention from potential fraudsters. Consequently, implementation choices and used technologies were driven by these requirements. The Table II presents each step, along with its prerequisites and implementation choices:

TABLE II. FRAUD DETECTION STEPS WITH THERE PREREQUISITES

Layer	Description & prerequisites	Implementation choices
Events streaming	Refers to events streaming from digital banking applications. This component must publish events as soon as they occur.	Kafka-connect. Kafka producer API
Data capture	Refers to events captured in a resilient way as well as making them available to different consumers.	Apache Kafka
Fraud prevention	Refers to real-time fraud prevention while transactions are in motion. This step must respond with a significantly reduced latency, given that the end-user would be blocked until this prevention is performed.	Apache Kafka Streams
Fraud detection	Refers to detection of fraud in a non-deterministic way, affecting a score to each transaction and persisting information about suspicious transactions.	Apache Spark Spark Streaming H2O PostgreSQL
Monitoring	Refers to making potential fraud alerts available to human supervisors that could analyze and eventually contact end-users and perform curative actions accordingly.	React NodeJS
Alerting	Refers to raising alerts once a suspicious alert is confirmed to be fraudulent. These alerts could be consumed afterward by third-party consumers for actions such as account blocking and SMS notifications...	Kafka-connect. Kafka producer API

### B. End-to-End Solution Architecture

The Fig. 2 below presents an overview of the suggested architecture after gluing together the building blocks exposed previously:

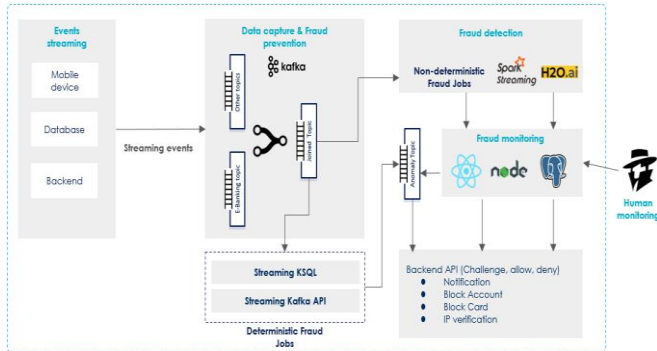


Fig. 2. End to end real time fraud detection architecture.

The prevention layer will be built with Kafka and KSQL. Kafka, the most ubiquitous and extensible stream processing platform, has been optimized for real-time use [30] [31]. KSQL, on the other hand, is a continuous query language. While it may be used for interactive data exploration, its primary aim is to construct stream processing apps. Our architectural scheme is as follows; Large data transactions originate from various sources, including websites, neobanks, social media, etc. These transactions are obtained in real-time using Apache Kafka and KSQL in the form of a stream. For instance –, if we have the same account number as that of the previous transaction at a different location in fewer than ten-minute period later, the system will deem it suspicious and reject it instantly without sending a verification email or SMS to the account's owner.

Real-time fraud detection consists of several layers, including a real-time transaction ingestion layer, a processing layer for handling massive amounts of information in storage for increased reliability and fault-tolerant, and fraud notifications via visual representation. First, the vast data of online transactions is ingested. Then, the processing layer retrieves the transactions in real time, which can handle the transaction data quickly and efficiently. This layer notably depicts two commonly used techniques. Spark streaming and Sparkling water for deploying the predictive model and its integration with the Spark distributed processing engine.

On the other hand, an isolation forest is used to predict the degree of fraud and identify it as accurately as possible in the shortest period. To verify whether a transaction is illegal, isolation forest learns the model from the account holder's behavioral patterns. We examine the location and time gap among different transactions, the frequency of transactions, and other criteria while regulating the account holder's history of transactions. The transactional data will then be saved and utilized for monitoring in a frontend application, which exposes visualizations and curative actions connected with backend APIs.

### C. Solution Infrastructure Deployment

At the core of this architecture implementation, we relied on a distributed cluster on which model training and spark streaming data processing and inference jobs were deployed. In addition, other components, namely Kafka and fraud monitoring applications, were deployed separately on other servers. The Table III shows the servers used for each element:

TABLE III. USED SERVERS

Component	Servers / Characteristics
Spark streaming / H2O	Driver : CPU: 1 core RAM: 4 Go Storage: 50 Go
	Worker 1 : CPU: 2 cores RAM: 8 Go Storage: 50 Go
	Worker 2 : CPU : 2 cores RAM : 8 Go Storage : 50 Go
Kafka	Worker 3 : CPU : 2 cores RAM : 8 Go Storage : 50 Go
	Broker 1 : CPU : 2 cores RAM : 8 Go Storage : 50 Go
	Broker 2 : CPU : 2 cores RAM : 8 Go Storage : 50 Go
Monitoring application	Broker 3 : CPU : 2 cores RAM : 8 Go Storage : 50 Go
	Application server / Database: CPU : 2 cores RAM : 8 Go Storage : 50 Go

In the next section, we will focus on the used dataset as well as the model implementation (ie spark streaming job and its integration with H2O isolation forest implementation). For these two components we will expose the approach along with key results and metrics.

## VI. SIMULATION AND RESULTS

This section depicts the database and the evaluation criteria that were utilized in our study. The outcomes of the suggested method's experiments are then provided.

### A. Dataset

The database used in our work contains online transactions generated with an approach that simulated real customer behavior. The generated dataset contains more than 100 million rows following the structure below:

- User\_id: identifier of the user connected to the portal.
- Account: account number of the customer connected to the portal.
- Event\_type: type of event captured by the audit trail.

- Event\_payload: payload containing event attributes.
- Event\_description: descriptive text of the event
- Device\_id: mac address of the device used for the action.
- Ip\_address: IP address
- Timestamp.

The event attribute reflects various actions that customers could typically perform in a digital banking platform:

- LOGIN\_ATTEMPT
- LOGIN\_SUCCESSFULL
- LOGIN\_FAILED
- LOGOUT
- VIEW\_ACCOUNT\_BALANCE
- VIEW\_ACCOUNT\_HISTORY
- VIEW\_ACCOUNT\_OPERATION
- MONEY\_TRANSFERT
- ADD\_BENEFICIARY
- REMOVE\_BENEFICIARY
- PROVISION\_CARD
- BILL\_PAYMENT
- VIEW\_CONTRACT
- VIEW\_CARD

To reflect real customer behavior, data was generated concerning the sequence of events that could occur from a user interacting with the bank application. For example, the interaction sequence should start with LOGIN\_ATTEMPT event followed by LOGIN\_SUCCESSFUL or LOGIN\_FAILED. Once the customer is logged in, they can view the account balance, add beneficiary to make money transfer to them, pay bills, or any other event reflecting the exposed services by the bank. To integrate suspicious events, the data generation script randomly picks some users for which money transfers are performed at an unusual rate or failed login attempts are performed from unknown devices. Those fraudulent transactions are then labeled and saved separately as a baseline for later model evaluation. The generated data served for model training and was published afterward to a Kafka topic using scripts relying on Kafka producer API.

### B. Model Training and Inference

Before model training, generated events were processed as part of the feature engineering step to extract relevant features for our context. Below are key features used to train the model:

- User\_id
- Account
- Login\_attempts\_count

- Last\_login\_timestamp
- Last\_transaction\_amount
- Beneficiary\_account
- Transactions\_sum
- Transaction\_to\_max
- Device\_id
- Device\_id\_last\_timestamp
- Device\_id\_bill\_payment

Once the features were extracted, the model was trained on the provisioned cluster using h2O integrated with an Apache Spark job. The integration was done using the Sparkling water package, which was installed and used afterward to create an h2OContext employed to train our model in a distributed way. In our model training, we sought to optimize isolation forest hyperparameters such as the number of trees and tree depth that would allow us to detect all the fraudulent transactions while minimizing false positives. During our training, we reached an optimal performance with values of 200 as the number of trees and 18 as tree depth. The performance of our model with these parameters is exposed through classification metrics in the section below.

### C. Experimental Criteria

During this work, we used our dataset partitioned into five sets to train the isolation forest. While the training set is made up of 80% of the data.

The experiment outcomes are assessed using accuracy, the F1-S, precision, and recall, as specified in Table IV. The Accuracy metric represents the overall performance of fraud detection. Precision is another word for a predictive value that is positive. A true positive rate is identical to the recall. The harmonious mean of (recall - accuracy) is the "F1-score". The (True Positive i.e. TP) alludes to the amount of accurately anticipated suspicious transactions within all right suspect transactions, false positive (i.e. FP) alludes to the total of regular transactions that are wrongly identified as suspicious, (TN i.e. true negative) relates to several precisely indicated normal actions for all right regular operations, and false negative i.e. FN refers to the amount of suspicious transactions that are erroneously marked as regular ones.

TABLE IV. EVALUATIONS METRICS

Performance metrics	Formulas
Precision:	$\frac{TP}{TP + FP}$ (3)
Recall:	$\frac{TP}{(TP + FN)}$ (4)
Accuracy:	$\frac{((TP + TN))}{(TP + TN + FP + FN)}$ (5)
F1 score:	$2 \times \frac{(\text{precision} \times \text{recall})}{(\text{precision} + \text{recall})}$ (6)

The ROC curve is accompanied by a graphical display that compares the TP to the FP at several criteria. We additionally employ the AUC i.e., area under the ROC curve alongside the abovementioned measurements as a comprehensive performance measure. Since it does not depend on a criterion

value, the AUC is considered a superior performance metric to accuracy. The nearer the AUC number is to one, the finer a model's overall efficiency.

#### D. Experimental Results

Utilizing our private dataset, we experimented with the isolation forest using Python and a sparkling water engine. The output model was packaged and integrated with Spark Streaming through Sparkling Water to perform fraud detection in real-time as per previously exposed architecture. Table V and Table VI summarize the obtained results after completing the training iteration.

TABLE V. TRAINING ITERATIONS

	Events	transactions	Labeled Fraud attempts
Iteration 1	20000000	187234	151
Iteration 2	20000000	234567	213
Iteration 3	20000000	198654	195
Iteration 4	20000000	272647	286
Iteration 5	20000000	324546	323

The Table VI presents the mean of critical metrics after training the model against the above mentioned dataset.

TABLE VI. MODEL METRICS

Metrics	Accuracy	Precision	Recall	F1-score
	0,99	0,87	0,97	0,91

#### VII. DISCUSSION

We discussed the procedures needed to set up an online transaction fraud detection architecture in real-time utilizing Spark, Kafka, and h2O in this article. After that, the experimentation kit was utilized to build an isolation forest-based machine-learning model. The system was able to expedite its analysis by combining real-time and batch-time analysis, yielding promising results. We also looked at the efficacy of the isolation forest model. Our model's performance has been evaluated using four distinct metrics such as accuracy, recall, f1-score, and precision.

On top of that, we compare the outcomes of the presented study's work to the current fraud detection techniques. As an example [32] have employed the SVM, apriori algorithm, and SVMIG (i.e SVM with Information Gain) to handle transactional fraud detection. The outcomes give an accuracy of 0.94. Authors of [33] have applied six ML learners involving LR, XGBoost, DT, SVM, ET (Extra Tree), and the RF on the European cardholder database. These learners were integrated with AdaBoost to boost their performance of fraud classification. The experiments yield more than 98% of accuracy.

Along with that, [34] have suggested a hybrid model named AED-LGB (AE with probabilistic LGBM) to detect fraudulent transactions using real word transactional dataset. Experimental evaluation shown around 0.98 of accuracy. Also, [35] have utilized the Naïve Bayes Based classifier for transaction fraud detection on a credit card dataset. They have compared the proposed model with the state-of-the-art ML methods. The finding reveals that the NB beat the others with an accuracy of 0.97.

In line with the findings in the present article and the findings in current state-of-the-art systems for detecting fraud this study provides a high digital transaction fraud detection accuracy (0.99) using relevant big data analysis tools to speed up model analysis and training and also to detect suspects' transactions as soon as they arise. In contrast to the research published in [32], [33], [34], and [35].

#### VIII. CONCLUSION AND FUTURE WORK

Fraud screening is critical in digital transactions, and the most significant difficulty is the financial burden of fraud if it is investigated, detected, or prevented. As though transactions happen in real-time, there is a need for a method that takes no time and remains as effective as the scope and structure of the bank that handles it. In this study, we presented an end-to-end real-time architecture using behavioral analysis for digital transactions fraud detection centered on combining the isolation forest algorithm and current big data analytics technologies. This technique aims to regulate latency, speed, and reliability by employing batch processing to give complete and precise interpretations of batch sets alongside immediate stream analysis to provide observations of live data. In our scenario, the batch layer handles data preparation and model training providing effective outcomes on a real dataset. The F1-score and recall of our model is about 91% and 97% correspondingly.

We want to do more study in two areas in the further works. The first looks at the computing requirements of a real-time suspicion detection technology. The second goal is to investigate the use of increasingly sophisticated ML techniques and the combination of DL (deep learning) algorithms and relevant big data tools in fraud detection.

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# Prediction of Anti-inflammatory Activity of Bio Copper Nanoparticle using an Innovative Soft Computing Methodology

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**Abstract**—The objective of this work is to use a novel soft computing approach to predict the anti-inflammatory effect of bio copper nanoparticles. Using a modified technique, various doses of the *Musa sapientum* extract and copper nanoparticles were examined for their anti-inflammatory capabilities. Protein denaturation was evaluated, and an inhibition percentage was computed. The outcomes demonstrated that the quantity of copper nanoparticles raised the inhibition percentage, indicating a greater anti-inflammatory efficacy. In order to forecast the anti-inflammatory action based on the input variables of contact duration, operating temperature, and beginning concentration, an artificial neural network (ANN) was created. Using experimental data, the ANN model was developed, tested, and its performance assessed. The outcomes showed that the ANN model has a high degree of accuracy in predicting the anti-inflammatory action. In the context of summary, copper nanoparticles produced by *Musa sapientum* show considerable anti-inflammatory action. The ANN model and the suggested soft computing technique, which included the creation of copper nanoparticles, made an accurate prediction of the anti-inflammatory capabilities. This study aids in creating new methods for estimating the efficacy of bioactive nanoparticles in diverse therapeutic uses, such as the treatment of inflammation.

**Keywords**—Copper; nanoparticles; green synthesis; prediction; artificial neural network

## I. INTRODUCTION

Humans regularly come into contact with natural goods through the foods they eat and the herbal supplements they take. It is challenging to easily determine bioactive natural compounds in complex combinations like plant extracts, which contributes to the slow rate of their discovery [1]. The body's natural protection against damage, infection, or stimulation is fundamentally the inflammation responses, which support tissue homeostasis in hostile settings [2]. Acute and chronic inflammation, are the two main categories used to

classify inflammation. An Acute inflammation is a type of innate immune response, but chronic inflammation lasts a extended time and leads to numerous debilitating chronic illnesses, including cancer, autoimmune conditions, cardiovascular disease, also neurological diseases. Thus according to statistics, chronic inflammatory illnesses cause three out of every five deaths worldwide [3]. The production and release of chemical mediators by the cells in the sick, damaged, or injured tissue serve as the catalyst for the inflammatory response. White blood cells also called leukocytes are used at the site of inflammation as just a consequence of additional signals produced by inflamed tissues. Any infectious or toxic agent is destroyed by leukocytes, which also remove cellular waste from injured tissue. This inflammatory response typically promotes the healing process. An unchecked inflammatory reaction, however, could be harmful [4].

One aspect of the body's immunological reaction is inflammation. An inflammatory response is responsible for infections, healing wounds, and any tissue injury. Inflammation is the outcome of numerous defensive system feedbacks in reaction to physical harm or illness. Acute inflammation develops quickly and becomes serious in a short period of while. Its symptoms linger for just a few times although, in some cases, they might persist for several weeks. Acute inflammation is frequently accompanied by swelling, redness, discomfort, immobility, and heat. Acute bronchitis, abrasions or cuts on the skin, sore throat from the flu or even cold, afflicted ingrown toenails, acute appendicitis, dermatitis, tonsillitis, sinusitis, high-intensity workout, infectious meningitis, and physical trauma are a few circumstances and diseases that can result in acute inflammation. Chronic inflammation seems to be a continuous state of tissue injury, active inflammation, and repair that lasts for a long time (months and or years). The harshness and consequences of chronic inflammation characteristically depend on the cause of

damage and then how well the body is able to repair and manage the damage. Common signs of chronic inflammation include body aches, fevers, rashes, weight increase or loss, weariness, joint discomfort, and mouth sores. Certain diseases, including diabetes, cancer, cardiovascular conditions, (COPD), rheumatoid arthritis, hepatitis, allergies, Tuberculosis, periodontitis, asthma, and also chronic peptic ulcer, might progress as a result of chronic inflammation [5]. Inflammation was therefore initially described by a collection of clinical symptoms rather than by a particular mechanism. Human disorders that exhibit the five traditional inflammatory symptoms of redness, pain, swelling, heat, and consequent decrease of organ function are caused by inflammation established in Fig. 1 [6].

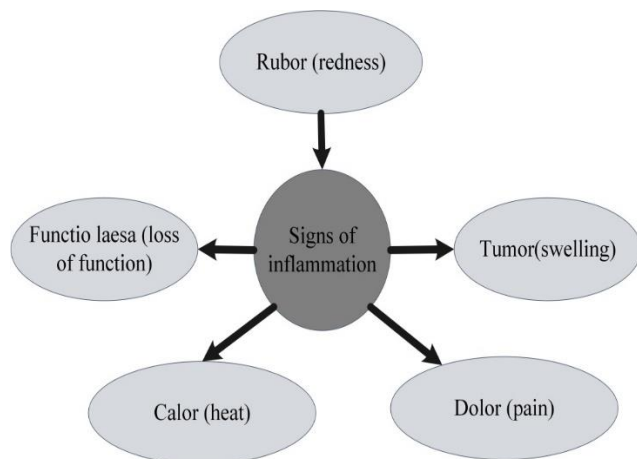


Fig. 1. Signs of inflammation.

Employing nanotechnology in the area of drug administration is a cutting-edge method to deliver medications on the Nano scale to particular organs in a regulated manner to enhance their therapeutic efficacy and minimize negative effects [7]. Among the most active fields of research right now in the fields of materials science, biomedicine, and healthcare is nanotechnology [8]. Metallic nanoparticles seem to be versatile and have stayed utilized in a wide range of industries, therapeutic, as well as medical application, such as wastewater treatment, drug delivery, cancer treatment, and DNA investigation, as well as for antibacterial agents, biosensors, and solar energy generation. It has been claimed that an economical and environmentally responsible alternative to both physical and chemical processes is the green production of metallic nanoparticles. Due to potential uses in business and medicine, copper nanoparticles (CuNPs) have caught the interest of researchers recently. The most efficient method has been determined to involve the biosynthesis of metal oxide nanomaterial's using various plant extracts, including such leaves, stems, cores, and flowers. Numerous phytochemicals found in plant extracts function as stabilizers and retarders of metal oxide nanoparticles. Additionally, the creation of nanoparticles utilizing phytochemical substances is safe for the environment, cheap, straightforward, and may be done at ambient temperature [9]. Additionally, it will aid in reducing the effects of environmental harm brought on by artificial techniques and materials [10].

Nano emulsion, nanoparticles, liposomes, niosomes, and other Nano carriers all have been designed to hold various medications and are meant to deliver them to particular tissues [11]. One of the Nano carriers that facilitate targeting, the delivery, and the controlled release of medications is thought to be niosomes. Niosomes also play an important role in the delivery of naturally occurring medicinal compounds, improving both their physical stability and effectiveness. They are mostly self-assembled bilayer vesicles made of non-ionic surfactants and cholesterol. It has the advantage of encasing and delivering medications that are both hydrophilic as well as hydrophobic. It might be administered via a number of delivery methods, such as parenteral, topical, and oral [12]. Metallic nanoparticles are multifunctional and are utilized in a widespread range of applications in science and medicine, involving cancer treatment, drug distribution, wastewater remediation, and DNA analysis. Metallic nanoparticles have newly generated a lot of attention due to their distinctive physical as well as chemical characteristics. Alternatives to chemical and physical processes that are both affordable and environmentally benign include the synthesis and depiction of metallic nanoparticles. Copper Nanoparticles (CuNPs) have received a lot of interest recently from researchers due to their numerous uses in medicine, industries, and other sectors [13].

Due to the existence of numerous bioactive chemicals in plants, numerous plant parts or entire plants have been employed for the green production of Cu NPs. Plant extracts were being used successfully for this purpose [4]. Cu Nanoparticles have successfully synthesized utilizing extracts from a variability of plant species, including *Musa sapientum* stem extract. Bananas (Genus *Musa*) have indeed been cultivated for a very long period [5]. Pharmacological research demonstrates the nutritional as well as traditional medicinal benefits of all banana parts. Numerous animal model studies, vitro experiments, and clinical studies also support the utilization of various banana portions in the treatment of a variety of illnesses, including cancer, ulcers, diabetes, hypertension, and diarrhoea [14].

The methods utilized to create them and characterize them are constantly being refined. As nanoparticles to be used in a variety of industries, controlling over their shape and size is crucial. Furthermore, because of their large surface energy, these nanomaterials are very unbalanced and aggregate to form raw material. As a result, several stabilizing agents such as surfactants, block copolymers, dendrimers, and microgels are used to stabilize metallic nanoparticles. The hybridization microgels, which include metallic nanoparticles, combine the characteristics of nanomaterials with polymeric microgels. Metallic nanoparticle-loaded hybrid microgels offer application promise in optics, biomedicine, photonics, electronics, and catalysis. Dynamic light scattering (DLS), Scanning electron microscopy, Transmission electron microscopy (TEM), atomic force microscopy, X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and ultraviolet visible spectroscopy (UV/Vis) are used to identify hybridized microgels. Since every approach is intended to collect a particular type of data that can't be gained using the other, it is difficult to evaluate one approach to

another because each has its own merits and drawbacks. Among some of the techniques described above, UV/Vis spectroscopy is just one approach that may be utilized to examine the dynamics of bulge as well as deswelling of polymeric microgels as well as hybrid microgels with tiny size of particles. Assessment of hybridized microgels loaded with Plasmonic nanoparticles and research into their usage often includes the use of UV/VIS spectroscopy. According to reports, it is a useful instrument for analyzing and adjusting the optical characteristics of Plasmonic nanoparticles put into polymeric microgels. UV/Vis spectroscopic is another method that may be used to study the catalytic performance of nanomaterials [15].

A quick analytic method for determining light's absorption or transmission is UV-visible spectroscopic. The majority of spectrometers have a functional range of wavelength among 200nm and 1100nm, despite the fact that the visual portion extends up to 800 nm and the UV frequency varies from 100nm to 380nm. Due to the vacuous nature of UV-vis lighting in the spectral area from 100 nm to 200 nm, which is regarded as infrared light exceeding 800 nm, it is of little practical value. The capacity of a substance to gather and emit photons determines its colour, and the human visual system is capable of distinguishing between up to 10 million distinct colours. Transmission is the process by which light travels via medium, reflecting off both transparency and impenetrable surfaces, and is bent by crystalline [16].

The more popular method for tackling this kind of issue is the artificial neural network, essentially mimics the human brain when addressing a problem. As a result, scientists are endeavouring to create an adaptive framework, such as an artificial neural network, to forecast the temperature depended on the results of many elements. Artificial intelligence (AI) is used in artificial neural networks (ANNs). An arithmetic model called an ANN is enthused by the structure and or functionality of neural networks in biology. A neural network utilizes a connectionist style of calculation to interpret the data and consists of a connected group of artificial neurons. Generally speaking, an Artificial Neural Network is a outstanding performance that changes its structure in requital to information passing and through the network even during the learning experience, whether that information is either internal or external. Modern tools for modelling non-linear numerical data comprise neural networks. They are characteristically applied to recognize patterns in data and otherwise model complex associations between inputs and outcomes. ANN has been effectively utilized in a wide range of applications. An artificial neural network (ANN) is a computational system that takes its cues from the biological neural networks that perform actions in the human brain. Neural networks have the ability to "learn" and correlate huge datasets gleaned from simulations or experimentation. The developed neural network is used as an evaluation method to make accurate predictions about the outcomes. They can produce excellent prediction accuracy ratings thanks to effective approaches for both validation and training [17]. The proposed work focuses on the comparison between the experimental and numerical data indicates a close agreement, with the numerical values closely matching the experimental

values. This suggests that the soft computing methodology, specifically the Artificial Neural Networks (ANNs) used in this study, effectively predicts the anti-inflammatory activity of CuNPs. The alignment between the experimental and numerical results validates the reliability and accuracy of the soft computing approach in predicting bioactive properties, contributing to its relevance in drug discovery.

The primary contributions using required establishing the study are as follows:

- The extract is made from *Musa Sapientum* powder.
- Using the extract, it was previously created, Cu nanoparticles are created.
- Cu nanoparticles were characterised using UV-visible spectroscopy in step three.
- Anti-inflammatory is discovered through calculation of inhibition.
- The effectiveness of the suggested methodology is proven by validating its function and evaluating it against alternative approaches.

This report's remaining sections are organized as follows: Section II presents the relevant works and provides a comprehensive analysis of them. Information on the problem statement is included in Section III. In Section IV, the proposed soft computing Artificial Neural Network topologies are thoroughly examined. The results of the experiment are given, examined, and thoroughly analysed in Section V, along with comparisons to current best practises. Discussion is given in Section VI. The conclusion of the paper is found in Section VII.

## II. RELATED WORKS

Metabolomics evaluation of the chosen sponge would be followed by molecular docking research to discover and expect the subordinate metabolites that capacity contributes to its capacity of constraining cancer. This investigation will look at the anti-inflammatory as well as anti-cancer possibility of the Red Sea sponges having own mass and silver nanostructure. Silver nanoparticles made from the Red Sea sponge *Phyllospongia lamellosa* are extracted using chloroform (CE) and ethyl acetate (EE). UV-visible spectrophotometric, Transmission electron microscopy, and Fourier-transform infrared spectroscopy (FTIR) studies were used to evaluate the produced silver nanoparticles. Cells from the MCF-7, MDB-231, and MCF-10A tumour types were used to test the compounds' anti-cancer properties. COX-1 and COX-2 anti-inflammatory activity was evaluated. Molecular docking as well as metabolomics examines constructed on liquid chromatography-mass spectrometry (LC-MS) also were employed. To determine whether such a formulation is applicable as an anti-cancer therapeutic agent in the study, further separation and decontamination of the active ingredients from the sample crude extract of the sponge are required, and in vivo tests are needed in the study [18].

The research used a dependable and ecologically friendly method to create silver nanoparticles from leaf extract of *Brachychiton populneus* (BP-AgNPs) in an aqueous solution.

FTIR, energy dispersive X-ray analysis, scanning electron microscopy, and UV-Vis spectroscopy were utilized to analyse the silver nanoparticles generated from the *Brachychiton populneus* (EDX). Ag Nanoparticles' antioxidant, ant diabetic, anti-inflammatory, and cytotoxic properties were also revealed. By using a UV-Visible spectrum, the creation of BP-Ag Nanoparticles was confirmed at 453 nm. According to the FTIR study, functional groups including such as nitro, alkane, phenol, alkene, alcohol, fluoro, and flavones that are contained in plant extract are responsible for the stability, synthesis, and capping of Ag Nanoparticles. Nanoparticles with a cubical shape were evenly dispersed, according to the SEM examination. Ag Nanoparticles had an average diameter of 12 nm, as determined from SEM images using ImageJ software. Silver at 3 keV and also additional trace elements including oxygen and also chlorine were confirmed by the EDX spectrum. In compared to conventional pharmaceuticals, the biologically synthesized silver nanoparticles showed demonstrated ant diabetic (alpha amylase assay), antioxidant (DPPH assay), cytotoxic (MTT assay) and anti-inflammatory (albumin denaturation assay), properties against U87 and HEK293 cell lines. BP-AgNPs have shown inhibition in these assays in a concentration reliant on way and had minor IC50 values than standards. These findings all point to the potential biological benefits of silver nanoparticles. The key characteristics of silver nanoparticles biologically synthesized suggest potential uses for them in the biomedical field. Additionally, the production of silver nanoparticles by plant-mediated processes uses less energy, is advantageous to living things, generates little waste, and is environmentally friendly [19].

In order to encapsulate diosmin as well as address its physicochemical problems, nanostructured lipid carriers (NLCs) suitable for ocular deliver optimized were optimised using the response surface methodology (RSM). A straightforward and scalable process was used to create NLCs: melt emulsification, accompanied by ultra-sonication. Four different independent variables comprised the research designs (liquid lipid concentration, surfactant concentration, solid lipid concentration, and kind of solid lipid). By using a variance analysis of variance, the factors' impact on the NLC size and PDI (responses) was evaluated (ANOVA). The desirability function was used to choose the optimal formulation (0.993). Diosmin was incorporated into NLCs at two distinct concentrations (80 as well as 160 M). A physical and chemical and technical investigation of drug-loaded nanocarriers (D-NLCs) revealed mean particle sizes of 83.5 nm as well as 82.21 nm for formulations made with diosmin at concentrations of 80.0 mM otherwise 160 mM, respectively, and a net negative surface charge of 18.5 nm and 18.0 nm, respectively, for the two batches. The constructions were examined for viscosity, pH (6.5), and osmolarity adjustments to make them more ocular environment friendly. Stability experiments were subsequently conducted to evaluate D-NLC behaviour beneath various storing circumstances for up to 60 days, revealing that NLC samples are well-stabilized at room temperature. NLCs are cytocompatible with retinal epithelium, according to in-vitro research on ARPE-19 cells. D-NLCs were also tested in-vitro for their impact on a framework of retinal inflammation, confirming their cytoprotective

properties at different doses. It was discovered that RSM is a trustworthy model for enhancing NLCs for diosmin encapsulation. Additional research is being conducted to evaluate and verify the anti-inflammatory efficacy of D-NLCs in order to achieve this goal. Furthermore, the antioxidant activity of loaded NLCs is not assessed because the improved manufacture of reactive oxygen species (ROS) represents a different feature of ocular degenerative disorders [20].

The Se Nanoparticles were examined for physicochemical characteristics and also anti-inflammatory activity in vivo in the research. *Kluyveromyces lactis* GG799 (*K. lactis* GG799) was used to synthesize SeNPs in a sustainable and environmentally, effective, and inexpensive manner. Sodium selenite was successfully converted by *K. lactis* GG799 producing bright red Se Nanoparticles with particle diameters between 80 as well as 150 nm, and the nanoparticles were collected inside the cells. Following isolation, component findings indicate that the SeNPs were primarily capped by protein and polysaccharides. By reducing oxidative stress as well as intestinal inflammation, dietetic supplementation containing 0.6 mg kg<sup>-1</sup> Selenium (in the procedure of biogenic SeNPs) significantly reduced dextran sulphate sodium (Would seem ulcerative colitis. These results indicated that Se Nanoparticles produced by *K. lactis* GG799 might represent a auspicious and secure Selenium supplement again for the management of IBD. However, to improve preventive and therapeutic properties and lessen the negative consequences, high bioactivity nanoparticles and low toxicity, are still required [21].

The extracts as of several edible portions of *Parkia Timoriana* exhibited considerable 2, 2 diphenyl 1 picrylhydrazyl (DPPH), 2,2' azino bis (3 ethylbenzothiazoline 6 sulfonic acid (ABTS), as well as Phosphomolybdate rummaging action in line with high antioxidant aptitudes. *P. timoriana* extract significantly decreased the growth of *Escherichia coli*, *Bacillus subtilis*, *Bacillus pumilus*, as well as *Pseudomonas aeruginosa*. The functional groups, as well as bioactive chemicals found in the various edible sections of the plant were identified by analysis of the extracts utilizing gas chromatography mass-mass spectrometry (GC-MS) and then Fourier transform infrared spectroscopy. Phenols, alkenes, carboxylic acids, glycogen, aliphatic amines, alkyl halides, primary amines, secondary amines, ether, esters, lipids, aromatics, halogen, nitro compounds, triglycerides, with anti-cancer, antimicrobial, as well as anti-inflammatory characteristics, among other substances, showed characteristic peaks. Additionally, 49 bioactive chemicals that are recognized to have a range of pharmacological actions were found by the GC-MS study. The found bioactive compounds were then subjected to and in silico molecular docking investigations, which suggested potential anti-inflammatory as well as anticancer activities. This is, as far as we are aware, the first publication on the bioactive components of *P. timoriana* extracts that have significant pharmacological, antibacterial, and antioxidant belongings. The research may result in the growth of new herbal treatments for a variety of disorders using *P. timoriana*, as well as maybe new drugs. Formulations are not examined, despite the fact that their

bioactivity as well as clinical studies are essential for the creation of novel medications [22].

Many substances, including phenolic compounds, flavones, flavanones, triterpenoid acids, chalcones, sugars, and fatty acids, amongst many others, have really been extracted from the *Eysenhardtia platycarpa* plant. In the study, computational screening for anti-inflammatory action was conducted using Molinspiration® as well as PASS Online on natural flavanone 1 (retrieved from *Eysenhardtia platycarpa*) as the main chemical as well as flavanones 1a–1d by way of its structural counterparts. Utilizing two investigational designs, a rat ear edoema caused by arachidonic acid and even a mouse ear lobe edoema caused by 12-O-tetradecanoylphorbol acetate, the hydroalcoholic solutions of flavanones 1, 1a-1d (FS1, FS1a-FS1d) also were assayed to evaluate their *in vivo* anti-inflammatory cutaneous impact. TNF-, IL-1, and IL-6 pro-inflammatory cytokines too were analyzed histologically in rat ear tissue that had been irritated by AA. The outcomes demonstrated that edoema inhibition was brought about by the solutions of flavanone hydro alcoholic in both tested mice. According to this study, the evaluated flavanones would be useful in the treatment of inflammatory skin disorders in the coming [23].

Antiviral and anti-inflammatory drugs may therefore be essential in the treatment of COVID-19 patients. *Pimenta dioica* leaves contains ethyl acetate extract, four bioactive substances were extracted and recognized using spectroscopic data: gallic acid 3, ferulic acid 1, rutin 2, as well as chlorogenic acid 4. Additionally, as a possible mechanism of action, molecular docking but also dynamics calculations for the separated and revealed compounds (1-4) in contradiction of SARS-CoV-2 major protease (Mpro) were carried out. Additionally, the half-maximal cytotoxicity (CC50) and SARSCoV-2 inhibitory doses of each substance were evaluated (IC50). The consequences of cure with *P. dioica* aqueous extract, gallic acid 3, ferulic acid 1, rutin 2, and chlorogenic acid 4 were observed by measurement of TNF-, IL-1, G-CSF, IL-2, IL-10, and gene function of miRNA 21-3P as well as miRNA-155 stages to evaluate the anti-inflammatory impacts crucial for COVID-19 affected ones. Likewise, lung toxic effects were stimulated in rats by mercuric chloride. Promising anti-SARS-CoV-2 properties were demonstrated by gallic acid 3, rutin 2, and chlorogenic acid 4, with IC50 ideals of 31 g/mL, 108 g/mL, and then 360 g/mL, correspondingly. Additionally, ferulic acid 1 as well as rutin 2 conducts was found to have stronger anti-inflammatory impacts. The outcomes could be encouraging for further preclinical and also clinical research, particularly on rutin 2 individually or in conjunction with the other separates for the treatment of COVID-19. These substances have not been studied separately or in conjunction with other organic or synthetic items as natural products [24].

The primary protein found in quinoa seeds, chenopodin, is described in this research for the first time in terms of its possible immunomodulatory properties. The study was capable of distinguishing two distinct types of chenopodin, denoted as LcC (Lower charge Chenopodin, and 30% of entire chenopodin) and HcC (Higher charge Chenopodin, and 70% of entire chenopodin), following analyze the molecular

characteristics of the pure protein. By assessing NF-B activity and IL-8 appearance investigations in undistinguishable Caco-2 cells, the biological functions of LcC and HcC were examined. IL-1 was used to induce inflammatory. According to the findings, LcC and HcC may have anti-inflammatory properties in an intestine typical system, and their actions may vary based on their physical structure. Additionally, *in silico* analysis and structurally estimations were used to look into the molecular action mechanisms and the structural or functional connections of the protein responsible for the identified bioactive components. This approach is ineffective because it does not usually preserve the relationship between transcript and protein levels. In fact, even a little change in transcriptional rates might have a significant impact on how much protein is produced [25].

To create extraction with a high concentration of polyphenols, two tomato pomace (TP) feedstocks were investigated. Biomass security is compromised by TPs rapid disintegration, therefore occurs naturally microflora was examined for preservation, and after 60 days of the treatment, own lactic bacterium predominated. Chemical characteristics of the extraction of TPs and TPs fermentation (TPF) and tests for anti-inflammatory and antioxidant activity were performed. A most bioactive polyphenol component, aglycone-polyphenols (A-PP), was used to categories phenolic and flavonoids acids. The quantity of A-PP was reduced by fermenting; however, the composition remained mostly same. Regardless of the decrease in A-PP, the existence of fermented metabolites with aromatic substitutes boosted antioxidant capacity. All TP and TPF possess anti-inflammatory qualities, which are solely reliant on the A-PP concentration. The Partial Least Square (PLS) method revealed greatest active compounds as kaempferol, naringenin chalcone, cinnamic acid as well as gallic acid along with description of the effective dosage, and fermenting kept the anti-inflammatory action. This attribute will recommend the use of the extraction for additional use as supplemental components or additional components in the nutraceutical, cosmetic, and bioactive compounds sectors, along with the good security aspect of the fermenting biomass. This method is ineffective since, in certain circumstances, high-dose antioxidant supplementation may be associated with health concern [26].

### III. PROBLEM STATEMENT

The complexity of extracts, isolation of phytoconstituents with the highest levels of purity, and the poorest yield of active phytoconstituents from plants are all barriers to the detection and growth of drugs from natural sources. Despite the difficulties in developing drugs from phytoconstituents, plants make attractive targets for the search for fresh anti-inflammatory leads. The main difficulties in developing new drugs are finding novel compounds with appropriate activity and pharmacokinetic characteristics. More chiral centres, steric complexity, more oxygen atoms, molecular stiffness, and more hydrogen bond donors as well as acceptors are only a few of the distinctive characteristics of the phytoconstituents. The investigation focuses on *Musa sapientum*'s anti-inflammatory properties in copper nanoparticles with Artificial Neural Network. Numerous studies have found that using *Musa sapientum*, particularly the



peels because of their potent anti-inflammatory and antibacterial properties, produces the best outcomes but here a soft computing approach like Artificial Neural Network is utilizing for predicting anti-inflammatory activity [27].

#### IV. MATERIALS AND APPROACHES

##### A. Extract Preparation

The powder of *Musa sapientum* was weighed and measured to be 1g. Following the measurement of the powdered sample, 100ml of distilled water was added to the sample and the mixture then was then boiled for about 5 to 10 minutes at a temperature of 60–80 degrees Celsius. After cooling down, filtration was performed. Filter paper, a funnel, and a measuring cylinder were used to filter the mixture's contents. The resultant filtrate was viscous.

##### B. Synthesis of *Musa Sapientum* Mediated Cu Nanoparticles

CuSO<sub>4</sub> in the amount of 0.01 mg was approximately weighed, and dissolved in 8 ml of distilled water, and then combined with the filtered extract. To produce green synthesis, the extract is retained in the shaker and allowed to sit in the stirrer for a period of one hour. An ultraviolet (UV) spectrometer was used to periodically check on the conversion of CuSO<sub>4</sub> to Cu Nanoparticles.

##### C. UV-Visible Spectra Examination

UV-Visible spectroscopy was utilised to track the Cu Nanoparticles' signature. For the characterization of colloidal particles, this is a useful force. Metal particles display substantial surface plasmon resonance (SPR) absorption in the visible range and are extremely sensitive to surface change, making them excellent candidates for research with UV-Visible spectroscopy. Surface Plasmon Resonance property confirmed the existence of Cu Nanoparticles.

##### D. Anti-Inflammatory Activity

The following procedure, which was modified somewhat from Muzushima and Kabayashi's original suggestion, was utilized to test the anti-inflammatory possessions of *musa sapientum*. In order to adjust the pH level of the mixture to 6.3, a small amount of 1N hydrochloric acid was used in combination with 0.45 mL of bovine serum albumin (1% aqueous solution) and also 0.05 mL of *musa sapientum* extract of differed fixation (10µL, 20µL, 30µL, 40µL, and 50µL). These samples underwent a 20-minute period of room temperature incubation followed by a 30-minute period of heating at 55 °C of temperature in a water bath. After cooling the prepared samples and the absorbance at 660 nm was calculated spectrophotometrically. The benchmark was Diclofenac sodium. As a control, Dimethyl Sulfoxide (DMSO) is used. The following Eq. (1) was used to calculate the percentage of protein denaturation.

$$\text{Inhibition \%} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100 \quad (1)$$

##### E. Soft Computing Approach

Soft computing approaches, such as Artificial Neural Networks (ANNs), offer distinct advantages and relevance compared to existing methods in various fields, including drug

discovery and prediction of bioactive properties. Unlike traditional computational techniques that rely on explicit mathematical models and assumptions. One key advantage of soft computing approaches is their ability to learn from data and adapt to changing conditions. ANNs, for example, can be trained using large datasets to capture intricate patterns and correlations, enabling them to make accurate predictions and classifications. This adaptability makes soft computing approaches well-suited for handling diverse and dynamic datasets, especially when dealing with complex molecular structures and interactions in drug discovery. Soft computing approaches can effectively handle incomplete or noisy data, which is common in biological and chemical systems. By employing robust algorithms and learning mechanisms, ANNs can tolerate missing or uncertain data points, providing reliable predictions even in the presence of such imperfections. This flexibility allows researchers to work with real-world datasets that may be incomplete or contain measurement errors, enhancing the applicability and reliability of the predictions. The relevance of soft computing approaches lies in their ability to handle complexity, adaptability to dynamic datasets, robustness to noise and incomplete data, and capability to model nonlinear relationships. These characteristics make them powerful tools in the prediction and analysis of bioactive properties, facilitating the discovery of potential drug candidates and enhancing our understanding of complex biological systems.

##### F. Artificial Neural Network

A variety of applications have successfully used ANN is established in Fig. 2. A computing system called an artificial neural network (ANN) is stimulated by the biological neural networks in the human brain that carry out specific tasks. Huge datasets gathered from simulations or experiments can be "learned" by neural networks, which can also correlate these datasets. Using the created neural network as an evaluation tool, precise outcome predictions are made. Thanks to their efficient validation and training methods, they may generate great prediction accuracy ratings.

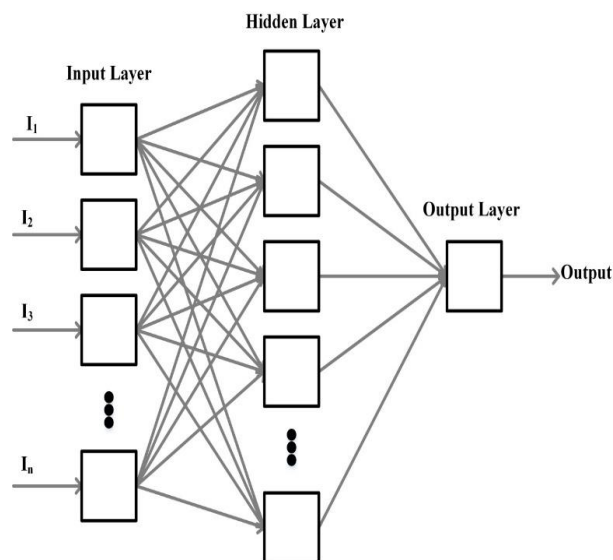


Fig. 2. Proposed artificial neural network.

1) *Data pre-processing*: The experimental results were modelled using a feed-forward back propagation training approach in an effort to forecast the effectiveness of Cu Nanoparticles on anti-inflammatory utilizing Artificial Neural Network. One S variable at a time formed the foundation of the experimentation in this study. This was accomplished by varying just one input factor while holding the other two variables constant. Experimental cases were created in the work using the outcomes of experiments. The testing and training sets of the dataset were split randomly. The remaining data were used for testing, and the rest for training. Eq. (2) was used to normalize the training and testing datasets in order to reduce error.

$$A_i = \frac{y_i - y_{\min}}{y_{\max} - y_{\min}} \times (s_{\max} - s_{\min}) + s_{\min} \quad (2)$$

The variable  $y_i$  stands in for the input or output in (2).  $y_{\min}$  and  $y_{\max}$  are the extreme values of  $y_i$ , while  $A_i$  is the normalised value of  $y_i$ . The range limits to which our  $y_i$  is scaled are  $s_{\min}$  and  $s_{\max}$ . The input and also output data in this study were normalised among 0 and 1. After modelling, results were restored to their original value. A three-layer Artificial Neural Network was used to simulate the experimental dataset.

2) *Creation of an artificial neural network model*: The usage of ANN [28] as a modelling tool is very common to approximate complicated systems that cannot be modelled using traditional modelling techniques. They are typically employed in classification, pattern recognition, as well as function approximation. To choose the artificial neural

network (ANN) and training procedure for a specific task, no precise formula has been discovered. Trial and error is used to determine the framework and method to apply while tackling a certain problem. However, this choice could begin with a modest network construction before moving on to a complicated one up until a satisfactory solution is found with a permissible smallest fault. There are numerous network designs used in ANN modelling. The fundamental design that uses a back propagation training technique to train input data is the feed-forward neural network. The framework may vary depending on the counting of layers in the architecture, the number of neurons in every layer, and then the allocation functions at the layer of input as well as output.

A three-layer ANN was used in the study, with the input layer (autonomous variable) including 3 neurons that is contact time, operating temperature, as well as initial concentration, a hidden layer containing 17 neurons, as well as an output layer (dependent variable) comprising 1 neuron. The output and hidden layers of the neural network were activated using both linear as well as non-linear activation functions according to the network structure. There were created experimental data instances. The training sub-dataset of 70% and then testing sub-dataset (30%) of the dataset were randomly separated. The efficiency of the constructed ANN models was evaluated. The powdered *Musa Sapientum* is used to create the extract. Cu nanoparticles are produced using the extract that we previously made. In step three, Cu materials were studied utilizing UV-visible spectroscopy. Calculating inhibition leads to the identification of anti-inflammatory. By confirming the function of the proposed methodology is demonstrated in Fig. 3.

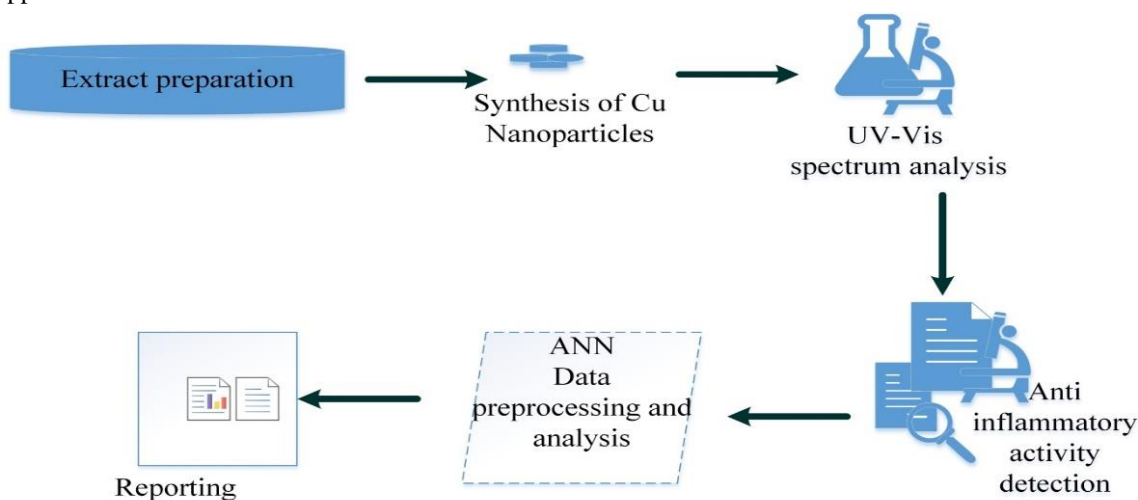


Fig. 3. Proposed ANN model for predicting anti-inflammatory activity.

## V. RESULTS

The purpose of the research was to determine whether *Musa Sapientum* and the copper nanoparticles that it was mediated by had anti-inflammatory properties. It made use of descriptive statistics. It has been determined that the inhibition percentage was reported to be 43.4% in 10  $\mu\text{L}$  concentration, 47.6% in 20  $\mu\text{L}$  concentration, 83.5% in 30  $\mu\text{L}$ , 85.5% in 40

$\mu\text{L}$ , and 85.9% in 50  $\mu\text{L}$  concentration. These results in a good anti-inflammatory activity were found from 10  $\mu\text{L}$  concentration to 50  $\mu\text{L}$  concentration in Table I and Fig. 4.

The standard value of the concentration at 10  $\mu\text{L}$  is 50.8%, 20  $\mu\text{L}$  is 57.8%, 30  $\mu\text{L}$  is 67.6%, 40  $\mu\text{L}$  is 77.9%, and 50  $\mu\text{L}$  is 89.6%; these values likewise gradually rise with concentration. The standard value of the concentrations is

compared with the Cu Nano particles inhibition % is tabularized in Table II and explained in Fig. 5.

TABLE I. INHIBITION PERCENTAGE FOR ANTI-INFLAMMATORY ACTIVITY

Concentration (μL)	Inhibition (%)
10	43.4
20	47.6
30	83.5
40	85.5
50	85.9

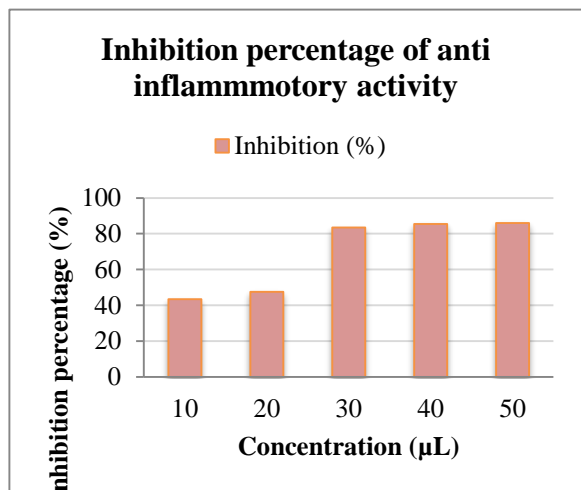


Fig. 4. Inhibition percentage for anti-inflammatory activity.

TABLE II. COMPARISON BETWEEN STANDARD AND CU NANOPARTICLE

Concentration (μL)	Inhibition (%)	
	standard	Cu Nanoparticles
10	50.9	43.4
20	57.9	47.6
30	67.7	83.5
40	78.0	85.5
50	89.7	85.9

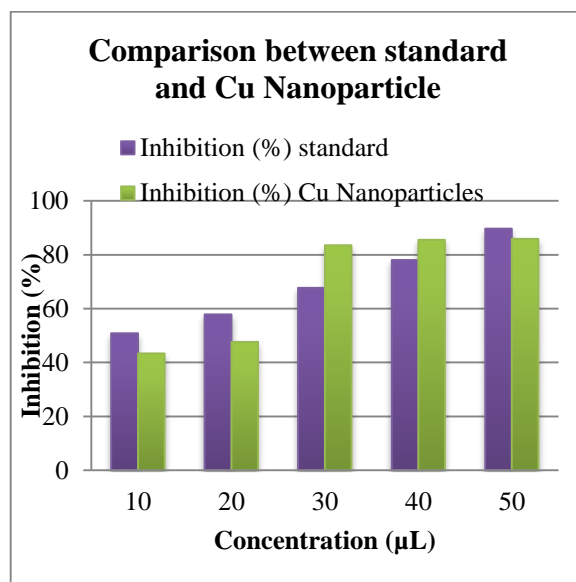


Fig. 5. Comparison between standard and Cu Nanoparticle.

TABLE III. EXPERIMENTAL AND NUMERICAL DATA ANALYSIS WITH EXISTING EXPERIMENTS

Concentration (μL)	Incineration	
	Experimental Data (CuNPs)	Numerical Data
10	43.5	44.6
20	47.5	47.1
30	83.6	85.5
40	85.4	87.9
50	85.8	88.4

Table III presents the experimental and numerical data analysis for different concentrations of Cu nanoparticles (CuNPs). The table shows the inhibition percentage of CuNPs obtained through experimental incineration and numerical calculations. The comparison between the experimental and numerical data indicates a close agreement, with the numerical values closely matching the experimental values. This suggests that the soft computing methodology, specifically the Artificial Neural Networks (ANNs) used in this study, effectively predicts the anti-inflammatory activity of CuNPs. The alignment between the experimental and numerical results validates the reliability and accuracy of the soft computing approach in predicting bioactive properties, contributing to its relevance in drug discovery [29].

#### A. Detection of the Ideal Number of Hidden Neurons

The neural network technology's key parameter is the number of hidden neurons. Essentially, this is helpful in figuring out the ideal brain architecture. Using a trial-and-error methodology, 1 to 20 neurons were utilised in hidden layer to optimize the network structure. The effectiveness of every chosen number of neurons is detailed.

#### B. Performance Evaluation

The structure model's accuracy is a measure of how accurately it operates. Typically, it is determined by the ratio of successfully predicted measurements to all observable data. Accuracy is stated in Eq. (3).

$$Accuracy(\%) = \frac{T_{positive} + T_{negative}}{(T_{positive} + F_{positive} + F_{negative} + T_{negative})} \times 100 \quad (3)$$

Nevertheless, the inhibition process approaches equilibrium for inhibition% of 50 μL with 85.9%. 50 μL was deemed to be the ideal concentration has 96.34% accuracy for process in the Table with a high priority for inhibition %. The correlation between the experiment's results and the projected ANN accuracy results is shown in Fig. 6 and Table IV.

TABLE IV. ACCURACY OF PROPOSED ANN

Concentration (μL)	Inhibition (%)	Accuracy (%)
10	43.4	64.76
20	47.6	65.88
30	83.5	77.61
40	85.5	77.58
50	85.9	96.34

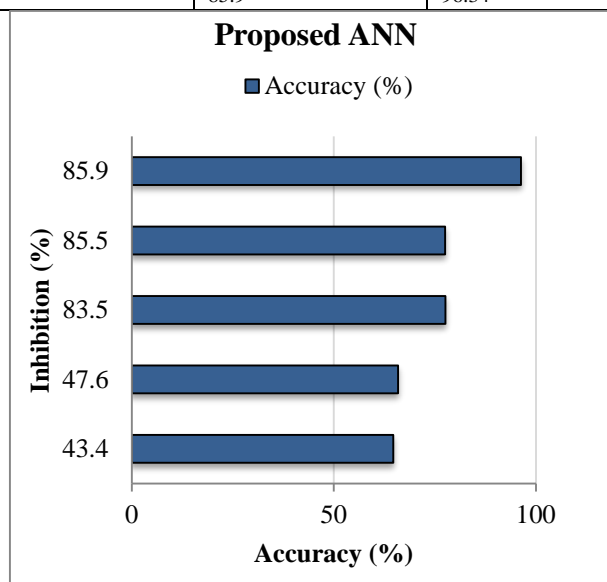


Fig. 6. Accuracy of proposed ANN.

## VI. DISCUSSION

Banana peel is a significant by-product of numerous small-scale and large-scale hospitality industries and functions as a sophisticated biological matter. Chemically, it is composed of simple cellulose, sugars, lignin, and hemicelluloses. It can serve as a suitable substrate for microbial operations to achieve products with value added because of its availability and worth. Numerous initiatives have been attempted to create protein-enriched animal feed, citric acid, industrial enzymes, and other commercially viable goods. It has been demonstrated that plantain bananas have anti-inflammatory and ulcer-healing properties. The medication made from plantain sources that helps ulcers heal may also have an impact on how wounds mend. For instance, plantain blossoms have been used to heal ulcers and diarrhoea, and extracts from the plant have antihyperglycemic properties. The peel has antibacterial, antifungal, and anti-denaturation effects. Banana leaf methanolic extract was claimed to have anti-inflammatory

and antibacterial properties in earlier research. The hemagglutininations as well as hydrogen peroxide-induced hemolysis of human red blood cells were inhibited by the banana extract. The anti-inflammatory properties of *Musa sapientum* and their connection to copper-mediated nanoparticles are shown in a bar graph. It is clear that copper-mediated nanoparticles have good anti-inflammatory effect because the virtually maximum percentage of inhibition (86%) was seen and 83.5% of that inhibition was detected in copper nanoparticles. Yet, with an inhibition percentage of 50 μL with 85.9%, the inhibition process gets closer to equilibrium. 50 μL was determined to have a 96.34% accuracy rate for the process and a vital element for inhibition percentage.

## VII. CONCLUSION

Cu Nanoparticles synthesised by *Musa sapientum* has significant biological processes, and the recognized biological technique is chosen over alternative ways because it is less harmful to the environment and calls for fewer downstream processing steps. Plant-based bio-resources are used in this cutting-edge, environmentally friendly approach as stabilizing and reducing agents. UV-Visual study indicates that Cu-NPs had formed. According to this study's findings, *Musa sapientum* has stronger anti-inflammatory effects when copper nanoparticles are included. This information can be used for further research into using them as reduced bio toxic substitutes for currently available chemically synthesized biomaterials. Numerous designed nanoparticles have been prepared and evaluated and finished the clinical studies in light of this. The healthy cells throughout the body are left behind as this infiltrate the unhealthy cells. As kind of a result of the aforementioned findings, it is clear that environmentally friendly copper nanoparticles could operate as a great biological activity agent and could also be efficiently and economically applied for numerous medicinal purposes. Future research issues have arisen as a result of how nanoparticle aggregation impacts biological activity by inhibiting their entrance inside bacterial cells in addition to how variations in manufacture, processing, and storage can cause oxidation and result in undesired forms. Based on specified inputs, the artificial neural network archetypal was provided to forecast the inhibition% of anti-inflammatory action. The model was evaluated, and the overall result for 50 μL was 96.34%. As a result, the ability of the artificial neural network to forecast inhibition percentage was examined with accuracy level of 96.34% for 50 μL. The proposed model also evaluated the Experimental and numerical data analysis for different concentrations of Cu. While the study's usage of Artificial Neural Networks (ANNs), a type of soft computing, has some intriguing benefits, the drawbacks that must be noted is the calibre and representativeness of the training dataset have a significant impact on ANN performance. Insufficient or skewed data might provide poor models and wrong forecasts. Therefore, efforts should be taken to guarantee that there are plenty and varied datasets available for the ANN model's training.

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# Automatic Essay Scoring for Arabic Short Answer Questions using Text Mining Techniques

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**Abstract**—Automated Essay Scoring (AES) systems involve using a specially designed computing program to mark students' essays. It is a form of online assessment supported by natural language processing (NLP). These systems seek to exploit advanced technologies to reduce the time and effort spent on the exam scoring process. These systems have been applied in several languages, including Arabic. Nevertheless, the applicable NLP techniques in Arabic AES are still limited, and further investigation is needed to make NLP suitable for Arabic to achieve human-like scoring accuracy. Therefore, this comparative empirical experimental study tested two word-embedding deep learning approaches, namely BERT and Word2vec, along with a knowledge-based similarity approach; Arabic WordNet. The study used the Cosine similarity measure to provide optimal student answer scores. Several experiments were conducted for each of the proposed approaches on two available Arabic short answer question datasets to explore the effect of the stemming level. The quantitative results of this study indicated that advanced models of contextual embedding can improve the efficiency of Arabic AES as the meaning of words can differ in the different contexts. Therefore, serve as a catalyst for future research based on contextual embedding models, as the BERT approach achieved the best Pearson Correlation (.84) and RMSE (1.003). However, this research area needs further investigation to increase the accuracy of Arabic AES to become a practical online scoring system.

**Keywords**—Arabic language; Automated Essay Scoring (AES); Automated Scoring (AS); Educational Technologies; NLP

## I. INTRODUCTION

Online learning has become an integral part of the educational system in the wake of the COVID-19 pandemic, during which most countries had to close their educational institutions as a precautionary measure to preserve the safety of the public from the spread of infection. Shifting to online education was an alternative solution to cope with the restrictions imposed by the lockdown of educational institutions; however, it imposes many social and educational challenges [1], particularly when it comes to online assessment. A study which looked into assessment during the COVID-19 lockdown has suggested the need for a multilevel approach to the problems of cheating and plagiarism [2]. Even prior to the pandemic, assessment was a well-known challenge in education encountered by both traditional and online education [3]. It continues to be a dominant issue in the online learning arena even in the post-pandemic world.

Assessment in education describes the “processes of evaluating the effectiveness of sequences of instructional

activities when the sequence was completed” [4], and it has been divided into formative and summative assessments [5]. Formative assessment is part of the instructional process in the classroom; it provides the feedback needed to adjust the teaching and learning activities to suit the learners while they are engaged. On the other hand, summative assessment is given periodically in order to assess the learners' level of knowledge or achievement at a certain point in time. The AES in the context of this work is considered as a form of summative assessment.

Despite the diversity of methods for assessing students' progress, the examination method has been used predominately to measure students' performance and knowledge. Namely, examinations are held at the end of the course in addition to course assignments [6]. The academic examination is a considerable undertaking in the education process due to the significant number of students who take the exams. A massive overhead of time and effort is involved, with teachers having to score exams instead of focusing on other important aspects of the educational process [7].

At this point, automated scoring (AS) systems appear to be one of the best solutions to overcome these challenges. AS systems offer a collection of different grading approaches based on measuring the similarity between the answer posed and the expected answer [8]. AS systems introduce an effective alternative scoring mechanism for several types of questions such as true/false (T/F) questions, multiple choice questions (MCQs), and fill-in the blank questions. Nevertheless, the grading of essay questions and short answer questions is a complex task in AS systems, as such systems need deep knowledge and understanding of the nature of texts in a language process [9]. Hence, automated essay scoring (AES) [10] has emerged as a way to grade student essays.

There are different approaches used in the context of AES to measure the similarity between model answers (MAs) and student answers (SAs). One approach is string-based similarity [11], which involves scaling the string's sequence and the composition of the letter; in comparison, corpus-based similarity [12] measures similarity depending on the information obtained from large corpora. Moreover, the knowledge-based similarity approach [13], which is one of the most popular approaches for measuring text similarity, utilizes information derived from the semantic network Arabic WordNet.

According to research presented in [14], many research efforts have focused on developing and studying automated



scoring for short and essay questions written in English. In comparison, a limited number of studies in this area have been conducted to address automated Arabic short answer questions. The Arabic language, spoken by approximately 400 million people [15], is a complex language, with many synonyms for one word, differences in the meaning of a word according to its different formation, and richness of morphology. Accordingly, there is a lack of a practical system in Arabic to conduct automated scoring of short or essay questions due to the accuracy of the proposed frameworks being insufficient. Some studies have proposed a framework that translates the Arabic answer into English to measure the similarity between the model answer and student answer [16]. In contrast, other studies have proposed solutions that are centred around processing the Arabic language. For example, the work presented in [17] showed that using synonyms and finding the root of words can close the difference between a model answer and student answer. Another study has suggested that using deep learning can enhance the accuracy of Arabic AES [14].

The focus of this study was automated short text answer scoring presented in Arabic using a text mining technique with deep learning algorithms for natural language processing (NLP). The study aimed to investigate the effects of stemming level on measuring similarity between student answer (SAs) and model answer (MAs) It contributes the following to the following to this research area:

- Provide a comparative empirical study by comparing different word-embedding approaches to examine the word's surrounding context.
- Investigate mechanisms that depend on raising the percentage of similarity between the SA and MA by increasing the number of correct words in the SA.
- Evaluate the proposed models in the literature using two different available Arabic corporuses.

The rest of this paper is organized as follows. Section II presents the related work, while Section III explains the methodology used in this study. Section IV presents and discusses the study results. Finally, the conclusion in Section V and recommendations for future work are given in Section VI.

## II. RELATED WORKS

This section presents works related to the processing of Arabic short answer scoring and the present state-of-the-art approaches for short answer scoring for the English and Arabic languages.

Previous students have introduced models for Arabic AES that use string-based techniques of text similarity; for example, research in [18] presents a system for online exams in Arabic that is based on the Stemming and Levenshtein algorithms. The system reduces the words that have the same stem to a common phrasing. The results of this study showed that the proposed system is effective as a classification tool for Arabic essay questions.

Several other studies dealing with AS in Arabic have employed corpus-based algorithms such as Latent Semantic Analysis (LSA), which is an NLP technique that evaluates the similarity between two documents. This method relies on generating vectors-presentation for semantic terms, words, or even the concepts [19]. Research in [20] presented a system for scoring Arabic short answers by embedding LSA with the main three important syntactic features: lemmatization, the mistake of words, and the number of common words. They employed bag-of-words (BOW) to present feature vectors that mapped into the Cosine algorithms to measure the similarity between student answers (SAs) and model answers (MAs). To evaluate their approach, an Arabic short answer corpus was generated, and the best result was 96.72%. Similarly, research in [21] applied a similar approach, though their approach was centred on a semantic perspective as it combined LSA with linguistic features. After performing the normalization process, the authors generated feature vectors using Term Frequency-Inverse Document Frequency (TF-IDF) as the input to the Cosine algorithm. To improve the accuracy of LSA, the study leveraged part-of-speech (POS) with Term Frequency (TF) to take into account the syntactic of words. Moreover, the work in [22] utilized LSA with pre-processing of answers, for example, by removing stop-words, applying the replacing synonyms technique, and applying a stemming process. Meanwhile, the study in [23] proposed a new automated essay scoring approach focused primarily on measuring the similarity based on the root extraction and the synonyms of the keywords in addition to using the Cosine similarity. Moreover, they used the ROUGE metric to evaluate the obtained results, which gave a high accuracy rate of 84.5%, which indicated that the model's scoring could approximate human scoring.

Furthermore, another related work rendered an automated grading model for Arabic essays with the aim of gaining and achieving better efficiency [17]. In this case, features were extracted from the SA and MA by utilizing the F\_score tools, and Arabic WordNet was used as a helpful method for semantic similarity, which is considered as a knowledge-based algorithm. The proposed model recorded better accuracy when Arabic WordNet was used than without it.

Moreover, other research efforts presented frameworks using hybrid approaches of a string-based corpus and knowledge-based corpus. Research presented by [24] compared different algorithms to inspect the optimal solution of Arabic automatic grading. They employed two string-based text similarities methods: the Damerau-Levenshtein algorithm and the N-gram algorithm. Further, the LSA and DISCO were used as corpus-based text similarity algorithms. The authors applied four testing methods, namely Stop, Raw, Stop-Stem, and Stem, to investigate the accuracy of string-based algorithms. However, they only used the stop method to test corpus-based algorithms, since the semantic similarity between the stop words does not need to be measured. In addition, they calculated the correlation constant between the manual grading and the automatic system grading. Thus, the results showed that the N-gram with stop method resulted in 0.820 as the best correlation. Generally, the character-based N-gram algorithm achieved better results than the other type.

On the other hand, for the corpus-based algorithms, the DISCO algorithm achieved a higher correlation than the LSA algorithm, since it is built on words that have a common distribution.

Similarly, research work in [8] introduced a comparative study by investigating 14 string-based algorithms and two corpus-based algorithms. These algorithms were evaluated across two main models. The first was the holistic model, which compares the full form of an SA to an MA without splitting the SA and ignoring the MA's partition scheme. The second was the partitioning model, which divides the answer of the student into a group of sentences based on the sentence boundary detection templates and then maps each sentence to the most similar element on the MA. The  $r$  correlation and the RMSE were used to measure the correlation, while the MaxSim and the AvgSim were used to calculate the similarity. Accordingly, the experiment showed that corpus-based algorithms produce lower error rate values, and the N-gram (Bi-gram, Tri-gram) approach recorded the best  $r$  correlation of 0.826, with the partitioning model achieving results better than the holistic model in all cases.

Additionally, the same authors have also addressed this issue by translating Arabic text into English language [16]. They developed a framework that evaluates the similarity between SAs and MAs by fundamentally translating Arabic answers into the English language. The reason behind this choice was the limitation of available Arabic text processing resources and tools. Their proposed system was composed of five main stages as they applied different measuring techniques of text similarity in a separate and hybrid way; thus, the obtained scoring was scaled using the K-mean cluster.

On the other hand, work in [25] used supervised machine learning and classification algorithms to produce a new Arabic essay grading database that is compatible with machine learning. The study depended on leveraging machine learning algorithms to evaluate the database. Thus, the study used the several classifiers to build the training model of the database such as NB, Meta-classifier, and decision tree (J48). The results obtained from the third experiment using Meta-classifier showed a higher accuracy rate of 83%. Likewise, [26] provided a system in the context of web-based learning focusing on the Vector Space Model (VSM) and Latent Semantic Indexing (LSI). The system firstly extracted significant information from the essays by applying the VSM for information retrieval techniques. Then it applied the VSM and LSI to determine the degree of similarity between the student essay and the model essay after each essay has been converted to vector space. Finally, it used the Cosine similarity to measure the score of SA. The results showed that the proposed system provided scoring accuracy close to the traditional scoring by the professor.

Several state-of-the-art deep learning approaches have been used to process text similarity and conduct automatic scoring (AS). These approaches mainly rely on automated multi-layered feature-distributed representation and learning. Embedding models have emerged based on deep learning methods: word-embedding and paragraph-embedding have

become cutting-edge models in the NLP field [27]. Several contributions have employed embedding models to address AS in the English language [28-30]. Moreover, the study in [31] provided two main approaches for grading short answer questions. In the first approach, the study used four different methods based on word-embedding models: Word2vec, GloVe, and Fasttext3 by summation pre-trained word vectors. In the second approach, it used trained three deep learning models to extract the paragraph vector. Finally, Cosine similarity was used to measure the similarity between the vector of the MAs and the vector of the SAs. The best value the study produced for RMSE was 0.797.

In addition, in its comparative empirical work, research provided in [32] developed a model for AS by configuration of three presentation feature vectors: a manually extracted feature, word2vec, and a contextual embedding feature using the BERTmodel. The best-recorded accuracy was by the configuration of three feature vectors of  $75.2 \pm 1.0$  Quantized Classification. Table I summarises the approaches to handling automated short answer scoring as introduced in this section.

TABLE I. SUMMARY OF APPLIED APPROACHES IN RELATED WORK

Approach	Published Work	Area
String-based	[25].	Arabic automated online exam scoring
Corpus-based	[17], [20], [21], [23]	Arabic automated short answer scoring
Hybrid approaches (String-based, Corpus based)	[8], [24].	Arabic automated short answer scoring
Hybrid approaches (string based, corpus based, knowledge based – WordNet)	[16]	Translate Arabic short answers into English for automated scoring
Word embedding & paraphrase embedding with cosine	[31]	English automated short answer scoring
Word embedding (Word2vec), contextual embedding (Bert)	[27], [32],[33].	English automated short answer scoring

To conclude, more research on how to leverage deep learning approaches, or use contextual embedding, for Arabic automatic short answer scoring is needed. Thus, this comparative empirical study attempted to implement three different approaches for the following feature presentation vectors: 1) word-embedding using Word2vec, 2) contextual-embedding using Bert, and 3) WordNet as the knowledge-based algorithm, with the Cosine algorithm to measure text similarity between student answers (SAs) and model answers (MAs). Furthermore, it also investigated the effect of stemming levels on the performance of the proposed approaches.

### III. METHODOLOGY

This section outlines the proposed process for evaluating two different models for measuring text similarity for Arabic short answer questions: (1) knowledge-based similarity and (2) word and contextual embedding similarity. The two models were implemented by some suggested libraries of NLP

and the Python programming language. The research methodology is illustrated in Fig. 1.

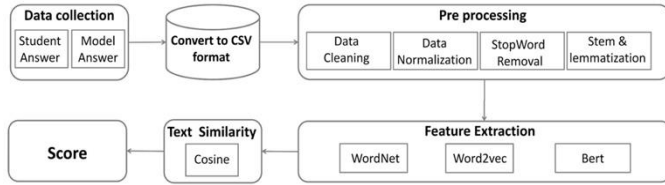


Fig. 1. Methodology.

In the first stage, data were collected, which include both SAs and MAs. In the second stage, data were converted to comma-separated value (CSV) format. In the third stage, the pre-processing took place, which consisted of four phases in the following order: data cleaning, data normalization, stop-word removal, and finally steam and lemmatization. In the fourth stage, the three different approaches (WordNet, Word2vec, and Bert) were tested to find the highest accuracy in AS. In the fifth stage, the similarity between the SAs and MAs was measured utilising the Cosine similarity. Finally, the scores were calculated.

#### A. Data Collection

In this study, data collection was based on two Arabic datasets provided by Ouahrani and Bennour [14] and Rababah and Al-Taani [23].

The dataset in AR-ASAG [14] consists of three different exams with the MAs and SAs of three different classes collected from a cybercrime course exam. Each exam consists of 16 short answer questions, and each question on each exam has a different number of student answers. The dataset thus contains 2,133 SAs with a total of 48 questions.

The Arabic dataset produced in [23] consists of 11 questions from the official Jordanian History course exam. Each question includes the MA created by the teacher and the answers of 50 students, with an average of 50 words per answer. The questions in both datasets include one or more of the question types shown in Table II.

TABLE II. DATASET QUESTION TYPES

Arabic Question Type	Translation
عرف	Define
اشرح	Explain
علل	Justify
ما النتائج المترتبة على	What are the consequences
ما الفرق	What is the difference

#### B. Convert to CSV Format

A comma-separated value (CSV) file is a set text file that uses a comma to separate values. Each line of the file is a data record that consists of one or more fields separated by commas. After the datasets were obtained, the data were converted to the CSV format.

#### C. Pre-process

1) *Cleaning data*: cleaning the data is an essential process in text mining that removes the noise from the data and prepares the data for processing. Therefore, all the punctuation marks were removed, including full stops, commas, and parentheses, in order to make the data more understandable in the comparison with the correct answer in the MA. The difference in data before and after cleaning is shown in Table III.

TABLE III. DATA CLEANING

Student Answer before Data Cleaning	Student Answer after Data Cleaning	Translation
هي كل سلوك غير أخلاقي يتم باستخدام الوسائل الالكترونية (الهاتف، الكمبيوتر...), يتمثل في حصول مرتكب الجريمة على ما يريد لتحقيق أهدافه الشخصية بينما يتحمل الضحية وهو المستخدم العقوبة، تتمثل في سرقة المعلومات	هي كل سلوك غير أخلاقي يتم باستخدام الوسائل الالكترونية الهاتف الكمبيوتر يتمثل في حصول مرتكب الجريمة على ما يريد لتحقيق أهدافه الشخصية بينما يتحمل الضحية وهو المستخدم العقوبة تتمثل في سرقة المعلومات	It is every immoral behaviour that takes place using electronic means (telephone, computer...), represented by the perpetrator obtaining what he wants to achieve his personal goals, while the victim, who is the user, bears the penalty, represented by stolen information.
هي سلوك غير قانوني عبر أجهزة إلكترونية، لأهداف مادية أو معنوية غالبا لإتلاف أو سرقة المعلومات وهي مثلا: النصب والاحتيال، التعدي الإلكتروني، التجسس وانتهاك الخصوصية	هي سلوك غير قانوني عبر أجهزة إلكترونية لأهداف مادية أو معنوية غالبا لإتلاف أو سرقة المعلومات وهي مثلا: النصب والاحتيال التعدي الإلكتروني والتجسس وانتهاك الخصوصية	It is illegal behaviour through electronic devices, often for material or moral purposes, to destroy or steal information, for example: fraud, electronic infringement, espionage and violation of privacy.
هي سلوك غير قانوني يتم باستخدام الأجهزة الإلكترونية، يتم تحميل المجرم منه على فوائد مادية ومعنوية، يتحمل الضحية خسارة مقابل ذلك الهدف من الجريمة إتلاف أو سرقة المعلومات	هي سلوك غير قانوني يتم باستخدام الأجهزة الإلكترونية يتم تحميل المجرم منه على فوائد مادية ومعنوية يتحمل الضحية خسارة مقابل ذلك الهدف من الجريمة إتلاف أو سرقة المعلومات	It is an illegal behaviour that takes place using electronic devices, for which the criminal is charged with material and moral benefits, and the victim bears a loss due to the goal of the crime, destroying or stealing information.

2) *Normalization*: At this stage, data were processed using advanced techniques by developing the normalization functions for some specific letters, as in Arabic, some letters are written in various forms. Thus, the Tashaphyne Library [34] was used for normalizing the following letters: Alef (أ،إ،آ)، Hamza (ء،ى،ؤ)، Ya'a (ي،ى)، and Ha'a (ه،ة). Furthermore, other methods were used for removing diacritics format (known in as Tashkeel) as shown in Table IV.

TABLE IV. NORMALIZATION

Letters form	Normalized into	Function name
أ،إ،آ	ا	Alef normalization
ي،ى	ي	Ya,a Normalization
ه،ة	ه	Ha'a Normalization
ء،ى،ؤ	ء	Hamza Normalization





output layers to support ultra-modern approaches that process different enormous jobs [33].

This work employed a pre-trained BERT model from the AraBert models' list. The bert-base-arabertv2 was predicted to extract layers where the external output layer was selected to draw out all remaining embedding layers. Thus, the proposed model utilized only the external node of the last embedding layer as it perfectly defined the sentences in a few dimensions. These embeddings will be closer to each other if they are more similar.

#### E. Text Similarity Measures

To measure the similarity between the character space vectors of an SA and an MA, the Cosine method was employed. Cosine works mathematically by calculating the Cosine of the angle between two vectors dropped down in a multi-dimensional space. The resulting similarity value falls in the range from -1 to 1. The -1 indicates strong non-similarity, while 1 refers to perfect similarity [39] and [27]. Thus, in this study, to align a predicted score with a human score, the data were normalized to 0-5.

### IV. RESULTS (SCORE) AND DISCUSSION

This section discusses the results of the comparative experiments that tested the three proposed approaches aimed at addressing Arabic automated short answer scoring. These experiments were conducted using data from two datasets: AR-ASAG and another dataset in [23]. Each dataset and approach were tested using the two mentioned stemming tools to examine the influence of the stemming level, light stem and base stem, on scoring precision for Arabic, which includes massive inflections. The proposed approaches were evaluated by comparing human scoring with the automated model scoring using the two most frequently mentioned measurement methods in related works for this area. All the experiments reported using both the Pearson correlation coefficient and Root Mean Squared Error (RMSE). The Pearson correlation coefficient is a precise measurement used to assess the linear relationship across two variables, represented in the range of -1, 1 to indicate the weakness or strength of the relationship, where the higher value is preferable. RMSE is the ideal method for measuring the variance between a predicted score and a true score. This method gives a non-negative value where, generally, a low RMSE is best. Table VII and Table VIII display the sample of grades to compare human scoring with model scoring.

#### A. Proposed Approaches on AR-ASAG

Table IX reports the results acquired from all three approaches that were applied to the dataset AR-ASAG. The first approach, WordNet with Cosine, achieved a relatively better Pearson correlation with the light stem (.75) while recording an RMSE with a lower value with the base stem. In Word2vec with Cosine, the light stem again produced an approximately higher Pearson correlation (0.7758) and lower RMSE (1.3577) than the base stem. Similar results can be observed in BERT with Cosine, with a light stem producing a Pearson correlation of 0.7616 and an RMSE value of 1.0439.

Overall, the Word2vec with Cosine resulted in the best Pearson correlation at .77 compared with the other approaches, while BERT with Cosine achieved the lowest RMSE with light stem on AR-ASAG.

#### B. Proposed Approaches on Dataset (Rababah & Al-Taani, 2017)

The same experiments were performed on the dataset [23] as that shown in Table X. WordNet, Word2vec, and BERT resulted in the lower RMSE with the base stem as 1.06, 1.12, and 1.003, respectively. The higher Pearson Correlation with base stem was achieved by Word2vec of .83 and BERT of 0.84. For this dataset, the BERT + Cosine approach recorded the best Pearson Correlation and RMSE.

TABLE VII. SAMPLE OF HUMAN & MODEL SCORING ON AR-ASAG

Approaches	Human Scoring	Model Scoring
WordNet+Cosine	3.5	3
	4	3
	5	2.5
	3.75	3
Word2vec+Cosine	4	3.79
	2	2.5
	4.5	4.33
	5	4.67
BERT+Cosine	2.5	2.5
	5	3
	2.25	3
	3	3

TABLE VIII. SAMPLE OF HUMAN & MODEL SCORING ON (RABABAH & AL-TAANI, 2017) DATASET

Approaches	Human Scoring	Model Scoring
WordNet+Cosine	2	3
	2	2.5
	2	1.5
	2	2
Word2vec+Cosine	1	1.5
	1	1
	1	2
	4.43	4.5
BERT+Cosine	1	1
	1	1.5
	2.5	3
	2	3

TABLE IX. THE RESULT OF PROPOSED APPROACHES ON AR-ASAG

Approaches	Stem	Pearson Correlation	RMSE
WordNet+Cosine	Base	0.7469	1.4977
	Light	0.7553	1.4646
Word2vec+Cosine	Base	0.7693	1.3879
	Light	<b>0.7758</b>	1.3577
BERT+Cosine	Base	0.7536	1.4516
	Light	0.7616	<b>1.0439</b>

TABLE X. THE RESULT OF PROPOSED APPROACHES ON DATASET OF (RABABAH & AL-TAANI)

Approaches	Stem	Pearson Correlation	RMSE
WordNet+Cosine	Base	0.806195	1.1220652
	Light	0.820854	1.153378
Word2vec+Cosine	Base	0.837094	1.0655779
	Light	0.828779	1.1118528
BERT+Cosine	Base	<b>0.841902</b>	<b>1.00308459</b>
	Light	0.837253	1.0439487

The following observations are introduced based on the results of the above experiments. First, the light root and base root are approximately equivalent as they achieved close results to each other, as another study [14] also reported. The best among them cannot be determined here, as this work recorded that the optimal performed stemming level can differ with different datasets and various feature representation approaches. The light stemming was better when performed on the AR-ASAG dataset, while the other dataset had a higher Pearson correlation and lower REMS with the base stem.

Moreover, processing the contextual embedding between words has improved the accuracy of Arabic AES compared with other similarity measurements. The BERT with Cosine achieved the best RMSE across the two used datasets as the lowest RMSE was 1.00308. In addition, the best Pearson Correlation among all performed experiments was 0.841902 for the BERT algorithm.

### V. CONCLUSION

This comparative empirical study evaluated the efficiency of different word embedding approaches in the context of Arabic automatic essay scoring (AES). Two available datasets were acquired, and several pre-processing methods were employed for these datasets. For the feature presentation, three different approaches were proposed to examine their efficiency as feature extract models in this domain. Therefore, the WordNet, Word2vec, and BERT approaches have been applied individually to extract the features of the student answer (SA) and model answer (MA), and the Cosine similarity was used to identify the closest-scoring model to human scoring by measuring the similarity between the SAs and MAs.

Four experiments were conducted for each proposed approach to study the effect of stemming techniques on the performance of these approaches. After that, Pearson correlations and RMSEs were calculated to compare the scores produced by the experiments with human scores. The results indicated that advanced models of contextual embedding can improve the efficiency of Arabic AES as the meaning of words can differ in the different contexts. Nevertheless, it is worth mentioning that these experiments were conducted on only two available Arabic short answers datasets, and hence the results are tied to them. The same experiments should be repeated on more datasets to get more generic results. Therefore, this area needs more investigation to improve the accuracy of Arabic AES in order for it to be realised as a practical online scoring system.

### VI. FUTURE WORK

Future work could endeavour to present a benchmark dataset for the Arabic language. Furthermore, proposing a hybrid approach, such as combining WordNet with word-embedding and contextual-embedding, could enhance the accuracy of the approach.

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# Combination of Adaptive Neuro Fuzzy Inference System and Machine Learning Algorithm for Recognition of Human Facial Expressions

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**Abstract**—A face recognition system's initial three processes are face detection, feature extraction, and facial expression recognition. The initial step of face detection involves colour model skin colour detection, lighting adjustment to achieve uniformity on the face, and morphological techniques to maintain the necessary face region. To extract facial characteristics such the eyes, nose, and mouth, the output of the first step is employed. Third-step methodology using automated face emotion recognition. This study's goal is to apply the Adaptive Neuro Fuzzy Inference System (ANFIS) algorithm to increase the precision of the current face recognition systems. For the purpose of removing noise and unwanted information from the data sets, independent data sets and a pre-processing technique are built in this study based on color, texture, and shape, to determine the features of the face. The output of the three-feature extraction process is given to the ANFIS model as input. By using our training picture data sets, it has already been trained. This model receives a test image as input, then evaluates the three aspects of the input image, and then recognizes the test image based on correlation. The determination of whether input has been authenticated or not is made using fuzzy logic. The proposed ANFIS method is compared to the existing methods such as Minimum Distance Classifier (MDC), Support Vector Machine (SVM), Case Based Reasoning (CBR) with the following quality measure like error rate, accuracy, precision, recall. Finally, the performance is analyzed by combining all feature extractions with existing classification methods such as MDC, KNN (K-Nearest Neighbour), SVM, ANFIS and CBR. Based on the performance of classification techniques, it is observed that the face detection failures are reduced, such that overall accuracy for CBR is 92% and it is 97% in ANFIS.

**Keywords**—ANFIS; Image processing; face recognition; feature extraction; fuzzy logic

## I. INTRODUCTION

Computer vision includes face recognition. Face recognition [1] is a biometric approach for identifying a person based on an image of their face. Biological characteristics are used to identify a person. Human eyes can quickly recognize

people by simply glancing at them, but they have a limited focus span. As a result, a computerized approach for facial recognition is developed. Face recognition [2] is the process of automatically detecting and authenticating a person from a photograph or video. Despite the fact that face recognition has been extensively explored [3], there are still obstacles to overcome a number of issues, including:

- Misalignment.
- Pose Variation.
- Illumination Variation.
- Expression Variation.

The efficacy and precision of face recognition must be improved; hence several approaches must be tested. A method for identifying a person based on their input image is called face recognition. Face recognition can be used on mobile devices due to its adaptability. Face recognition on mobile devices has a variety of disadvantages, such as processing power restrictions, storage space restrictions [4], network bandwidth restrictions, privacy problems, and security issues [5]. On mobile devices, face recognition can be used to identify users, identify social networking sites, and separate individuals. It is well-liked in the marketing and security industries [6]. There are many conventional security apps, including applications for username (identity) and password (credentials) [7]. Passwords can be cracked or detected, making traditional mobile apps easy targets for theft. Contrarily, face recognition apps are more effective than conventional ones because they are more versatile and safer, and they do away with the necessity for the user to remember passwords [8]. The finest biometrics for these devices are face recognition programs because they include cameras. The novelty of the proposed work is we consider the color, shape and texture feature of the image. In existing methods, they are considered any on parameter either color or shape or texture. Machine learning implementation we are using the ANFIS model. This paper's

goal is to introduce a facial recognition system for mobile devices.

This paper is structured as follows: Literature review is presented in Section II. The proposed model is explained in Section III. Results are shown and discussed in Section IV. Finally, the conclusion of the presented work is discussed in Section V.

## II. LITERATURE SURVEY

We will go through a handful of the many different types of recognition techniques that exist. Based on the input image, the authors of [9] suggested a face identification system for mobile phones. They did this by developing a number of ROI preprocessing steps, the Viola-Jones approach, and Principal Component Analysis (PCA). The system's goals are to speed up and simplify image searches. A unique application for facial recognition on mobile devices was introduced by the developers of [10] that leverages the Bridge Approach (BA) to speed up processing and makes it possible to use the system from any location with an internet connection. Face detection and feature extraction are done with the OpenCV library; face recognition is done with the WEKA library. The face and eye detection, as well as a set of Region of Interest (ROI) preprocessing, were proposed as part of the design and implementation of a face recognition system for the mobile phone platform by the authors of [11]. The PCA has an accuracy rate of 93.8 percent, and Linear Discriminant Analysis (LDA), which has an accuracy rate of 96 percent, are the recognition techniques used. The use of facial recognition on mobile devices was done by the authors of [12]. The PCA method was used by them for recognition. After using the technique, the accuracy for a given threshold was about 92 percent, and it took 0.35 seconds for a small sample of test photos to identify the person. The authors of [13] developed a facial recognition system in MATLAB and tested it on Direct Region of Interest Device (DROID) mobile devices. It examined various face detection techniques (such as color segmentation and template matching) and provided two

methods for recognition (Eigen & Fisher face). With a computation time of 1.58 seconds on DROID, it has an Eigen face recognition rate of 84.3 percent and a fisher face recognition rate of 94 percent [14].

## III. PROPOSED METHOD

In this research work, face recognition is done using image processing, pre-processing, feature extraction, and ANFIS. Input images were collected using digital camera pre-processing technique was used remove the noise. Feature extraction was used to extract the essential feature from the pre-processed output image. The ANFIS was used to recognize the face. Receiver Operating Characteristic (ROC) curve was used to evaluate the proposed system performance.

### A. Input Image

Every matrix element in a recorded image is typically referred to as a pixel [15]. Two categories can be used to describe input images taken with a digital camera:

- 1) Testing image
- 2) Training image

Training images and Testing images were obtained using a digital camera for Fig. 1. In this research, we used 16 different data sets. 1600 photos total were used as input, with 1120 images used for the training data set and 480 images used for the testing data (Given in Table I). We are utilizing a jpeg image with dimensions of 256 x 234 pixels.

### B. Pre-processing

In this research work, normalization method and soft coring filter were used (shown in Fig. 2). In Fig. 3, Pre-processing is a method used to remove the noise from the input image. Normalization method was used to convert the RGB image into gray scale image using (1) [16].

$$I(x, y, z) = \frac{Gx + Gy + Gz}{3} \quad (1)$$

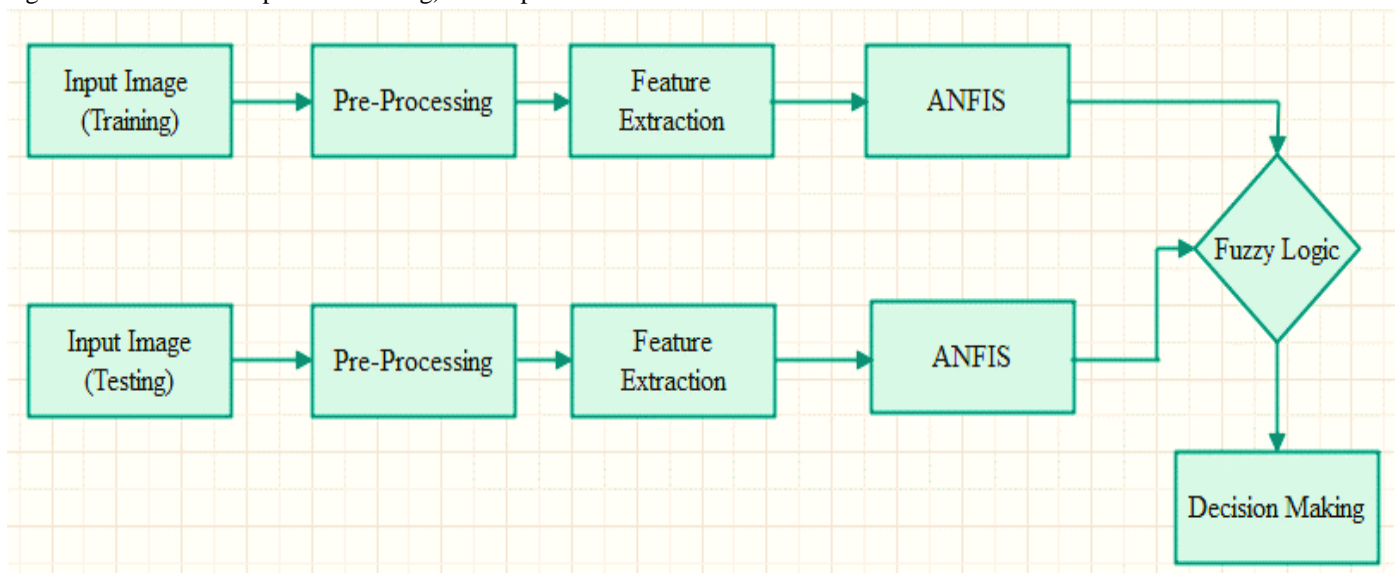


Fig. 1. Block diagram for proposed system

TABLE I. SAMPLE DATABASE



Fig. 2. Pre-processed output image.

The output of the soft coring function was applied after the normalized output picture had been passed through the high pass filter  $\alpha(\cdot)$  using equation (4).

$$P(x, y) = Ih(x, y) + \alpha(I(x, y)), \quad (2)$$

where,

$P(x, y)$  – Preprocessed output image

$Ih(x, y)$  – Highpass filter output image

$$Ih(x, y) = I(x, y) - Z(e^{jwx}, e^{jwy}) \quad (3)$$

$Z(e^{jwx}, e^{jwy})$ - High pass filter co-efficient

$\alpha(I(x, y))$ - Soft coring function

$$\alpha(I(x, y)) = m \cdot I(x, y) \left(1 - e^{-\frac{|I(x, y)|}{\tau}}\right) \quad (4)$$

$m, \tau$  – Random variables ranges between 0 to 1.

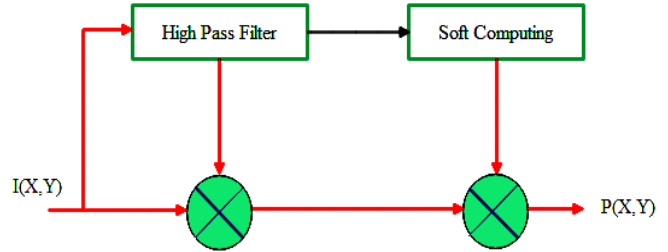


Fig. 3. Soft coring filter.

A nonlinear technique called soft coring filtering is used to remove extraneous data from normalized images [17]. Based on a kernel function that may be executed in the frequency domain, a Gaussian high pass filter is utilized to graphically display the data. With the aid of the sliding windowing technique, the Gaussian high pass filter quickly produces a Fourier transform in two dimensions of convolutions [18].

Gaussian high pass filter was used to remove the noise from the input image using equation (3). To extract the input image's line and edge information, the soft coring kernel function was employed. Two dimensional images were filtered using the soft coring approach, which significantly reduced data loss as compared to the median filtering method. Two step pre-processing method contributes to the quality of the image to be enhanced, reduction of processing time, compensation of illumination, reduction of the shaded background, maintenance of the image contrast and brightness [19]. Median filtering cannot apply for the boundary or edges of the input image to overcome this issue we used soft coring filter.

### C. Feature Extraction

1) *Texture feature extraction:* After the preprocessing the images are used for feature extraction. Geometry-based techniques use geometric information as a features measure, such as feature relative locations and sizes of the face components. Kanade [20] devised a method that used a vertical edge map to locate the eyes, mouth, and nose. These procedures necessitate a threshold and may have a negative impact on the final result [21]. Co-occurrences matrix-based technique was used to extract the texture feature using. The following features of co-occurrence matrix can be measured.

- Inertia (contrast).
- Energy.
- Entropy.
- Contrast.

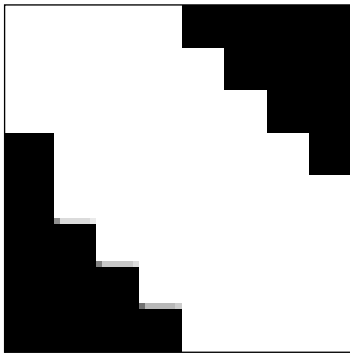


Fig. 4. Texture Feature extraction output image.

The output of the texture feature method is shown in Fig. 4. The element difference moment of order 2 is called as contrast [22]. It has relatively minimum values when maximum values appear in the main diagonal of co-occurrence matrix

$$Contrast = \sum_{g1} \sum_{g2} (g1 - g2)^2 C_{g1 g2} \quad (5)$$

where,  $g1$  = grey level value of pixel location at  $(x,y)$ ;

$g2$ =grey level value of pixel location at  $(x,Dx,y,Dy)$ ;

$Dx,Dy$ =displacement vector of  $x$  and  $y$ ;

$C$ =co-occurrence matrix

The energy value is calculated by using the following (6). If all values in the co-occurrence matrix are equal, then energy value is maximum.

$$ENERGY = \sum_{g1} \sum_{g2} C_{g1 g2}^2 \quad (6)$$

Entropy is used to calculate the information of the grey level image. To calculate the entropy value the (7) is used:

$$ENTROPY = - \sum_{g1} \sum_{g2} C_{g1 g2} \log_2 C_{g1 g2} \quad (7)$$

2) *Shape features extraction*: To match the found face components, this method uses a previously established standard face pattern template [23]. This makes use of the proper energy function. The facial image with the best match to a template will use the least amount of energy. Y. Zhong et al. [24] adopt this method, which requires prior knowledge of a priori template modelling. It also necessitates additional computing costs, which have a significant impact on its performance [25]. For faster searching speeds and more template matching optimization, genetic algorithms can be utilized. In this research work, we used canny edge detection method for shape feature extraction (output shown in Fig. 5). This method was used to detect wide range of object edges in an image.

3) *Color feature extraction*: In this research work we used threshold-based segmentation as color feature extraction method. Skin color is used to isolate the face in this method [26]. Any non-skin color part of the face is considered a potential for localization of the eyes and/or mouth. Due to the diversity of ethnic backgrounds, this approach performs poorly on facial image datasets. Color feature is extracted by using (8).

$$E(x, y) = \begin{cases} 0 & \text{if } P(x, y) < T1 \\ 1 & \text{if } T1 \leq P(x, y) \leq T2 \\ 0 & \text{if } P(x, y) > T2 \end{cases} \quad (8)$$

where  $T1$  –Lower threshold value,  $T2$ - Upper threshold value.



Fig. 5. Shape feature extraction output image.

4) *ANFIS (Adaptive Neuro Fuzzy Interface System)*: The outputs of feature extraction methods for colour, texture, and form were fed into the ANFIS. The ANFIS machine learning method, which combines fuzzy logic and neural network methods, is supervised [27]. We are using feed-forward neural networks as a neural network methodology and the Takagi-Sugeno fuzzy logic method as a fuzzy logic method. The architecture of the ANFIS is shown in Fig. 6, which has many layers. Layer 1: In this research work, we used Gaussian membership function. Layer 2: In this layer every node is adaptive, it is labelled as  $\pi$ . The output of this layer is the multiplying result of the first layer as shown in ANFIS architecture, Fig. 6. In this research, the target value is calculated using O R logic. Layer 3: In this layer every node is adaptive, it is labelled as  $N$ . The output of this layer is the ratio of firing strength of each node to the sum of all the nodes firing strength. Layer 4: In this layer every node is adaptive. Layer 5: In this layer there is a single node, it is non adaptive and represented as  $\sum$ . Layer 6: Output Layer. Six rules make up the Takagi-Sugeno fuzzy model. With ANFIS, the problems with facial detection are overcome. A hybrid learning strategy was used to identify the face utilising the back propagation gradient approach and the least squares method. The nodes in the ANFIS network met the specifications for each tier. IF/THEN rules might build a network realisation in ANFIS. Each layer of the ANFIS network's neurons carried out the same duty [28]. To implement this algorithm, we were used MATLAB software. Fig. 7 and 8 display the ANFIS confusion matrix and colour feature extraction result.



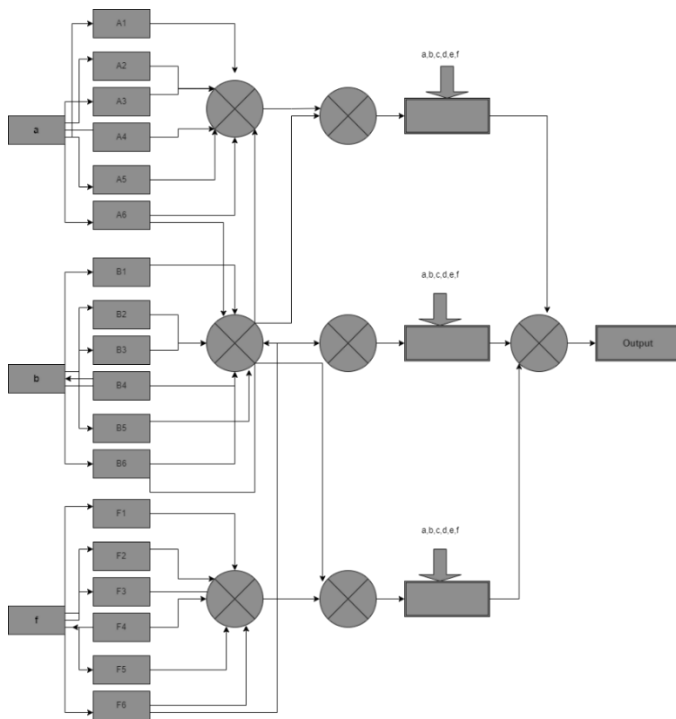


Fig. 6. ANFIS architecture.



Fig. 8. ANFIS output.

5) *Face recognition*: The last procedure in our suggested approach employs the Pearson Correlation Coefficient. Pearson correlation assesses the degree to which two variables are linearly related [29]. We use the Pearson correlation to determine the covariance between a person's features and authorized users' features in the database in order to gain access to the mobile device.

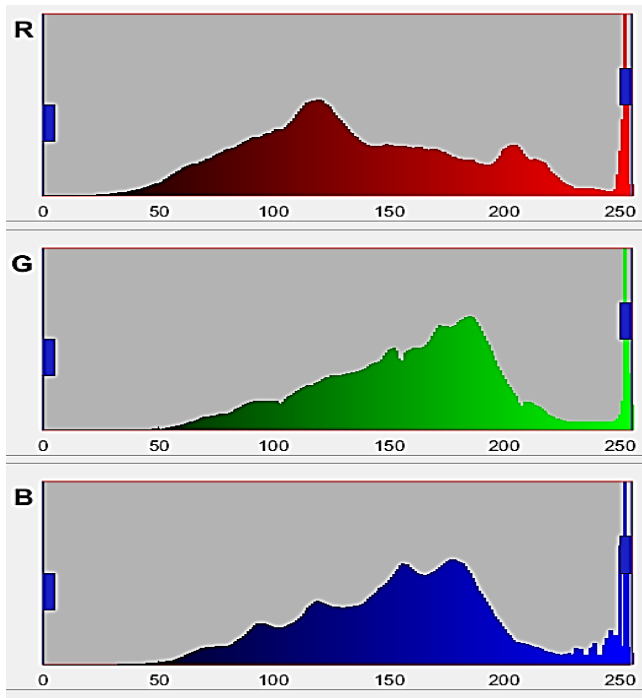


Fig. 7. Color feature extraction output.

If the covariance ratio is equal to or higher than a specific threshold, the system will accept the person as an authorized user; otherwise, the system will deny the access request. The built-in Pearson correlation function in MATLAB is used in this project. We have n "data pairings," where n is the number. The symbol n stands for the bivariate sample n2. The two images A and B have a greater correlation coefficient, which suggests that they are closely related. Based on the covariance rate, we determined whether or not the person is known. If the covariance ratio is equal to or higher than a specific threshold, the system will accept the person as an authorized user; otherwise, the system will deny the access request [30]. It contrasts the 30 measurements of the person requesting access to the system with the measurements of those who have been granted access in the (SQLite) database.

#### IV. RESULTS

The ROC curve is a graph used to depict the relationship between sensitivity and specificity and to represent the output of a classification system for various threshold values. True Positive Rate (TPR), probability detection, and recall are additional names for sensitivity [31]. Specificity is also known as the False Positive Rate (FPR), the likelihood of a false alert, and fallout. A diagnosis paradigm for classifying instances into groups is the ROC curve. The continuous output is the diagnosis output (real value). The classifier having different boundaries between different classes can be classified by threshold value [32]. The binary classification system is having two classes, one normal cell class which is labelled as positive (P) and other one is abnormal cell class, and it is labelled as negative (N).

The binary classifier has four possible outcomes are

- True Positive (TP).



- False Positive (FP).
- True Negative (TN).
- False Negative (FN).

TABLE II. TRUE POSITIVE AND NEGATIVE VALUES

		Training Image	
		P	N
Testing Image	P	TP	FN
	N	FP	TN

Plotting the cumulative distribution functions of specificity on the x-axis and sensitivity on the y-axis results in the ROC curve. Using (9) and (10) as a basis for actual positive and negative values, determine the sensitivity and specificity values. The following criteria are used to calculate the true positive and negative values, as shown in Table II.

$$Sensitivity = \frac{TP}{(TP+FN)} \quad (9)$$

$$Specificity = \frac{TN}{TN+FP} \quad (10)$$

where, TP- True Positive, TN- True Negative, FN- False Negative, and FP- False Positive.

The examination of ROC curves is a more effective method for choosing an optimization model, class distribution, disease diagnosis, and decision-making. The ROC curve is employed in a variety of fields, including biometrics, machine learning, hazard prediction, radiography, model performance evaluation, and medicine. Based on the diagonal splits in the ROC area, ROC curve analysis is used to identify person [33]. The disease-affected image is represented by the ROC curve above the diagonal, and the disease-free picture is represented by the ROC curve below the diagonal. The threshold value largely determines the ROC curve output, thus choosing the right threshold value will help the analysis of the ROC curve perform better. Fig. 9 displays the ROC curve. Plotting the cumulative distribution functions of specificity on the x-axis and sensitivity on the y-axis results in the ROC curve [34]. The system is performing well and efficiently if the curve in the plot is above the 45-degree slope line. In this research work, we used soft coring filtering method to remove the noise from the input image. The performance of the soft coring filter was compared with median filter based on the quality measure like Mean Square Error (MSE), Peak to Signal Noise Ratio (PSNR), Structural SIMilarity (SSIM), Peak Root mean square Difference (PRD) and Signal Noise Ratio (SNR) [35].

The MSE value was calculated using the following formula.

$$MSE = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [f(x,y) - f^\wedge(x,y)]^2 \quad (11)$$

where f(x,y) – input image; x- row value; y-column value.

The PSNR value was calculated using the following formula.

$$PSNR = 10 \log_{10} \left( \frac{MAXi^2}{MSE} \right) \quad (12)$$

where MAXi – Pixel value maximum; MSE-Mean Square Error.

The SSIM value was calculated using the following formula.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y+C1)(2\sigma_{xy}+C2)}{(\mu_x^2+\mu_y^2+C1)(\sigma_x^2+\sigma_y^2+C2)} \quad (13)$$

where  $\mu$  - mean;  $\sigma$ - variance.

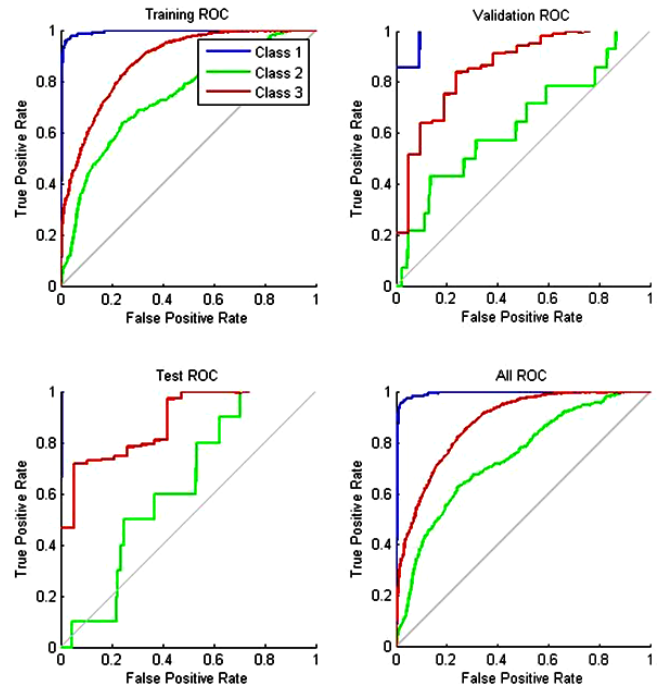


Fig. 9. ROC Output.

The PRD value was calculated using the following formula.

$$PRD = \sqrt{\frac{MSE}{\sum f^2}} \times 100 \quad (14)$$

where MSE-Mean Square Error; f-image.

To calculate the SNR value using the following formula

$$SNR = \frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (f^\wedge(x,y))^2}{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [f(x,y) - f^\wedge(x,y)]^2} \quad (15)$$

where f(x,y) – input image; x- row value; y-column value.

Tables III and IV show the performance of filtering technique in terms of MSE, PSNR, SSIM, PRD and SNR. In soft coring filter MSE, SNR and PRD values were low when compared with median filter technique whereas PSNR and SSIM values were high compared with median filter technique [36]. This graph can be used to determine how well filtering methods based on the MSE, PSNR, SSIM, PRD, and SNR perform (shown in Fig. 10 and 11). The MSE, SNR, and PRD values of the median filter were high when compared to the Soft coring filter technique. The median filter's PSNR and SSIM values were poor when compared to the Soft coring filter method. It suggests that when compared to median filters, soft coring filters perform better.

TABLE III. PERFORMANCE ANALYSIS FILTER USING MSE, PSNR AND SSIM

Data Set	Median Filter			Soft Coring Filter		
	MSE	PSNR	SSIM	MSE	PSNR	SSIM
Data set 1	0.0122	30.6193	0.4956	0.0023	41.2563	0.9079
Data set 2	0.0134	30.0458	0.4972	0.0031	41.7865	0.9045
Data set 3	0.0137	30.1246	0.4942	0.0018	41.9658	0.9061
Data set 4	0.0129	30.2148	0.4987	0.0015	41.6587	0.9032
Data set 5	0.0125	30.3127	0.4963	0.0017	41.9623	0.9027
Data set 6	0.0121	30.1248	0.4982	0.0021	41.8865	0.9062
Data set 7	0.0122	30.0458	0.4956	0.4972	41.7865	0.9045
Data set 8	0.0125	30.1246	0.4942	0.0018	41.6587	0.9032
Data set 9	0.0129	30.6193	0.4987	0.0015	41.2563	0.9062
Data set 10	0.0137	30.2148	0.4982	0.0023	41.9658	0.9079
Data set 11	0.0125	30.3127	0.4956	0.0017	41.7865	0.9061
Data set 12	0.0134	30.6193	0.4942	0.0021	41.8865	0.9045
Data set 13	0.0137	30.2148	0.4972	0.4972	41.6587	0.9032
Data set 14	0.0125	30.1246	0.4963	0.0015	41.2563	0.9079
Data set 15	0.0134	30.3127	0.4987	0.0023	41.9623	0.9027
Data set 16	0.0122	30.0458	0.4956	0.0018	41.9658	0.9061

TABLE IV. PERFORMANCE ANALYSIS FILTER USING PRD AND SNR

Data Set	Median Filter		Soft Coring Filter	
	PRD	SNR	PRD	SNR
Data set 1	0.092	4.94	0.043	7.89
Data set 2	0.097	4.87	0.043	7.96
Data set 3	0.098	4.89	0.043	7.35
Data set 4	0.096	4.93	0.043	7.69
Data set 5	0.092	4.23	0.043	7.78
Data set 6	0.095	4.45	0.043	7.63
Data set 7	0.097	4.94	0.043	7.96
Data set 8	0.092	4.89	0.043	7.35
Data set 9	0.098	4.93	0.043	7.69
Data set 10	0.096	4.94	0.043	7.78
Data set 11	0.092	4.45	0.043	7.63
Data set 12	0.095	4.23	0.043	7.89
Data set 13	0.097	4.87	0.043	7.96
Data set 14	0.096	4.94	0.043	7.35
Data set 15	0.092	4.93	0.043	7.78
Data set 16	0.098	4.87	0.043	7.69

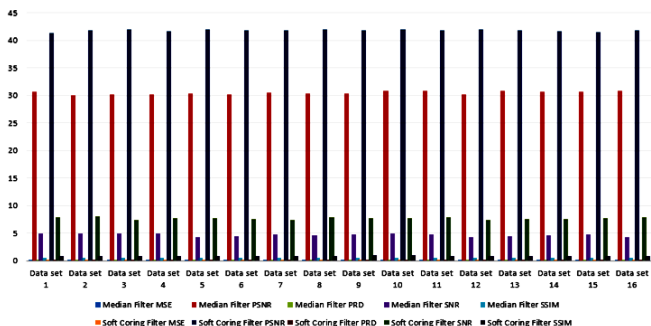


Fig. 10. Performance analysis of preprocessing technique (a) SNR (b) PSNR (c) PRD (d) MSE (e) SSIM.

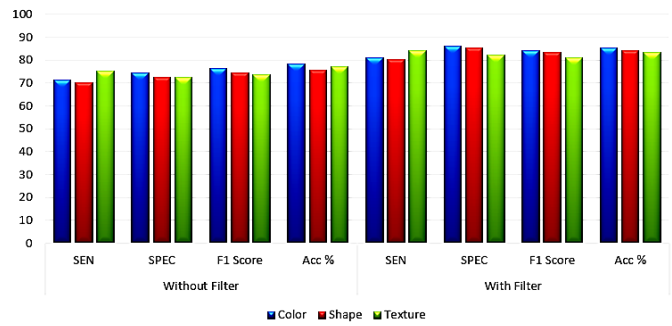
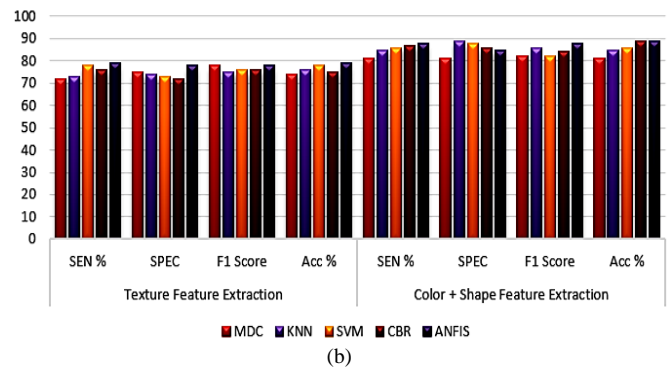
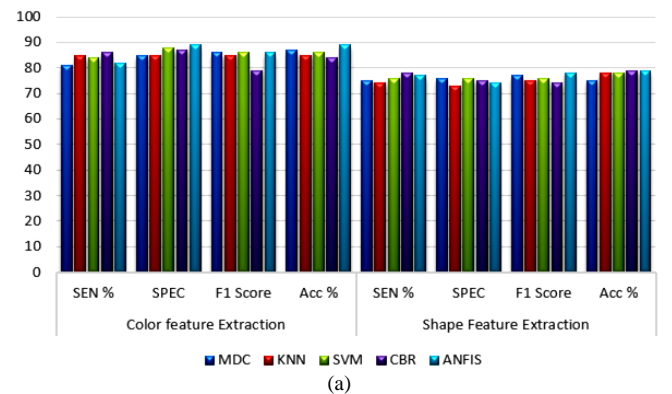


Fig. 11. Performance analyses of Feature extraction techniques.

Table V illustrates the sensitivity, specificity, F1 score, and accuracy of the feature extraction approach. In Fig. 12, color, shape, and texture were quantified using feature extraction techniques with and without filters for these four metrics. With the filter, the sensitivity values were 81.25, 80.26, and 84.36. Other feature extraction methods have lower sensitivity than the texture feature extraction approach. With the filter, the specificity values were 86.23, 85.32, and 82.34. Other feature extraction methods have lower specificity than the colour feature extraction approach [37-38]. The F1 score after applying the filter was 84.35, 83.56, and 81.26. In comparison to other feature extraction techniques, colour feature extraction produced a higher F1 score. There were three different filter accuracy values: 85.26, 84.35, and 83.28. Compared to other feature extraction techniques, the colour feature extraction method offered greater accuracy.



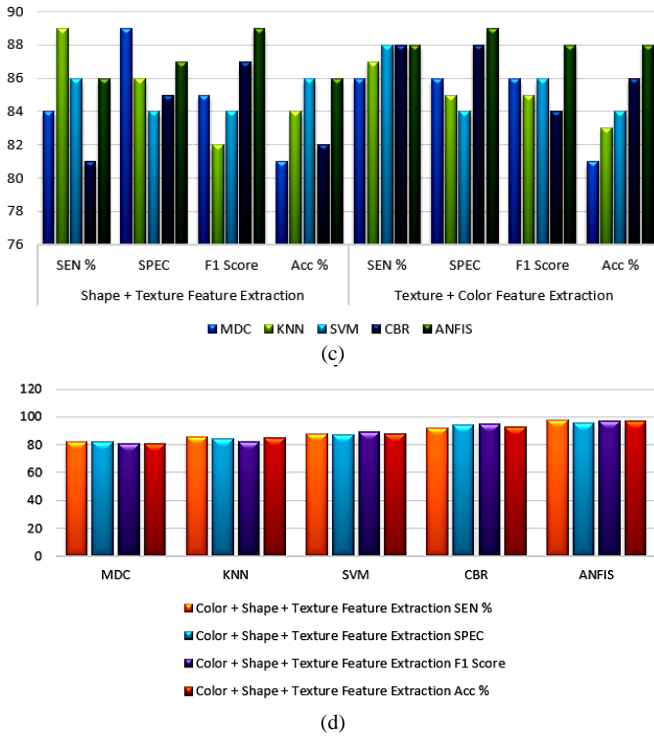


Fig. 12. (a),(b),(c),(d) Performance analysis of classification.

TABLE V. FEATURE EXTRACTION ANALYSIS

Technique	Without Filter %				With Filter %			
	SEN	SPEC	FI	Acc	SEN	SPEC	FI	Acc
Color	71.21	74.36	76.28	78.54	81.25	86.23	84.35	85.26
Shape	70.32	72.36	74.35	75.63	80.26	85.32	83.56	84.35
Texture	75.36	72.36	73.62	77.25	84.36	82.34	81.26	83.28

From Tables VI to IX, it was concluded that classification strategies that integrated feature extraction approaches with values of attributes like sensitivity, specificity, F1 score, and accuracy generated better results. To recognize faces, three approaches were used: assessing the performance of colour, shape, and texture feature extractions separately, then combining (colour and shape), (shape and texture), and (texture and colour), and lastly merging all feature extraction methods (colour, shape, and texture). The fusion of colour, shape, and texture feature extraction methodology produced more accuracy than earlier feature extraction techniques, as seen in Fig. 12 [39]. Accuracy values for the MDC, KNN, SVM, CBR, and ANFIS techniques are 81, 85, 88, 93, and 97, respectively.

The overall performance of several classification algorithms used for facial recognition classification in terms of execution time is shown in Table X and Fig. 13. ANFIS performed faster than the other categorization algorithms in a comparison. Each data set took 36, 34, 35, 32, 34, 33, 34, 31, 32, 34, 35, and 36 seconds to execute in seconds. The total effectiveness of several classification algorithms utilized for face recognition categorization is shown in Table XI and Fig. 14. According to a comparison of classification methods, ANFIS had higher accuracy than all other methods, with 97.67

percent, 97.45 percent, 97.56 percent, 97.54 percent, 97.61 percent, 97.43 percent, 97.36 percent, 97.63 percent, 97.72 percent, 97.68 percent, 97.28 percent, 97.34 percent, 97.52 percent, 97.62 percent, and 97.48 percent. The average number of iteration performance measures employed is shown in Table XII and Fig. 15. According to a comparison of categorization techniques, ANFIS had the lowest average number of iterations of all methods, with 39, 38, 37, 37, 39, 38, 38, 37, 37, 36, 38, 37, 36, 37, 38 and 36 of data sets.

TABLE VI. CLASSIFICATION METHOD USING COLOR FEATURE EXTRACTION AND SHAPE FEATURE EXTRACTION

Technique	Color feature Extraction %				Shape Feature Extraction %			
	SEN	SPEC	FI	Acc	SEN	SPEC	FI	Acc
MDC	81	85	86	87	75	76	77	75
KNN	85	85	85	85	74	73	75	78
SVM	84	88	86	86	76	76	76	78
CBR	86	87	79	84	78	75	74	79
ANFIS	82	89	86	89	77	74	78	79

TABLE VII. CLASSIFICATION METHOD USING TEXTURE FEATURE EXTRACTION AND COLOR + SHAPE FEATURE EXTRACTION

Technique	Texture Feature Extraction %				Color + Shape Feature Extraction %			
	SEN	SPEC	FI	Acc	SEN	SPEC	FI	Acc
MDC	72	75	78	74	81	81	82	81
KNN	73	74	75	76	85	89	86	85
SVM	78	73	76	78	86	88	82	86
CBR	76	72	76	75	87	86	84	89
ANFIS	79	78	78	79	88	85	88	89

TABLE VIII. CLASSIFICATION METHOD USING TEXTURE + SHAPE FEATURE EXTRACTION AND TEXTURE + COLOR FEATURE EXTRACTION

Technique	Shape + Texture Feature Extraction %				Texture + Color Feature Extraction %			
	SEN	SPEC	FI	Acc	SEN	SPEC	FI	Acc
MDC	84	89	85	81	86	86	86	81
KNN	89	86	82	84	87	85	85	83
SVM	86	84	84	86	88	84	86	84
CBR	81	85	87	82	88	88	84	86
ANFIS	86	87	89	86	88	89	88	88

TABLE IX. CLASSIFICATION METHOD USING COLOR + SHAPE + TEXTURE FEATURE EXTRACTION

Technique	Color + Shape + Texture Feature Extraction %			
	SEN	SPEC	FI Score	Acc
MDC	82	82	81	81
KNN	86	84	82	85
SVM	88	87	89	88
CBR	92	94	95	93
ANFIS	98	96	97	97

TABLE XI. PERFORMANCE ANALYSIS BASED ON EXECUTION TIME

Data set	Execution Time (seconds)				
	MDC	KNN	SVM	CBR	ANFIS
Data set 1	58	52	38	34	36
Data set 2	57	51	36	35	34
Data set 3	58	52	37	33	35
Data set 4	56	50	36	33	32
Data set 5	57	51	38	34	34
Data set 6	55	52	37	35	33
Data set 7	57	52	38	34	32
Data set 8	58	51	36	35	34
Data set 9	56	52	37	34	36
Data set 10	57	52	36	35	34
Data set 11	55	51	36	33	35
Data set 12	58	52	38	35	32
Data set 13	56	50	36	33	34
Data set 14	57	51	37	33	33
Data set 15	58	52	36	34	32
Data set 16	57	52	36	34	34

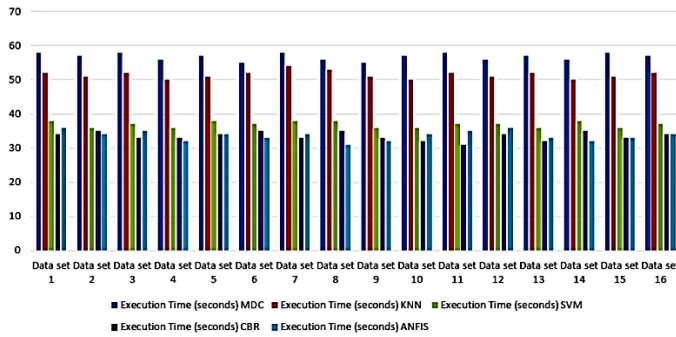


Fig. 13. Performance analysis based on Execution Time

TABLE XII. PERFORMANCE ANALYSIS BASED ON ACCURACY

Data set	Accuracy (%)				
	MDC	KNN	SVM	CBR	ANFIS
Data set 1	82.36	85.25	88.21	92.86	97.67
Data set 2	81.86	85.65	88.86	92.72	97.45
Data set 3	82.39	85.39	88.27	92.79	97.56
Data set 4	81.57	85.76	88.38	92.27	97.54
Data set 5	82.56	85.28	88.74	92.43	97.61
Data set 6	82.24	85.78	88.57	92.62	97.43
Data set 7	81.86	85.65	88.86	92.79	97.45
Data set 8	82.39	85.39	88.27	92.27	97.56
Data set 9	81.57	85.76	88.38	92.86	97.54
Data set 10	82.39	85.28	88.21	92.72	97.61
Data set 11	81.57	85.76	88.86	92.79	97.45
Data set 12	82.56	85.28	88.27	92.79	97.56
Data set 13	82.24	85.78	88.38	92.27	97.54
Data set 14	82.36	85.25	88.21	92.43	97.45
Data set 15	81.86	85.65	88.86	92.62	97.56
Data set 16	82.39	85.39	88.27	92.79	97.54

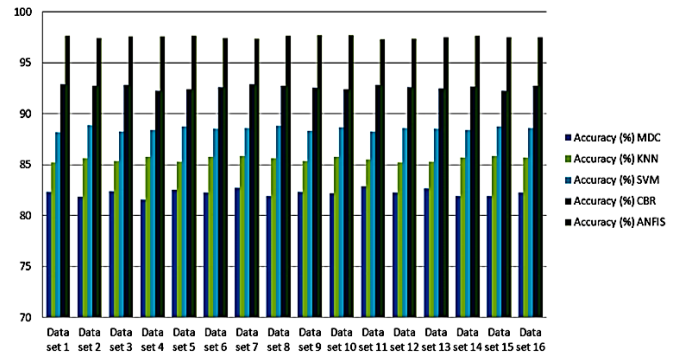


Fig. 14. Performance analysis based on accuracy

TABLE XIII. PERFORMANCE ANALYSIS BASED ON AVERAGE NUMBER OF ITERATIONS

Data set	Average Number of iterations				
	MDC	KNN	SVM	CBR	ANFIS
Data set 1	102	86	74	52	39
Data set 2	101	88	72	56	38
Data set 3	103	89	73	55	37
Data set 4	104	87	71	53	37
Data set 5	102	86	74	54	39
Data set 6	101	84	74	51	38
Data set 7	101	88	73	55	38
Data set 8	103	89	71	53	37
Data set 9	104	87	74	54	37
Data set 10	101	89	73	55	39
Data set 11	103	87	71	53	38
Data set 12	104	86	74	54	37
Data set 13	101	84	74	51	39
Data set 14	103	89	73	55	38
Data set 15	104	87	71	53	37
Data set 16	102	86	74	55	37

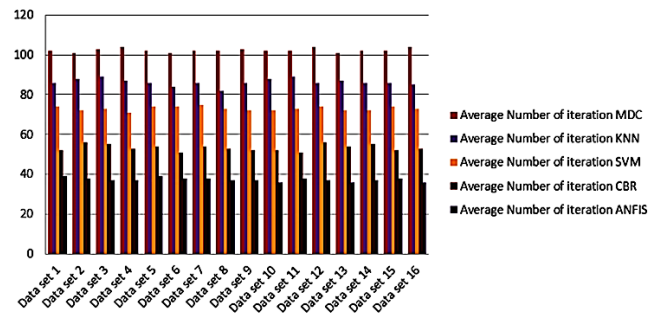


Fig. 15. Performance analysis based on average number of iterations

The overall performance of precision for various classification techniques utilised for the classification of data sets is shown in Table XIII and Fig. 16. According to a comparison of classification methods, ANFIS has higher precision than all other approaches, with precision values for every data set of 97.23%, 97.11%, 97.15%, 97.21%, 97.21%,

97.18%, 97.16%, 97.27%, 97.26%, 97.11%, 97.21%, 97.23%, 97.24%, 97.27%, and 97.28%. The overall recall performance of various classification techniques utilised for classifying data sets is shown in Table XIV and Fig. 17 respectively. Upon comparative analysis of classification methods, ANFIS had higher recall above all other methods that was 96.67%, 96.58%, 96.29%, 96.42%, 96.78%, 96.63%, 96.74%, 96.76%, 96.28%, 96.39%, 96.74%, 96.26%, 96.58%, 96.59%, 96.96% and 96.76% for each data sets.

TABLE XIV. PERFORMANCE ANALYSIS BASED ON PRECISION

Data set	Precision				
	MDC	KNN	SVM	CBR	ANFIS
Data set 1	84.75	86.32	89.56	91.58	97.23
Data set 2	84.56	86.24	89.62	91.56	97.11
Data set 3	84.36	86.31	89.58	91.54	97.15
Data set 4	84.45	86.74	89.54	91.64	97.21
Data set 5	84.63	86.32	89.56	91.62	97.18
Data set 6	84.82	86.72	89.53	91.58	97.16
Data set 7	84.56	86.24	89.62	91.56	97.11
Data set 8	84.36	86.31	89.58	91.54	97.15
Data set 9	84.45	86.74	89.54	91.64	97.21
Data set 10	84.63	86.32	89.56	91.62	97.18
Data set 11	84.56	86.24	89.62	91.58	97.16
Data set 12	84.36	86.31	89.58	91.56	97.11
Data set 13	84.45	86.74	89.54	91.54	97.15
Data set 14	84.63	86.32	89.56	91.64	97.21
Data set 15	84.56	86.24	89.62	91.62	97.18
Data set 16	84.45	86.74	89.54	91.54	97.15

Data set 9	83.24	85.18	87.46	90.80	96.29
Data set 10	83.22	85.13	87.36	90.85	96.42
Data set 11	83.28	85.11	87.42	90.84	96.78
Data set 12	83.21	85.16	87.39	90.87	96.63
Data set 13	83.26	85.12	87.46	90.88	96.67
Data set 14	83.24	85.16	87.36	90.80	96.58
Data set 15	83.22	85.18	87.42	90.85	96.29
Data set 16	83.28	85.13	87.39	90.84	96.42

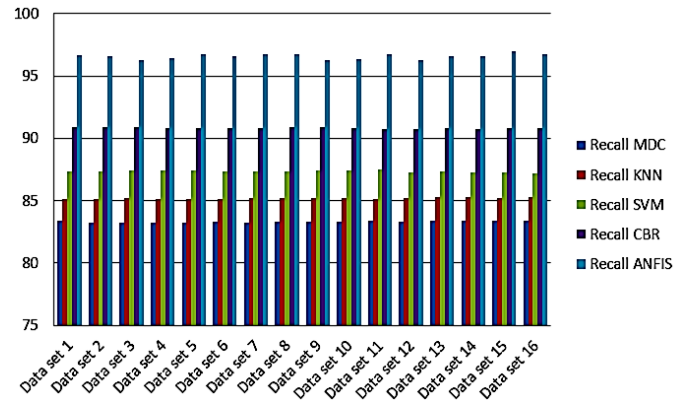


Fig. 17. Performance analysis based on recall

Table XV and Fig. 18 show the overall performance based on error rate of different classification technique employed for classification of data sets. Upon comparative analysis of classification methods, ANFIS had low error rate above all other methods that was 0.086, 0.074, 0.083, 0.056, 0.064, 0.073, 0.084, 0.074, 0.059, 0.065, 0.072, 0.089, 0.085, 0.086, 0.071 and 0.087 for each data set.

TABLE XVI. PERFORMANCE ANALYSIS BASED ON ERROR RATE

Data set	Error Rate				
	MDC	KNN	SVM	CBR	ANFIS
Data set 1	0.524	0.436	0.286	0.213	0.086
Data set 2	0.578	0.431	0.272	0.217	0.074
Data set 3	0.562	0.486	0.262	0.214	0.083
Data set 4	0.573	0.463	0.253	0.219	0.056
Data set 5	0.548	0.456	0.282	0.216	0.064
Data set 6	0.545	0.448	0.269	0.215	0.073
Data set 7	0.524	0.486	0.253	0.217	0.086
Data set 8	0.578	0.463	0.282	0.214	0.074
Data set 9	0.562	0.456	0.269	0.219	0.083
Data set 10	0.573	0.448	0.253	0.216	0.056
Data set 11	0.548	0.486	0.282	0.215	0.064
Data set 12	0.545	0.463	0.269	0.217	0.073
Data set 13	0.524	0.456	0.253	0.214	0.086
Data set 14	0.578	0.448	0.282	0.219	0.074
Data set 15	0.562	0.486	0.269	0.216	0.083
Data set 16	0.573	0.463	0.253	0.215	0.056

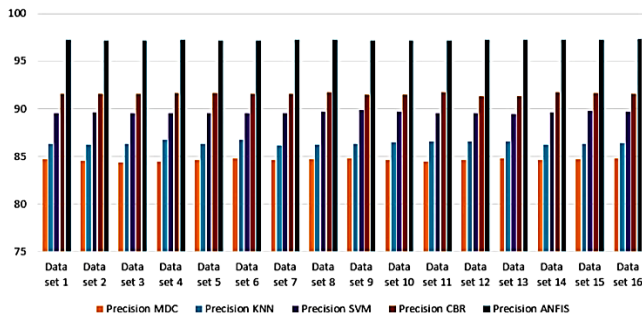


Fig. 16. Performance analysis based on Precision

TABLE XV. PERFORMANCE ANALYSIS BASED ON RECALL

Data set	Recall				
	MDC	KNN	SVM	CBR	ANFIS
Data set 1	83.36	85.12	87.36	90.89	96.67
Data set 2	83.21	85.16	87.38	90.87	96.58
Data set 3	83.26	85.18	87.42	90.88	96.29
Data set 4	83.24	85.13	87.39	90.80	96.42
Data set 5	83.22	85.11	87.46	90.85	96.78
Data set 6	83.28	85.16	87.36	90.84	96.63
Data set 7	83.21	85.12	87.42	90.87	96.67
Data set 8	83.26	85.16	87.39	90.88	96.58



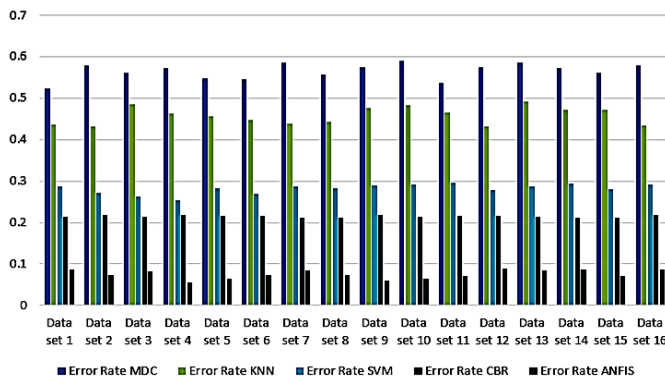


Fig. 18. Performance analysis based on error rate

## V. CONCLUSION

Face Detection is required as a preprocessing procedure in a workflow for a variety of applications such as active presence analysis, recognition, and reidentification. In the past, numerous research in the area of face detection were conducted, and multiple robust methods were suggested and tested on diverse datasets. These approaches are also used in a variety of applications. Despite the fact that this domain appears to be rather old and that considerable work has obviously gone into it, there is still opportunity for development. Previous research has focused on challenges such as face positions, emotions, picture scales, and occlusions, with promising results. Work on advanced topics such as low-resolution pictures, suggested anchoring, scale-invariance of models, and model size reduction has been investigated in recent years, with many solutions given. In this article, we will cover the most recent papers in this field, the difficulties they address, and the technologies they employ. The Adaptive Neuro Fuzzy Inference System (ANFIS) method was designed to overcome this problem. In classification techniques like MDC, KNN, SVM, CBR, ANFIS; The performance of ANFIS resulted in better recognition of face. The proposed research method was compared with the existing methods such as MDC, KNN and SVM which proved to provide better accuracy than the latter. CBR accuracy value were 92% and it is 97% in ANFIS. The performance of proposed system was analysed using the following quality measure like execution time, accuracy, F1 score, precision, recall, iteration and error rate ANFIS resulted in better performance compared to other existing system. The limitation of the proposed system is we were used MATLAB software, it needs more memory space to run this project. In future we will try to implement this project in opensource software's like Open CV.

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# Comparative Analysis of DIDIM and IV Approaches using Double Least Squares Method

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**Abstract**—Usually, identifying dynamic parameters for robots involves utilizing the Inverse Dynamic Model (IDM) which is linear in relation to the parameters being identified, alongside Linear Least Squares (LLS) methods. To implement this approach, precise measurements of both torque and position must be obtained at a high frequency. Additionally, velocities and accelerations must be estimated by implementing a band-pass filtering technique on the position data. Given the presence of noise in the observation matrix and the closed-loop nature of the identification process, we have modified the Instrumental Variable (IV) method to address the issue of noisy observations. A novel identification technique, named (Direct and Inverse Dynamic Identification Model) DIDIM, which requires only torque measurements as input variables, has recently been successfully applied to a 6-degree-of-freedom industrial robot. DIDIM employs a closed-loop output error approach that utilizes closed-loop simulations of the robot. The experimental results reveal that the IV and DIDIM methods exhibit numerical equivalence. In this paper, we conduct a comparison of these two methods using a double step least squares (2SLS) analysis. We experimentally validate this study using a 2-degree-of-freedom planar robot.

**Keywords**—Identification; double least squares; instrumental variable; DIDIM method; robotics dynamics

## I. INTRODUCTION

The identification process for robots usually relies on the use of the inverse dynamic model and linear least squares methods. To create an overdetermined system, the IDM is sampled during the robot's motion with exciting trajectories. This technique has proven successful in identifying many robots and prototypes [1], [2], [3]. However, it requires precise measurements of joint positions and torques at a high sampling frequency (above 100Hz). Moreover, the identification is done in closed-loop due to the unstable nature of the double integrator, resulting in a noisy observation matrix. Consequently, in theory, the LLS estimator can present a bias [4].

To tackle this problem, we have adjusted the instrumental variable (IV) technique [5], taking inspiration from Hugues Garnier's team's research [6], [7], [8]. Recently, a new identification method was introduced and validated on a 2-degree-of-freedom robot [9]. This approach only requires joint torques as input parameters. The robot is simulated in closed loop, assuming the same control structure and exciting trajectories. The best-fit parameters minimize the squared difference between the simulated and measured torques. Experimental findings indicate that the results from the IV

method match numerically with those from the DIDIM method, indicating a strong connection between the two approaches.

The objective of this paper is to compare the methods using the double least squares technique and to experience the method of DIDIM with IV if it is perfect to our robot or not. The paper is organized as follows: Section II covers the modeling and identification of robots, Section III presents the identified prototype, Section IV explains the IV and DIDIM methods, Section V discusses the double least squares method, and finally, Section VI analyzes the results of the experiments.

## II. MODELING AND IDENTIFICATION OF ROBOTS

### A. Modelisation

The expression for the inverse dynamic model of a robot with  $n$  degrees of freedom is given as [10]:

$$\tau_{idm} = M(\theta)\ddot{\theta} + N(\theta, \dot{\theta}) \quad (1)$$

Where  $\theta$  represents the  $(n \times 1)$  vector of joint positions,  $\dot{\theta}$  and  $\ddot{\theta}$  are its temporal derivatives,  $\tau_{idm}$  denotes the  $(n \times 1)$  vector of joint torques,  $M(\theta)$  stands for the  $(n \times n)$  symmetric inertia matrix, and  $N(\theta, \dot{\theta})$  represents the  $(n \times 1)$  vector that combines centrifugal, Coriolis, gravitational, and friction forces. By employing the modified Denavit and Hartenberg geometric description (DHM), we can derive a linear inverse dynamic model in terms of standard dynamic parameters [10]:

$$\tau_{idm} = IDM_{STD}(\theta, \dot{\theta}, \ddot{\theta})\chi_{STD} \quad (2)$$

$IDM_{STD}(\theta, \dot{\theta}, \ddot{\theta})$  represents the standard linear regressor of size  $(n \times c)$ , where  $\chi_{STD}$  is the  $c \times 1$  column vector of standard dynamic parameters. These parameters include the inertia tensor coefficients  $XX_j, XY_j, XZ_j, YY_j, YZ_j, ZZ_j$  of body  $^j J_j$ , its mass denoted  $m_j$ , the first moment vector around the origin of body  $j$  denoted  $^j M_j, = [MX_j MY_j MZ_j]$ , the Coulomb and viscous friction parameters denoted respectively as  $Fs_j$  and  $Fv_j$ , and the actuator inertia  $Ia_j$ .

One crucial stage in the identification process is to identify the basic parameters. This is because some standard parameters combine in the inverse dynamic model's expression, and only their combination or grouping can be identified. The search for basic parameters involves determining the rank of  $IDM_{STD}$  and identifying linear combinations among its columns. Two

primary methods can be used to calculate the minimum inertial parameters: a literal method that involves energy calculations [10] and a numerical method based on QR decomposition [11].

The general relation for the minimal system is as follows:

$$\tau_{idm} = IDM(\theta, \dot{\theta}, \ddot{\theta})\chi \quad (3)$$

**IDM** ( $\theta, \dot{\theta}, \ddot{\theta}$ ) is the minimal linear regressor of dimension  $n \times b$ , where  $\chi$  is the column vector of base parameters of dimension  $(b \times 1)$ . However, due to noise and model errors, the actual torque  $\tau$  deviates from  $\tau_{idm}$  and can be expressed as:

$$\tau = \tau_{idm} + e = IDM(\theta, \dot{\theta}, \ddot{\theta})\chi + e \quad (4)$$

### B. Identification

The inverse dynamic model is sampled while the robot is being actuated to obtain an overdetermined system, which can be expressed as [12]:

$$Y(\tau) = W(\theta, \dot{\theta}, \ddot{\theta})\chi + \rho \quad (5)$$

$$\text{Or: } Y(\tau) = \left[ \begin{matrix} (Y^1(\tau))^T \\ \dots \\ (Y^n(\tau))^T \end{matrix} \right]^T, \mathbf{Y}^j(\tau) = \left[ \tau^j(1) \dots \tau^j(n_e) \right]^T$$

$$W(\theta, \dot{\theta}, \ddot{\theta}) = \begin{bmatrix} \mathbf{W}^1 \\ \dots \\ \mathbf{W}^n \end{bmatrix}, \mathbf{W}^j = \begin{bmatrix} \text{IDM}^j(\theta_1, \dot{\theta}_2, \ddot{\theta}_3) \\ \dots \\ \text{IDM}^j(\theta_{n_e}, \dot{\theta}_{n_e}, \ddot{\theta}_{n_e}) \end{bmatrix}$$

$Y(\tau)$  is the measurement vector with a dimension of  $(r \times 1)$ , and  $W$  is the observation matrix with a dimension of  $(r \times b)$ , where  $r = n_e \times n$ , and  $n_e$  is the number of recovered samples.

The estimation theory provides a broad range of methods. Classical methods can be employed to solve overdetermined systems, as long as the elements of  $W$  are handled appropriately to obtain good results.

$$\hat{\chi} = \min_{\hat{\chi}} \|\rho\|^2 \quad (6)$$

Since we are considering both base parameters and exciting trajectories,  $W$  has a maximum rank, leading to an explicit and unique solution for  $\hat{\chi}$ .

$$\hat{\chi} = \left( (W^T W)^{-1} W^T \right) Y = W^+ Y \quad (7)$$

In practice, the identified values are estimated with their standard deviation by assuming that  $W$  is deterministic and that  $\rho$  is a centered random vector with independent components, standard deviation  $\sigma_\rho$ , and covariance matrix  $C_\rho$  given by:

$$C_\rho = E(\rho\rho^T) = \sigma_\rho^2 I_r \quad (8)$$

where,  $I_r$  is the  $r$ -dimensional identity matrix. Assuming that the error vector is centered and has independent components with equal variances, the standard deviation  $\sigma_\rho$  can be calculated using the following unbiased estimator:

$$\sigma_\rho^2 = \|Y - W\hat{\chi}\|^2 / (r - b) \quad (9)$$

The expression for the covariance matrix of the estimation error is:

$$C_{\hat{\chi}} = \sigma_\rho^2 (W^T W)^{-1} \quad (10)$$

We deduce the standard deviation:

$$\sigma_{\hat{\chi}_j} = \sqrt{C_{\hat{\chi}}(\mathbf{j}, \mathbf{j})} \quad (11)$$

The relative standard deviation is estimated by:

$$\sigma_{\hat{\chi}_{j\%}} = 100 \sigma_{\hat{\chi}_j} / |\hat{\chi}_j| \quad (12)$$

While [13] has used this interpretation, it should be approached with caution in our case as the assumption of a deterministic  $W$  is not satisfied. The proposed model is not perfect, and the measurements are noisy, requiring preprocessing.

Although this criterion can be used to evaluate the quality of identification, the fact that  $W$  is not deterministic, and the experimental data is noisy poses a challenge. To overcome this, [13] suggests filtering both  $Y$  and the columns of  $W$ .

### C. Conclusion

The LLS approach is particularly advantageous because it avoids the need to integrate a differential system and eliminates issues with initial conditions. However, calculating velocities and accelerations via bandpass filtering of position is required. Lastly, the direct dynamic model (DDM) provided below must be validated through post-simulation.

$$M(\theta)\ddot{\theta} = \tau - N(\theta, \dot{\theta}) \quad (13)$$

Given that  $M(q)$  is a positive definite square matrix, the accelerations can be expressed as:

$$\ddot{\theta} = M^{-1}(\theta)(\tau - N(\theta, \dot{\theta})) \quad (14)$$

## III. METHOD IV AND DIDIM

### A. Method IV

The statistical assumptions necessary for the LLS estimator to work efficiently are not met in practical applications. Equation (5) involves constructing the observation matrix  $W$  using joint positions  $\theta$ , as well as numerically computed derivatives  $\dot{\theta}$  and  $\ddot{\theta}$ , making  $W$  noisy. Additionally, the identification process is performed in a closed loop, further violating the assumptions. As a result, the LLS estimator may be inconsistent.

The IV method addresses this issue [5]. By constructing an instrumental matrix  $V$ , the IV method proposes a consistent estimator that satisfies:

$$V^T Y = V^T W_{\hat{\chi}} + V^T \rho_{iv} = V^T W \hat{\chi}_{iv} \quad (15)$$

The solution in the sense of the instrumental variable is:

$$\hat{\chi}_{iv} = (V^T W)^{-1} V^T Y \quad (16)$$

Later on,  $V$  is computed as a function of  $\hat{\chi}^k$  (since only the IV method is discussed in this subsection, we use  $\hat{\chi}^k$  instead of  $\hat{\chi}_{iv}^k$  as there is no ambiguity). This defines an iterative procedure as follows:

$$\hat{\chi}^{k+1} = (V_k^T W)^{-1} V_k^T Y \quad (17)$$

where,

$$V_k = V(\hat{\chi}^k) \quad (18)$$

Given that  $V_k^T W$  matrix is invertible, the following assumptions are made:

$$\lim_{m \rightarrow \infty} (V_k^T W / m) \quad (19)$$

$$\lim_{m \rightarrow \infty} (V_k^T \rho_{iv} / m) = E(V_k^T \rho_{iv}) \quad (20)$$

Each value of  $\hat{\chi}^k$  converges to  $\chi$  with  $m$ , where  $m$  denotes the number of repetitions of  $W$  and  $\rho_{iv}$ .

One of the primary challenges is to determine an instrumental matrix  $V$ . One possible solution involves constructing an observation matrix using simulated data rather than measured data. These simulated data, known as instruments, are the outputs of an auxiliary system that approximates the noise-free model of the system to be identified [6][8]. In robotics, this auxiliary model is the robot's DDM, given by equation (13) [14]. The IV method adapted for identifying a robot's dynamics can be outlined by the following algorithm, as illustrated in Fig. 1:

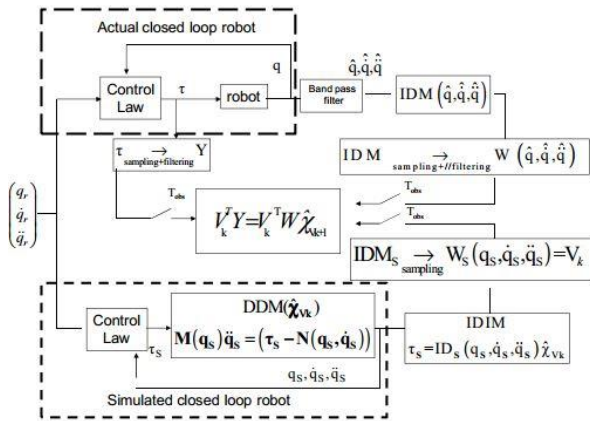


Fig. 1. Instrumental variable procedure.

\*During each iteration,  $\theta_s$ ,  $\dot{\theta}_s$ , and  $\ddot{\theta}_s$  are calculated by simulating and integrating the robot's DDM with the parameters identified in the previous iteration. The same control structure and exciting trajectories used for the real robot are applied.  $W_s$  is obtained by sampling  $IDM(\theta_s, \dot{\theta}_s, \ddot{\theta}_s)$ , and the instrumental matrix is selected as follows:

$$V(\hat{\chi}^k) = W_s(\theta_s(\hat{\chi}^k), \dot{\theta}_s(\hat{\chi}^k), \ddot{\theta}_s(\hat{\chi}^k)) \quad (21)$$

\* $Y(\tau)$  and  $W(\theta, \dot{\theta}, \ddot{\theta})$  they are constructed as in (5).

\*  $\hat{\chi}^{k+1}$  is given by (17). The algorithm stops when the relative errors become negligible:

$$\left( \frac{\|\rho_{iv}^{k+1}\| - \|\rho_{iv}^k\|}{\|\rho_{iv}^k\|} \right) \leq tol_1 \quad (22)$$

$$\max_{1, \dots, b} \left| \frac{\hat{\chi}^{k+1} - \hat{\chi}^k}{\hat{\chi}^k} \right| \leq tol_2 \quad (23)$$

Where  $tol_1$  is an ideally small value set by the user. Typically, there is a trade-off between accuracy and convergence speed.

It has been demonstrated in [15][16] that applying a filter  $F(s)$  to the columns of  $V$  is not mandatory. However, to reduce the sizes of  $Y$ ,  $W$ , and  $V$ , we use a sub-sampling filter and isolate the frequency range of interest. Typically, the cutoff frequency of this filter is set to 10 times the closed-loop system's bandwidth value to achieve a balance between precision and convergence speed.

### B. DIDIM Method

DIDIM is a closed-loop output error (CLOE) identification method that does not require position measurement [9]. The output  $y = \tau$  is the actual torque  $\tau$ . The simulated output  $y_s = \tau_{ddm}$  is the simulated torque of the DDM given by (13).

The signal  $\theta_{ddm}(t, \chi)$  is the result of integrating the DDM. The optimal solution  $\hat{\chi}$  minimizes the quadratic criterion  $J(\chi) = \|Y_s - Y\|^2$ . The vectors  $Y(\tau)$  and  $Y_s = Y(\tau_{ddm})$  are obtained by sampling the vectors  $\tau$  and  $\tau_{ddm}$  respectively.

The solution to this nonlinear problem is obtained through the application of Gauss-Newton regression. This approach relies on a Taylor series expansion of  $y_s$  around the current estimate of parameters at time  $k$ , represented by  $\hat{\chi}^k$  (given that this subsection only pertains to the DIDIM method, we use the notation  $\hat{\chi}^k$  instead of  $\hat{\chi}_{didim}^k$  for clarity):

$$y_s(\chi^{k+1}) = y_s(\chi^k) + \left( \frac{\partial(y_s(\chi))}{\partial \chi} \right)_{\chi^k} (\chi^{k+1} - \chi^k) + o \quad (24)$$

Where  $\left( \frac{\partial(y_s(\chi))}{\partial \chi} \right)_{\chi^k}$  is the Jacobian matrix of dimension  $(n \times b)$ . The MDD input torque  $\tau_{ddm}$  can be calculated analytically with the MDI expression (3) such that:

$$y_s(\chi) = \tau_{ddm}(\chi) = \tau_{idm}(\chi) = IDM(\theta_{ddm}(\chi), \dot{\theta}_{ddm}(\chi), \ddot{\theta}_{ddm}(\chi)) \chi \quad (25)$$

In this case, the Jacobian matrix is given by:

$$\begin{aligned} \left( \frac{\partial(y_s)}{\partial \chi} \right)_{\chi^k} &= \left( \frac{\partial(\tau_{ddm})}{\partial \chi} \right)_{\chi^k} = \left( \frac{\partial(\tau_{idm})}{\partial \chi} \right)_{\chi^k} \\ &= \frac{\partial}{\partial \chi} \left( IDM(\theta_{ddm}(\hat{\chi}^k), \dot{\theta}_{ddm}(\hat{\chi}^k), \ddot{\theta}_{ddm}(\hat{\chi}^k)) \hat{\chi}^k \right) \end{aligned} \quad (26)$$

As we use the same control for both the simulation and the real robot, the simulated states (positions, velocities, and accelerations) are minimally dependent on  $\chi$ . At each  $\hat{\chi}^k$  value, the Jacobian matrix (26) can be approximated as:

$$\left(\frac{\partial(y_s)}{\partial\chi}\right)_{\hat{\chi}^k} = IDM(\theta_{ddm}(\hat{\chi}^k), \dot{\theta}_{ddm}(\hat{\chi}^k), \ddot{\theta}_{ddm}(\hat{\chi}^k)) \quad (27)$$

Taking into account (27), the Taylor expansion becomes:

$$y = \tau = IDM(\theta_{ddm}(\hat{\chi}^k), \dot{\theta}_{ddm}(\hat{\chi}^k), \ddot{\theta}_{ddm}(\hat{\chi}^k))\chi^{k+1} + (o + e) \quad (28)$$

The MDI (3) estimates the states  $(\theta, \dot{\theta}, \ddot{\theta})$  using  $(\theta_{ddm}, \dot{\theta}_{ddm}, \ddot{\theta}_{ddm})$  obtained by simulating and integrating (13). At each iteration  $k$ , we sample (28) to obtain an over-determined linear system given by:

$$Y = W_{ddm}(\theta_{ddm}(\hat{\chi}^k), \dot{\theta}_{ddm}(\hat{\chi}^k), \ddot{\theta}_{ddm}(\hat{\chi}^k))\chi^{k+1} + \rho_{didim} \quad (29)$$

The MCLs are then applied to obtain the estimate at  $k+1$  denoted  $\hat{\chi}^{k+1}$ .

$$\hat{\chi}^{k+1} = (W_{ddm}^T W_{ddm})^{-1} W_{ddm}^T Y \quad (30)$$

This algorithm is iterated until:

$$\left(\|\rho_{didim}^{k+1}\| - \|\rho_{didim}^k\|\right) / \|\rho_{didim}^k\| \leq tol_1 \quad (31)$$

$$\max_{1 \dots b} \left| \left( \hat{\chi}^{k+1} - \hat{\chi}^k \right) / \hat{\chi}^k \right| \leq tol_2 \quad (32)$$

Where  $tol_1$  is an ideally small value set by the user. Generally, a compromise is made between accuracy and speed of convergence.

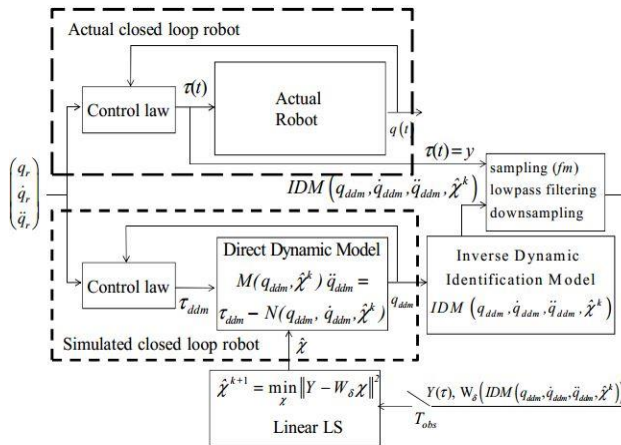


Fig. 2. Procedure of the DIDIM method.

The DIDIM method is named after its use of both direct and inverse dynamic models. As shown in Fig. 2, this approach combines these models to achieve dynamic identification.

### C. MDD Simulation and Integration

According to [8], the instrumental matrix must be close to the  $W_{nf}$  matrix defined by:

$$W_{nf} = W(\theta_{nf}, \dot{\theta}_{nf}, \ddot{\theta}_{nf}) \quad (33)$$

where,  $\theta_{nf}, \dot{\theta}_{nf}, \ddot{\theta}_{nf}$  are the noiseless values of  $\theta, \dot{\theta}, \ddot{\theta}$ .

Assuming model errors are negligible, it is necessary to have a well-tuned control loop that keeps  $\theta_{nf}, \dot{\theta}_{nf}$  and  $\ddot{\theta}_{nf}$  close to the reference states  $\theta_r, \dot{\theta}_r$  and  $\ddot{\theta}_r$ . According to (33), the simulated states  $\theta_s, \dot{\theta}_s$  and  $\ddot{\theta}_s$  must remain close to  $\theta_r, \dot{\theta}_r$  and  $\ddot{\theta}_r$  at every iteration of the algorithm. To achieve this, we use the same control structure for simulation as we do for the robot and adjust the control gains at each iteration to maintain the closed-loop bandwidth. This ensures that the bandwidth remains constant, regardless of the estimate  $\hat{\chi}^k$ . Therefore, we obtain:

$$(\theta_{nf}, \dot{\theta}_{nf}, \ddot{\theta}_{nf}) = (\theta_s, \dot{\theta}_s, \ddot{\theta}_s) = (\theta_r, \dot{\theta}_r, \ddot{\theta}_r) \forall \hat{\chi}_{iv}^k \quad (34)$$

Adapting the control gains at each iteration in the simulator allows us to ensure the approximation (27). Thus, (34) becomes:

$$(\theta_{nf}, \dot{\theta}_{nf}, \ddot{\theta}_{nf}) = (\theta_{ddm}, \dot{\theta}_{ddm}, \ddot{\theta}_{ddm}) = (\theta_r, \dot{\theta}_r, \ddot{\theta}_r) \forall \hat{\chi}_{didim}^k \quad (35)$$

This relation allows us to write that we have:

$$(\theta_{ddm}, \dot{\theta}_{ddm}, \ddot{\theta}_{ddm}) = (\theta_s, \dot{\theta}_s, \ddot{\theta}_s) \forall \hat{\chi}_{iv}^k \text{ and } \forall \hat{\chi}_{didim}^k \quad (36)$$

We arrive at the following results: the matrix  $W_{ddm}$  is precisely our instrumental matrix  $V$ , and (30) can be expressed in this way as well:

$$\hat{\chi}_{didim}^k = (V_k^T V_k)^{-1} V_k^T Y \quad (37)$$

The article does not provide an explanation of gain modulation at each iteration as it is beyond the scope of the paper. A brief overview can be found in [15],[16].

### D. Initialization of Algorithms

There are multiple methods to initialize the algorithm, such as using the CAD values or the identified LS values. However, since we ensure (34) and (35) in simulation, the easiest approach is to set  $\hat{Z}_{j0}$  and the other parameters to 0, which is called regular initialization [9]. This method results in an invertible initial mass matrix.

## IV. PROTOTYPE TO IDENTIFY AND RESULTS

We employ the IV and DIDIM methods on a two-degree-of-freedom planar robot depicted in Fig. 3, utilizing the modified Denavit-Hartenberg notation for geometric representation. The robot operates without a reducer (direct drive) and is actuated using DC motors. The inverse dynamic model is dependent on 8 minimal parameters  $\chi = [ZZ_{1R} \text{fv}_1 \text{fs}_1 \text{ZZ}_2 \text{MX}_2 \text{MY}_2 \text{fv}_2 \text{fs}_2]^T$ . Position control of the robot is achieved through a PD controller, with a closed-loop bandwidth of 2Hz, and an acquisition frequency of 200Hz. The torque is obtained from the current reference  $v_{ir}$ , with the current loop having a broad bandwidth (1KHz):

$$\tau_j = g t_j v_{irj} \quad (38)$$

$g t_j$  being the  $j$ -axis actuation gain.



Fig. 3. Prototype 2 DDL plan to identify.

Experimental application of the IV and DIDIM methods is carried out on the 2-degree-of-freedom planar prototype. In the IV method, the current command image and the position of each motor are measured, while only the current command image of each motor is measured in the DIDIM method.

In both methods, the columns of  $V$  are filtered using an under-sampling filter with a cutoff frequency of 20Hz, as the closed-loop bandwidth is 2Hz. All information regarding the rigid model is preserved, and the MATLAB decimate command is utilized for filter implementation.

Both methods use identical exciting trajectories and control structures as those used on the actual robot for simulation. The control gains are adjusted for every iteration.

In the case of the IV method, a fourth-order bidirectional Butterworth filter is used to filter the position, with a cutoff frequency of 20Hz. The velocity and acceleration are obtained through a centered difference calculation, ensuring that there is no phase distortion. Lastly, each column of  $W$  is filtered using the same under sampling filter as that used for filtering the columns of  $V$ .

Both methods are initialized with regular initialization. The simulation and MDD integration are carried out on the same MATLAB-SIMULINK platform for both methods. The platform is run on a laptop equipped with an INTEL Pentium 4 single-core processor operating on WINDOWS XP. Each iteration, which includes MDD integration and optimal solution calculation, takes approximately thirty seconds.

The experimental results are reported in Table I for the IV method and in Table II for the DIDIM method. Table III shows the convergence of the parameters, with both algorithms converging in just three iterations.

The key finding is that the IV method provides the same numerical estimation as the DIDIM method. The only difference is in the values of the parameters  $F_{v1}$  and  $F_{v2}$ , which have minimal impact on the robot's dynamics. As these parameters have a high relative standard deviation, their removal from the model results in little variation in the identified values of the other parameters and the residual norm.

From these experimental results, we can conclude that numerically  $\hat{\chi}_{IV} = \hat{\chi}_{DIDIM}$ . This can be explained by the following intuitive reasoning: the instruments are constructed from a simulation and integration of the MDD. Therefore, if the instruments are representative of the model to be identified,

then we can assume that  $W = V + w$  where  $w$  is a noise matrix of dimension  $(r \times b)$ . Furthermore, if each column of  $w$  denoted by  $w_k$  is orthogonal to the space spanned by the columns of  $V$ , then we have  $V^T w = \text{zeros}(b, b)$ . With these conditions, we do indeed obtain  $\hat{\chi}_{IV} = \hat{\chi}_{DIDIM}$ .

The next section will present the method of least squares, which we will use to prove this statement.

TABLE I. IDENTIFICATION WITH IV

Parameters	$\hat{\chi}^0$	$\hat{\chi}^3$	$2\sigma_{\hat{\chi}}$	$\% \sigma_{\hat{\chi}}$
$ZZ_{1R}$	1.0	3.45	0.036	0.52
$F_{v1}$	0.0	0.04	0.032	40.0
$F_{c1}$	0.0	0.82	0.05	3.0
$ZZ_2$	1.0	0.061	0.0006	0.49
$LMX_2$	0.0	0.124	0.0013	0.52
$LMY_2$	0.0	0.0065	0.0005	3.5
$F_{v2}$	0.0	0.013	0.0084	30.0
$F_{c2}$	0.0	0.137	0.008	3.0

TABLE II. IDENTIFICATION WITH DIDIM

Parameters	$\hat{\chi}^0$	$\hat{\chi}^3$	$2\sigma_{\hat{\chi}}$	$\% \sigma_{\hat{\chi}}$
$ZZ_{1R}$	1.0	3.45	0.036	0.52
$F_{v1}$	0.0	0.03	0.030	40.0
$F_{c1}$	0.0	0.82	0.05	3.0
$ZZ_2$	1.0	0.061	0.0006	0.49
$LMX_2$	0.0	0.124	0.0013	0.52
$LMY_2$	0.0	0.0067	0.0005	3.5
$F_{v2}$	0.0	0.015	0.0084	30.0
$F_{c2}$	0.0	0.137	0.008	3.0

TABLE III. CONVERGENCE OF VALUES FOR THE TWO METHODS

Parameters	$\hat{\chi}^0$	$\hat{\chi}^1$	$\hat{\chi}^2$	$\hat{\chi}^3$
$ZZ_{1R}$	1.0	3.46	3.45	3.45
$F_{v1}$	0.0	0.04	0.02	0.03
$F_{c1}$	0.0	0.82	0.85	0.82
$ZZ_2$	1.0	0.06	0.061	0.061
$LMX_2$	0.0	0.122	0.124	0.124
$LMY_2$	0.0	0.05	0.068	0.067
$F_{v2}$	0.0	0.005	0.014	0.015
$F_{c2}$	0.0	0.135	0.137	0.137

## V. DOUBLE LEAST SQUARES METHOD

### A. General Idea

As stated in [4], Theil introduced the method of two-stage least squares in 1953, and independently, Basman also introduced it in 1957 for simultaneous equation modeling. The Two-Stage Least Squares (2SLS) approach involves estimation in two stages:

- During the first stage, we carry out a regression of each column of  $W$ , denoted by  $W_{:,k}$ , on  $V$ , to separate the part of  $W_{:,k}$  that is correlated with  $\rho$  from the part that is correlated with the model. This leads to an estimation of  $W_{:,k}$ , denoted by  $\hat{W}_{:,k}$ . By concatenating the estimated columns  $\hat{W}_{:,k}$ , we obtain an estimate of the matrix  $W$ , denoted by  $\hat{W}$ .



- To perform the second stage, we regress  $Y$  on  $\hat{W}$ . Thus, we obtain the following general solution:

$$\hat{\chi}_{2SLS} = (\hat{W}^T \hat{W})^{-1} \hat{W}^T Y \quad (39)$$

This is the 2SLS solution.

### B. Implementation

Typically, when using 2SLS, the first regression stage for each column of  $W$  is defined as follows:

$$W_{:,k} = V \Pi_k + w_k \quad (40)$$

Where  $\Pi_k$  is a coefficient vector of dimension  $(b \times 1)$  and where  $w_k$  is a noise vector of dimension  $(r \times 1)$ . We obtain the estimate of each column  $W_{:,k}$  as:

$$\hat{W}_{:,k} = V \hat{\Pi}_k \quad (41)$$

After performing this regression for each column of  $W$  and concatenating the estimated columns, we obtain a matrix equation in the form:

$$\hat{W} = V \hat{\Pi} \quad (42)$$

Where  $\hat{\Pi} = [\hat{\Pi}_1 \dots \hat{\Pi}_k \dots \hat{\Pi}_b]$  is a matrix of constant coefficients of dimension  $(b \times b)$ . This relationship also involves:

$$W = \hat{W} + w = V \hat{\Pi} + w \quad (43)$$

The second step is the regression of  $Y$  on  $\hat{W}$ . We have:

$$\hat{W} = V \hat{\Pi} = V(V^T V)^{-1} V^T W \quad (44)$$

By incorporating this relation into (39) and assuming that relation (19) holds, we obtain:

$$\hat{\chi}_{2SLS} = (V^T W)^{-1} V^T Y \quad (45)$$

$$\hat{\chi}_{2SLS} = \hat{\chi}_{IV} \quad (46)$$

Therefore, the 2SLS solution is equivalent to the instrumental variable solution.

### C. Using 2SLS to Compare IV and DIDIM

Using the 2SLS algorithm to identify the dynamic parameters of robots is feasible, given our knowledge on constructing the instrumental matrix  $V$ . However, our objective is to establish a link between the IV method and the DIDIM method.

By utilizing 2SLS, we can examine the projection of each column  $W_{:,k}$  of  $W$  (and thus,  $W$  as a whole) onto the space formed by the columns of  $V$ . Equation (44) denotes the orthogonal projection of each column  $W_{:,k}$  onto the space generated by the columns of  $V$ . To conduct the first regression of each column  $W_{:,k}$  on  $V$ , we express it as follows:

$$W_{:,k} = (\text{ones}(r,1) V) \Pi_k + w_k \quad (47)$$

Where

$$V = [V_{:,1} \dots V_{:,b}] \quad (48)$$

$$\Pi_k = [\pi_{0,k} \pi_{1,k} \dots \pi_{b,k}]^T$$

An offset term denoted as  $\pi_{0,k}$  is deliberately introduced to estimate the average value of the residual  $w_k$ . The estimated value of this term, denoted as  $\hat{\pi}_{0,k}$ , is expected to be zero in theory.

Once we have obtained the estimates, we can interpret the results as follows:

$$\hat{\pi}_{j,k} = 1 \quad \text{pour } j=k \quad (49)$$

$$\hat{\pi}_{j,k} = 0 \quad \text{pour } j \neq k \quad (50)$$

In terms of physicality, this indicates that the instruments are reliable (i.e., adequately reflecting the model to be identified) and that we have effectively separated the portion of  $W_{:,k}$  that correlates with  $\rho$  and the portion that corresponds to the model. Through concatenation, we achieve:

$$\hat{W} = [\text{ones}(r,1) V] \hat{\Pi} \quad (51)$$

With:

$$\hat{\Pi} = \begin{bmatrix} \text{zeros}(1,b) \\ I_{b,b} \end{bmatrix} \quad (52)$$

$I_{b,b}$  represents the identity matrix with dimensions  $(b \times b)$ . Now, let's delve into the details of this relationship:

$$\hat{W} = \text{zeros}(r,b) + V I_{b,b} = V \quad (53)$$

So, with (39) we get:

$$\hat{\chi}_{2SLS} = (V^T V)^{-1} V^T Y = \hat{\chi}_{\text{didim}} \quad (54)$$

Or, according to (46):

$$\hat{\chi}_{2SLS} = \hat{\chi}_{iv} = \hat{\chi}_{\text{didim}} \quad (55)$$

Another way to arrive at this result is by expressing that we have, using equations (43) and (53):

$$W = V + w \quad (56)$$

Alternatively, using geometric construction, we can establish that every residual  $w_k$  is perpendicular to the subspace formed by the columns of  $V$  (normal equation). Consequently, this leads to the following implication:

$$V^T w = \text{zeros}(b,b) \quad (57)$$

So by incorporating (56), (57) into (16), we get:

$$\hat{\chi}_{iv} = (V^T V)^{-1} V^T Y \quad (58)$$

And we find well (55).

D. Conclusion

Through the utilization of 2SLS, we have established that the solution yielded by the IV method is equivalent to the solution obtained through DIDIM, given that relations (49) and (50) are upheld. These two relationships hold great significance as they imply the following physical interpretations:

- The instruments demonstrate high quality, effectively capturing the essence of the physical model under consideration. This has allowed us to successfully separate the component of W that correlates with the model from the component that correlates with  $\rho$ .
- Moreover, the model error remains significantly minimal in comparison to other sources of noise.

During the experimental phase, we conduct the dual regression at every iteration of the IV method. Furthermore, we specify the necessary conditions to ensure the continuous validation of both relationships (49) and (50).

VI. EXPERIMENTAL RESULTS AND ANALYSIS

The experimental trials are carried out using identical conditions as outlined in Section IV. The dual regression is executed for every iteration and each column of W. The resulting estimated vectors  $\hat{\Pi}_k$  are stored in an array for subsequent analysis of the estimations.

The determined coefficient values for each  $\hat{\Pi}_k$  at every iteration are consolidated in Table IV. To improve clarity, the results for each column are presented individually, Tables IV to XI.

TABLE IV. ESTIMATES OF  $\Pi$ , J = 1

Parameter	$\hat{\Pi}_1^0$	$\hat{\Pi}_1^1$	$\hat{\Pi}_1^2$	$\hat{\Pi}_1^3$
$\pi_{0,1}$	0.0	0.0	0.0	0.0
$\pi_{1,1}$	1.0	1.0	1.0	1.0
$\pi_{2,1}$	0.001	0.0	-0.001	0.001
$\pi_{3,1}$	0.0	0.0	0.0	0.0
$\pi_{4,1}$	0.0	0.0	0.0	0.0
$\pi_{5,1}$	0.0	0.0	0.0	0.0
$\pi_{6,1}$	0.002	0.001	0.002	-0.001
$\pi_{7,1}$	-0.001	0.001	0.002	0.001
$\pi_{8,1}$	0.0	0.0	0.0	0.0

TABLE V. ESTIMATES OF  $\Pi$ , J = 2

Parameter	$\hat{\Pi}_2^0$	$\hat{\Pi}_2^1$	$\hat{\Pi}_2^2$	$\hat{\Pi}_2^3$
$\pi_{0,2}$	0.001	0.0	-0.001	0.001
$\pi_{1,2}$	0.002	0.002	-0.001	-0.001
$\pi_{2,2}$	1.001	1.002	1.001	1.001
$\pi_{3,2}$	0.001	0.002	0.001	-0.002
$\pi_{4,2}$	-0.002	-0.002	0.002	0.002
$\pi_{5,2}$	-0.002	-0.001	0.0	-0.001
$\pi_{6,2}$	0.001	0.001	0.002	-0.001
$\pi_{7,2}$	0.001	0.001	0.002	0.001
$\pi_{8,2}$	-0.002	-0.002	-0.002	-0.002

TABLE VI. ESTIMATES OF  $\Pi$ , J = 3

Parameter	$\hat{\Pi}_3^0$	$\hat{\Pi}_3^1$	$\hat{\Pi}_3^2$	$\hat{\Pi}_3^3$
$\pi_{0,3}$	0.0	0.0	0.0	0.0
$\pi_{1,3}$	0.0	0.0	0.0	0.0
$\pi_{2,3}$	-0.001	0.0	-0.001	-0.001
$\pi_{3,3}$	1.0	1.0	1.0	1.0
$\pi_{4,3}$	0.0	0.0	0.0	0.0
$\pi_{5,3}$	0.0	0.0	0.0	0.0
$\pi_{6,3}$	0.001	0.001	0.002	-0.001
$\pi_{7,3}$	0.001	0.001	-0.002	0.001
$\pi_{8,3}$	0.0	0.0	0.0	0.0

TABLE VII. ESTIMATES OF  $\Pi$ , J = 4

Parameter	$\hat{\Pi}_4^0$	$\hat{\Pi}_4^1$	$\hat{\Pi}_4^2$	$\hat{\Pi}_4^3$
$\pi_{0,4}$	0.0	0.0	0.0	0.0
$\pi_{1,4}$	0.0	0.0	0.0	0.0
$\pi_{2,4}$	0.0	0.0	-0.001	-0.001
$\pi_{3,4}$	0.0	0.0	0.0	0.0
$\pi_{4,4}$	1.0	1.0	1.0	1.0
$\pi_{5,4}$	0.0	0.0	0.0	0.0
$\pi_{6,4}$	0.002	0.0	0.002	-0.001
$\pi_{7,4}$	0.0	0.001	-0.002	-0.002
$\pi_{8,4}$	0.0	0.0	0.0	0.0

TABLE VIII. ESTIMATES OF  $\Pi$ , J = 5

Parameter	$\hat{\Pi}_5^0$	$\hat{\Pi}_5^1$	$\hat{\Pi}_5^2$	$\hat{\Pi}_5^3$
$\pi_{0,5}$	0.0	0.0	0.0	0.0
$\pi_{1,5}$	0.0	0.0	0.0	0.0
$\pi_{2,5}$	0.001	0.001	-0.001	-0.001
$\pi_{3,5}$	0.0	0.0	0.0	0.0
$\pi_{4,5}$	0.0	0.0	0.0	0.0
$\pi_{5,5}$	1.0	1.0	1.0	1.0
$\pi_{6,5}$	0.0	0.0	0.001	-0.001
$\pi_{7,5}$	0.0	0.001	0.0	0.001
$\pi_{8,5}$	0.0	0.0	0.0	0.0

TABLE IX. ESTIMATES OF  $\Pi$ , J = 6

Parameter	$\hat{\Pi}_6^0$	$\hat{\Pi}_6^1$	$\hat{\Pi}_6^2$	$\hat{\Pi}_6^3$
$\pi_{0,6}$	0.002	0.001	0.002	0.001
$\pi_{1,6}$	-0.001	0.001	-0.001	0.002
$\pi_{2,6}$	-0.001	-0.001	-0.001	-0.001
$\pi_{3,6}$	0.001	0.002	0.001	0.002
$\pi_{4,6}$	-0.001	-0.002	-0.002	-0.001
$\pi_{5,6}$	-0.001	-0.001	-0.001	0.001
$\pi_{6,6}$	0.998	0.999	0.998	0.998
$\pi_{7,6}$	0.002	0.001	-0.001	-0.002
$\pi_{8,6}$	0.002	0.002	0.001	0.002

TABLE X. ESTIMATES OF  $\Pi$ ,  $J = 7$

Parameter	$\hat{\Pi}_7^0$	$\hat{\Pi}_7^1$	$\hat{\Pi}_7^2$	$\hat{\Pi}_7^3$
$\pi_{0,7}$	-0.002	-0.001	0.002	-0.001
$\pi_{1,7}$	-0.001	0.001	-0.001	0.002
$\pi_{2,7}$	0.001	-0.001	-0.002	0.001
$\pi_{3,7}$	-0.002	0.001	-0.001	-0.002
$\pi_{4,7}$	0.001	0.002	-0.001	0.002
$\pi_{5,7}$	-0.002	0.001	-0.001	0.002
$\pi_{6,7}$	0.002	0.002	0.001	0.002
$\pi_{7,7}$	1.002	0.999	1.001	0.998
$\pi_{8,7}$	-0.002	0.002	0.001	-0.002

TABLE XI. ESTIMATES OF  $\Pi$ ,  $J = 8$

Parameter	$\hat{\Pi}_8^0$	$\hat{\Pi}_8^1$	$\hat{\Pi}_8^2$	$\hat{\Pi}_8^3$
$\pi_{0,8}$	0.0	0.0	0.0	0.0
$\pi_{1,8}$	0.0	0.0	0.0	0.0
$\pi_{2,8}$	-0.001	-0.002	-0.001	0.002
$\pi_{3,8}$	0.0	0.0	0.0	0.0
$\pi_{4,8}$	0.0	0.0	0.0	0.0
$\pi_{5,8}$	0.0	0.0	0.0	0.0
$\pi_{6,8}$	0.001	-0.001	0.001	-0.001
$\pi_{7,8}$	0.002	0.001	-0.002	0.001
$\pi_{8,8}$	1.0	1.0	1.0	1.0

The estimated values obtained through 2SLS are identical to those presented in Table I and Table II. Based on these experimental findings, we can conclude that it is possible to

write  $\hat{\Pi} = \begin{bmatrix} \text{zeros}(1,b) \\ I_{b,b} \end{bmatrix}$  for each iteration. This suggests that relations (49) and (50) are practically fulfilled. Consequently, we have effectively confirmed through experimentation that we have  $\hat{\chi}_{iv} = \hat{\chi}_{didim}$ .

The slight discrepancies we observe could be attributed to minor modeling errors.

The crucial aspect of this analysis revolves around relations (36), (49), and (50). Essentially, these relations indicate that we can treat the states simulated by the IV method and the DIDIM method as interchangeable, and that column  $W_{:,k}$  projects orthogonally onto its counterpart  $V_{:,k}$ . Importantly,  $W_{:,k}$  is not derived from a linear combination of multiple columns of  $V$ , which could potentially be the case in an absolute sense. As a result, we effectively differentiate the component of  $W_{:,k}$  that is correlated with the model from the component correlated with  $\rho$ . The strong adherence of relations (49) and (50) primarily arises from the careful adjustment of control gains during each iteration in the simulation, aiming to ensure that  $(\theta_s, \dot{\theta}_s, \ddot{\theta}_s) = (\theta_{ddm}, \dot{\theta}_{ddm}, \ddot{\theta}_{ddm}) = (\theta_{nf}, \dot{\theta}_{nf}, \ddot{\theta}_{nf})$  closely approximates  $(\theta_r, \dot{\theta}_r, \ddot{\theta}_r)$ , while keeping modeling errors at a minimum. Experiments were conducted with significant modeling errors. For example, we intentionally omitted the term  $LMX_2$  from the model. As a result, both methods converge to an inaccurate solution. Consequently, relations (49) and (50) are no longer fulfilled. This serves as evidence that our projections are flawed because

$Y$  is being regressed on a subspace that no longer accurately represents the model.

### A. The Parameters Used

To overcome these issues, an alternative identification approach is proposed. This method relies on a closed-loop simulation, where the direct dynamic model is used with the same control law and reference trajectories as those applied to the real robot. The parameters obtained through this identification method are determined by minimizing the 2-norm of the error between the measured torque and the simulated torque. This results in a nonlinear least squares problem. The analytical expression of the sensitivity functions is greatly simplified by using the inverse model to express the simulated torque, which greatly facilitates the calculation of the solution.

In the robot identification procedure, the inverse dynamic model (IDM) and the linear least squares (LLS) method are commonly used. To create an overdetermined system, the IDM is sampled during the robot's motion using stimulating trajectories. This approach has proven to be effective in identifying numerous robots and prototypes [17], [20], [3].

However, it requires accurate measurements of joint positions and torques at a high sampling frequency (greater than 100 Hz). Furthermore, the identification is performed in a closed loop due to the inherent instability of the double integrator, resulting in a noisy observation matrix. Consequently, in theory, the linear least squares estimator may exhibit bias [19].

To address this issue, we have adapted the instrumental variables (IV) technique, building upon the research work conducted by Hugues Garnier's team [6], [9], [8]. Recently, a new identification method has been proposed and validated on a two-degree-of-freedom robot [18]. This approach only requires the joint torques as input parameters. The robot is simulated in a closed loop, assuming the same control structure and stimulating trajectories.

The optimal parameters are determined by minimizing the squared difference between the simulated and measured torques. Experimental results demonstrate a significant correlation between the outcomes obtained using the instrumental variables (IV) method and those of the DIDIM method, indicating a strong agreement between these two approaches.

## VII. CONCLUSION

This paper presents a comparative analysis of the IV and DIDIM methods using 2SLS. The theoretical framework is substantiated by experimental findings. The results of this study demonstrate that under specific conditions, we achieve a numerical equality of  $\hat{\chi}_{iv} = \hat{\chi}_{didim}$ .

From our standpoint, this outcome holds significance as it indicates that the IV method, as employed in robot identification and widely used in various applications, tends to converge towards the model-based approach. This observation provides a possible explanation for the IV method's resilience to assumptions made about noise. However, it would be overly

simplistic, and possibly incorrect, to equate the IV method with the model-based method. The outcome relies on the construction of our instruments and how they are implemented.

In the end, 2SLS could serve as a diagnostic tool, enabling us to examine the projection of each regressor column onto the space formed by the instrumental matrix columns. The MDI and DIDIM methods will be implemented on cable-driven parallel structure interfaces, such as the VIRTUOSE robots developed by HAPTION; also, will explore other methods for robot enhancement.

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# Skin Cancer Classification using Delaunay Triangulation and Graph Convolutional Network

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**Abstract**—Oftentimes, many people or even medical workers misdiagnose skin cancer, which may lead to malpractice and thus, resulting in delayed recovery or life-threatening complications. In this research, a Graph Convolutional Network (GCN) method is proposed as a classification model and Delaunay triangulation as its feature extraction method to classify various types of skin cancers. Delaunay triangulation serves the purpose of boundary extraction, and this implementation allows the model to focus only on the cancerous lesion and ignore the skin around it. This way, the types of skin cancer can be predicted more accurately. Furthermore, GCN offers many advantages in medical image analysis over traditional CNN models. GCN can model interactions between different regions and structures in an image and perform messaging between nodes, whereas CNN is not explicitly designed to do such thing. Other than that, GCN can also leverage transfer learning and few-shot learning techniques to address the challenges of limited annotated medical image datasets. However, the result shows that the proposed model tends to overfit and is unable to generate correct predictions for new skin cancer images. There are several reasons that could lead the model to overfit, such as imbalance data, incorrect feature extraction, insufficient features for data prediction, or the data containing noise.

**Keywords**—Skin cancer; Delaunay triangulation; graph convolutional network; GCN; multilabel image classification; convolutional neural network; CNN

## I. INTRODUCTION

Skin cancer is the most prevalent form of cancer for people with white or light-colored skin all over the world. Exposure to ultraviolet radiation (UVR) is a primary etiologic agent in the emergence of skin cancer, which may result in DNA damage and genetic abnormalities, subsequently leading to skin cancer [1]. In general, skin cancers are classified as melanoma or non-melanoma. Skin cancer, which includes both melanoma and non-melanoma, are the particularly prevalent form of cancer malignancies in the white population. However, the one responsible for the majority of deaths caused by cancer is melanoma skin cancer [2].

Melanoma screening is not suggested as a population screening tool for wide range of reasons. This is because the effectiveness of early detection or screening programs has not yet been tested in randomized trials [3]. Although the majority of at-risk patients attend medical appointments or even a doctor's appointment that offers the option of skin testing in melanoma detection, only a few medical practitioners have specialized knowledge or training in melanoma detection. In

the study published by Annals of Oncology, researches compared the performance of 58 international dermatologists and found CNN's skin cancer diagnoses to be more accurate than diagnoses made by a panel of dermatologists. [4].

Considering that not many non-dermatologist healthcare workers and dermatologists could correctly identify melanomas, it could harm patients with skin cancer. Not knowing that one has skin cancer, patients would carry on with their lives and consider it as a normal mole, little that they know that it is a skin cancer. Ignoring the first signs of skin cancer would let the cancer grow malignant, and eventually will harm the patients. Even when healthcare workers successfully diagnose a patient with skin cancer, there are still possibilities of human error such as misdiagnosing skin cancer type (melanoma or non-melanoma, malignant or benign) which could further harm the patients through medical malpractice, namely giving the inappropriate treatment which would result in delayed recovery, and negative medical outcomes (additional pains or even other non-life threatening and life-threatening complications).

Misdiagnosis and malpractice only harm patients in a way that is very dangerous for that person and even would cost a person's life. Considering that these issues happened in real life and could even happen to ourselves, this study strives to help medical workers and patients overcome these issues. With the help of current technology, it will aid medical personnel in identifying both malignant and benign melanoma skin cancers, as well as skin cancers that are not melanoma related. Time and effort are required to gain experiences. Medical professionals have spent years researching and treating patients in a manner that only they can. Several researches have proven that modern technology outperforms medical professionals in terms of knowledge. In some cases, if not all, a doctor's opinion is needed rather than relying solely on technology. Additionally, technology can be used as a tool to substantiate medical opinion with expert advice [5].

Several research projects on the automated classification of melanoma imagery utilizing computer vision and machine learning algorithms have been carried out. Despite the fact that these researches show promising outcomes, the application of computer vision and traditional machine learning has a significant impact on classification performance through features identified in skin lesion segmentation results and classification methods [5]. This study proposes the fusion of Delaunay triangulation and graph convolutional network (GCN) as a method to classify images of skin cancer types.

The use of deep learning hoped to reduce human intervention and improve accuracy.

Both methods used were hoped to give better results in classifying skin cancer. Delaunay triangulation is used to segment cancer from the skin or to extract masks from lesion regions without requiring a training phase so that the neural network can better classify the type of skin cancer. Whilst convolutional neural network (CNN) has emerged as the most advanced network for pattern identification in medical image analysis, it is not without limitations [6], graph convolutional network (GCN) can handle irregular and non-grid data. Many real-world applications, such as social analytics, identifying fraudulent activity, traffic forecasts, computer vision, and others, generate graphs naturally. Data can be shown as graphs that encode structural details to represent relationships between items and provide more interesting insights underlying the data [7].

The data used in this study are skin cancer images obtained from the Kaggle website. The images are then resized and go through further data preprocessing steps. Skin cancer mask points were then generated using the Delaunay triangulation method. The obtained points were stored in an array and used in the modeling step using the GCN model. Delaunay triangulation serves the purpose of boundary extraction, and this implementation allows the model to focus only on the cancerous lesion and ignore the skin around it. Furthermore, GCN offers many advantages in medical image analysis over using traditional CNN models. GCN can model interactions between different regions and structures in an image and perform messaging between nodes. Other than that, GCN also can leverage transfer learning and few shot learning techniques to address the challenges of limited annotated medical image datasets.

By using cancer lesion points obtained using Delaunay triangulation and GCN as its model, classification tasks may be performed more accurately, even when dealing with images with significant noise that can lead to overfitting. When using CNN as the model, the images were processed as it is without any further data preprocessing steps. CNN itself is considered as the most advanced network for pattern identification in medical image analysis. However, when faced with images of skin cancer taken from quite a distance, the model would not perform well. Rather than focusing on the cancer lesion alone, the model would also focus on the skin surrounding it. The model would attempt too hard in seeking the most suitable fit to the data which will lead to overfit, as not everyone has the same skin color.

## II. RELATED WORK

There are many studies relevant to the proposed topic of this research. One example is a study by Shi Yin and friends who performed the diagnosis of kidney disease using ultrasound imaging [8]. In this study, the researchers used a methodology that builds on recent advances in Deep MIL, employing a convolutional neural network (CNN) to extract instance-level data from 2D kidney ultrasound images and a graph convolutional network (GCN) examine the characteristics of and further optimize the instance level. It works by looking at possible correlations between instances of

the same bag. ReLU activation function was used in this study. GCNs, knowledge-based MIL collection, and instance-level monitoring based on instances with reliable labels can improve MIL classification performance. The dataset used in this study was based on a dataset of US clinical renal scans from renal patients collected at the Children's Hospital of Philadelphia (CHOP). This study shows that their proposed method obtained an accuracy of 84.89%.

Other research on skin cancer detection is proposed by Abilash Panja, Christy Jackson J, and Abdul Quadir [9]. The researchers presented a deep convolutional neural network (CNN) to classify melanoma images into either benign or malignant groups. The model is constructed with convolution layer, activation layer, batch normalization layer, and pooling layer, with each of the convolutional layers has an activation function that uses ReLU, while the output layer has an activation function that is sigmoid, and the use of binary cross entropy for model fitting. Deep neural network's stability and performance are improved by using a normalization layer. The dataset used in this work originates from the ISIC archive repository dataset, which includes 2637 input photos for training from two benign and harmful classes, as well as 800 test images. The research compared the epoch and loss function performance differences with 100 random images, and has achieved 83.38% accuracy with 10 epochs, 87.52% with 25 epoch, 91.21% with 50 epoch, and 95.61% with 100 epoch. A dropout value of 0.5% was used as a constant in all experiments, giving the best performance at 100 epochs with 95% accuracy.

Research by Muhammad Arif and friends also predicts skin cancer using two different datasets: the datasets associated with the Interactive Atlas of Dermoscopy (EDRA) and the newly suggested International Skin Imaging Collaboration (ISIC), 2017. There are 2000 photos accessible for training, with only about 400 of those identified as melanoma. It also includes 150 images that can be utilized as the test set and 600 images to function as the set used for validation. This research uses ADF techniques in image processing to reduce noise, K-means clustering, and modified K-means clustering. In this research, modified K-means clustering shows better results than other methods with accuracy up to 0.9992%. This study discovered the fact that the neural network hybrid CNN (CNN+IHHO) classifier outperforms other approaches that includes ResNet, VGG, and DenseNet, with a performance rating of 97.3%. [10].

In most researches, the Convolutional Neural Network is the most common method to use when classifying images and can give more than 80% accuracy. However, this research proposes a fusion of Delaunay Triangulation method and Graph Convolutional Network (GCN) to predict skin cancer. Delaunay Triangulation is used to extract the cancer lesion areas and separate it from the healthy skin area. The extracted feature is used to train the GCN model, in hopes that the model can provide higher accuracy than previous studies by using only the cancer lesion area.



### III. METHODOLOGY

#### A. Dataset Description

The data was collected by International Skin Imaging Collaboration (ISIC) through Kaggle platform [11], consisting of 2357 skin cancer images of over 2000 patients from various sources such as Hospital Clínic de Barcelona, Medical University of Vienna, Memorial Sloan Kettering Cancer Center, Melanoma Institute Australia, The University of Queensland, and the University of Athens Medical School in 2020 [12]. There are two folders in the dataset, Training and Testing. Training folder is composed of nine folders with the total of 2239 images, representing nine types of skin cancer disease: Actinic Keratosis, Basal Cell Carcinoma, Dermatofibroma, Melanoma, Nevus, Pigmented Benign Keratosis, Seborrheic Keratosis, Squamous Cell Carcinoma, and Vascular Lesion. Testing folder also consists of nine folders with a total of 118 images. However, this research only uses the first five folders and classifies those five types of skin cancer disease due to insufficient resources of RAM and memory.

#### B. Proposed Methodology

The proposed methodology consists of (1) Exploratory Data Analysis, (2) Data Preprocessing, and (3) Modeling and Evaluation. The flow of the process is shown in Fig. 1.

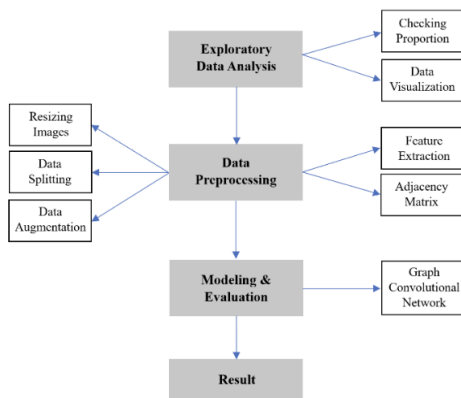


Fig. 1. Proposed methodology.

1) *Exploratory data analysis*: Research begins with importing and loading the data into the software, and then randomly visualizing nine images to get an overall depiction of the dataset. The software used for this research is Google Colab, with Python as the programming language. The process of visualizing the dataset and retrieving insights from it was done using the functions and libraries that are available in Python such as Matplotlib and Tensorflow Keras. After the data visualization process, the proportion of each skin cancer class is checked to decide whether the data needs to be balanced through data augmentation process or left as is.

2) *Data preprocessing*: The process consists of resizing all images into 180x180 pixels dimension, data splitting, data augmentation for training set, feature extraction process, and adjacency matrix creation. In the data splitting process, data is divided into three sets, namely the training set, validation set,

and testing set. Training set will be used for modeling process and validation set will be used for model evaluation. After splitting, the data augmentation process is carried out to add the number of images in each class to balance the training set. Then, a feature extraction process is carried out using Delaunay Triangulation method to generate the graph representation of each cancer image along with the average pixel values inside the graph, which can help differentiate between healthy skin and cancer skin region. Lastly, adjacency matrices are created based on the Delaunay points to describe the connectivity between nodes in each graph.

3) *Modeling and evaluation*: A Graph Convolutional Network model was created and trained using the pixels and adjacency matrix of all images in the training set as inputs. After that, the model is evaluated using the validation set. During evaluation process, the model is being analyzed whether it was overfitting or underfitting. The model result was compared with the previous result and was then modified a few times to improve its performance.

4) *Result*: After finding a model with the best performance, the model was then implemented to the testing set to predict the outcomes.

#### C. Delaunay Triangulation

Delaunay triangulation is a method of dividing a region into sub regions in triangular shapes [13]. This method generates a graph representation of the cancer shape in each image, which can be used as an input in Graph Convolutional Network. The graph will make it easier to distinguish the cancer skin from the normal skin as well as measuring the size of the cancer region.

The Delaunay triangulation implemented in this research is based on Quickhull Algorithm to compute the 2D convex hull of a set of points that are generated from the contour of each image, with the process as follows:

- Each image is converted into Grayscale color to find its contour.
- A set of points (100 points) are extracted from the contour of each image.
- Convex hulls are computed from those points using Quickhull Algorithm below [14]:
  - a) Find maximum and minimum points along the x dimension of that set of points.
  - b) Add the minimum and maximum points to the convex hull.
  - c) Connect the maximum and minimum points into a line.
  - d) Divide the remaining points into two subsets based on whether they are above or below the line.
  - e) Find points that are the farthest from the line and add them to the convex hull.
  - f) Construct a triangle using the line and the farthest point.
  - g) Remove all points in the subset that lies inside the triangle.

h) Step d to g are carried out recursively until no points remain in any subset.

i) The remaining set of points in the convex hull represents Delaunay triangulation.

- The average pixel values of each Delaunay triangle are extracted.
- Lastly, adjacency matrices are created based on the Delaunay points. Adjacency matrices have rows and columns labeled by graph vertices, with the number 0 or 1 in position  $(x_i, x_j)$  based on whether  $x_i$  and  $x_j$  are adjacent (1) or not (2), respectively [15].

#### D. Graph Convolutional Network

In this research, Graph Convolutional Network is used as a model to predict the types of skin cancer. Graph Convolutional Network (GCN) is a type of multilayer neural network that directly operates on graph-structured data, where it produces a vector representation of each node based on the features of its surrounding node [16]. GCN is used as it is suitable for inputs generated by Delaunay Triangulation, which is in the form of graphs (vertices, edge, and adjacency information for the triangles).

In the research, the GCN model propagates values forward through five layers using the Forward Propagation equation. The equation can be seen below (1):

$$H^{[i+1]} = \alpha(W^{[i]} H^{[i]} \bar{A}) \quad (1)$$

where  $H^{[i+1]}$  is the feature representation of layer  $i+1$ ,  $\alpha$  is the activation function applied for the inputs in each layer,  $W^{[i]}$  is the weight values for layer  $i$ ,  $H^{[i]}$  is the feature representation of layer  $i$ , and  $\bar{A}$  is the normalized adjacency matrix [17].

### IV. RESULT AND DISCUSSION

The Training dataset consists of 2239 skin cancer images distributed in nine folders. However, by using only five classes due to insufficient resources, there are only 1380 images left to use. The overall depiction of skin cancer provided by the dataset can be seen in Fig. 2.

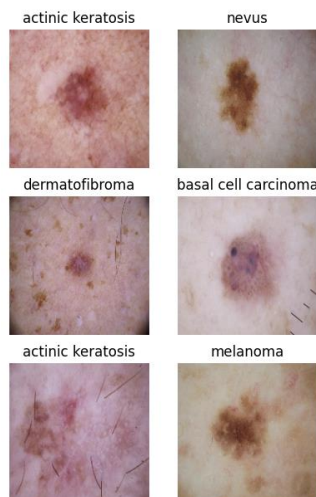


Fig. 2. Data depiction.

In the above figure, six images of skin cancer belonging to five classes are visualized using TensorFlow Keras library in Python to process the images, and Matplotlib library to visualize the processed images. The five classes of skin cancer in the dataset are Actinic Keratosis, Basal Cell Carcinoma, Dermatofibroma, Melanoma, and Nevus.

1) *Actinic keratosis*: Also known as Solar Keratosis, Actinic Keratosis is a precancerous skin condition caused by a long-term exposure of Ultraviolet radiation from the sun. This condition is mostly found at places that are commonly exposed to sun, such as the backs of the hands or the face, often affecting forehead, temple, balding scalp, upper or vermilion of lower lip, cheeks, ears, and nose [18].

2) *Basal cell carcinoma*: Basal Cell Carcinoma is a skin cancer forming in the basal cell of a skin, which is located in the lower part of epidermis (outside layer of a skin). This type of cancer has a form of shiny bump or scaly flat patch on the skin and can gradually grow over time. This condition is caused by DNA mutation, inherited gene defects, or excessive exposure of ultraviolet (UV) rays. It is most commonly found among elderly male, as well as people with fair skin, blue eyes, and blond or red hair [19].

3) *Dermatofibroma*: Also known as Cutaneous Fibrous Histiocytoma, Dermatofibroma is a benign fibrous nodule that appears commonly on the skin of lower legs, upper backs, and arms. This condition is mostly found among females more than males and occurs in adults of any ethnicity. Some causes of dermatofibromas are a reaction to trauma, such as insect bite or small cuts in the area where the nodule later formed [20].

4) *Melanoma*: Melanoma is a type of skin cancer that is produced by malignant transformations of melanocytes, which are the cells that produce pigment on the skin [21]. It is caused mainly by overexposure of Ultraviolet radiation or artificial sources like solarium, can spread to many parts of the body, and can be incurable. This cancer is mostly found in people with pale skin, moles in skin, many sunburns, or old age [22].

5) *Nevus*: Also called a mole, Nevus (plural: Nevi) is a patch of skin formed due to an overgrowth of cells in the epidermis (outermost layer) part of skin. Nevus is harmless and common; it can be seen at birth or develop in early childhood. Any individual, of all ages and ethnicities can develop a nevus on their skin, and as they get older, nevi can become darker and thicker or even grow into wart-like form [23].

The proportion and number of images in each class from the dataset can be seen in Table I.

TABLE I. DATA PROPORTION

Class	Number of Images	Proportion
Melanoma	438	32%
Basal Cell Carcinoma	376	27%
Nevus	357	26%
Actinic Keratosis	114	8%
Dermatofibroma	95	7%

Result shows that the proportion of data in each class is imbalanced. Therefore, a data augmentation process is necessary to balance the data and ensure a good performance for the model. An imbalanced data can cause bias towards the model and cause lower accuracy to minority classes. Data augmentation will increase the size of those minority classes to obtain the same size as the largest class [24]. Several transformation techniques such as vertical and horizontal flipping, shifting, zooming, as well as rotating images are used when duplicating the data to increase its variety. The transformation process is carried out using `ImageDataGenerator()` function from Tensorflow Keras library.

After the Exploratory Data Analysis process, Data Preprocessing is carried out starting with resizing the height and width of all images into 180 pixels. Resizing images is important as images captured by cameras can vary in size, but a neural network only receives 1 input size. Thus, establishing a base size for all images is crucial so the images can be fed into the algorithms [25].

In Data Splitting process, the resized images in the Training folder are divided into Training set and Validation set, with the proportion of 80% and 20% respectively. An empirical analysis has proven that the best results are obtained by allocating 20-30% of the original dataset for validation set and the remaining 70-80% proportion for training set, as it can provide adequate data for training a model as well as avoid overfitting [26].

After splitting the dataset, Feature Extraction process is carried out using Delaunay triangulation method to generate a graph representation of each image and extract its pixels, as explained in the methodology. Delaunay triangulation method is carried out using `Delaunay()` function from Scipy library in Python, and its result can be seen in Fig. 3.

In the figure, the original image is shown on the left side, whereas images on the right side are the result after Delaunay triangles are generated. The Delaunay method is able to generate triangles properly in the cancer area of four classes. However, triangles in Nevus class are generated in the background instead of the area of interest. This is the weakness found when using Delaunay Triangulation method for skin cancer data.

In this research, adjacency matrices are created using NumPy library in Python, with the adjacency information based on the graph formed by Delaunay triangles. The distance of all points on the graph are calculated using Euclidean Distance formula, and two points are considered connected or adjacent if the distance is greater than 2.5 pixels. The Euclidean Distance method uses Pythagorean theorem [27], with the equation as seen below (2):

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (2)$$

where  $d_{ij}$  is the distance between position  $i$  and  $j$ ,  $(x_i, y_i)$  is the coordinate of a point in position  $i$ , and  $(x_j, y_j)$  is the coordinate of a point in position  $j$ .

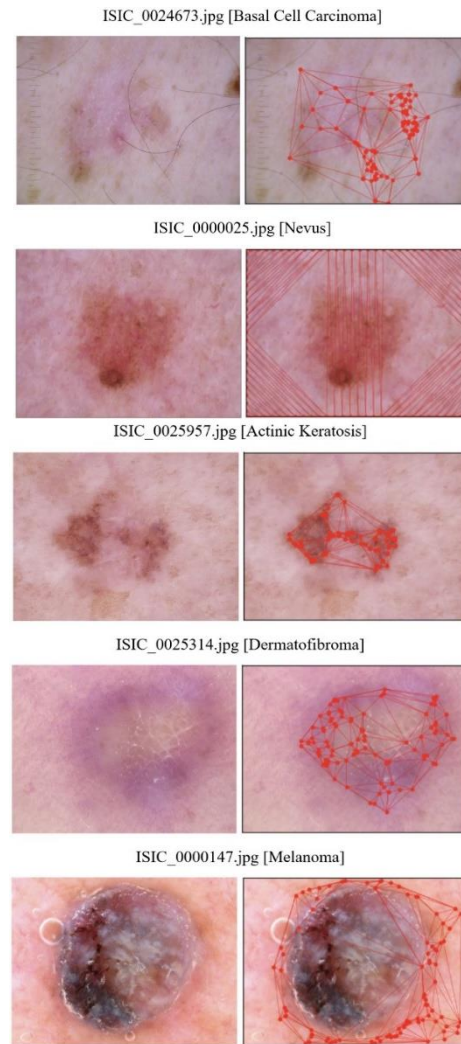


Fig. 3. Delaunay points.

After generating the graph representation of each image, a GCN model is built to receive two inputs, which are the adjacency matrix and pixels matrix of each image. The model is constructed using 5 Graph Convolutional layers, a batch normalization after each Graph Convolutional layer, 1 flatten layer, and 1 output layer. Each graph convolutional layer has 32, 64, 128, 256, and 512 filters respectively, and all layers use ReLU activation function as well as L2 regularization method.

Batch normalization layers are added as they can normalize the output of the layer. Input that has been normalized can increase stability of the optimization process, which helps improve model's performance [28]. L2 regularization is added in each Graph Convolutional layer as it can do regularization to help overcome overfitting problem. L2 regularization can learn complex patterns well, so it is suitable for data in the form of images, which have complex patterns [29].

A ReLU activation function is used in all Graph Convolutional layers as it is the most often used function in the neural network model and can overcome the vanishing gradient problem, which occurs when the gradients of activation function become very small during backpropagation process and causes very small updates in the weights of earlier layers,



so the model learns slowly or not learning at all. This problem may occur when using sigmoid and hyperbolic tan (tanh) activation functions [30]. The graph of ReLU function can be seen in Fig. 4 [31], and the formula of ReLU is defined below (3):

$$f(x) = \max(0, x) \quad (3)$$

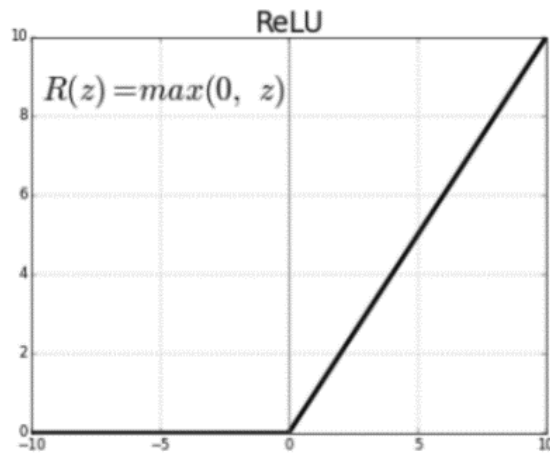


Fig. 4. ReLU activation function.

The model is compiled using ‘Adam’ optimizer and ‘categorical\_crossentropy’ as its loss function. Categorical cross entropy is specifically used for multi-class classification problems by taking class 1, 2, or n shaped labels, whereas the Adam optimizer is used because for classification problems, it often performs better at generalizing than other optimizers [32]. Thus, it is better at preventing overfitting for most cases.

After compilation, the model is trained with 50 epochs and a batch size of 64, so the model can train for up to 50 iterations and utilize 64 training examples in one iteration. Once the model is trained, evaluation process is carried on. The accuracy and loss during the last epoch can be seen in Table II.

TABLE II. ACCURACY AND LOSS OF LAST EPOCH

	<i>Accuracy</i>	<i>Loss</i>
<i>Training Set</i>	0.66	1.22
<i>Validation Set</i>	0.32	3.10

The accuracies and losses of training and validation set during the model training using all epochs from 1 to 50 can be seen in Fig. 5 and 6. During the training process, the accuracy of the model significantly improved, and the loss values were stable throughout each epoch. However, the accuracy of the validation process increased or decreased significantly during the modeling process. The loss value of the validation process decreased significantly from epoch 0 to approximately epoch 1 and experienced a fairly large increase and decrease from approximately epoch 1 to epoch 7.

The above Accuracy and Loss Graph is based on the range of epochs and visualized using Matplotlib library in Python. In the graph, it can be seen that the accuracy for training set kept increasing until it reached more than 60%, showing that the model works quite well in predicting the training set. However,

the accuracy difference between training and validation set gradually increases, as the accuracy of validation set makes no significant improvement during each epoch. Thus, this shows that the GCN model tends to overfit, even though the loss value during training process of each epoch kept decreasing.



Fig. 5. Training & validation accuracy.

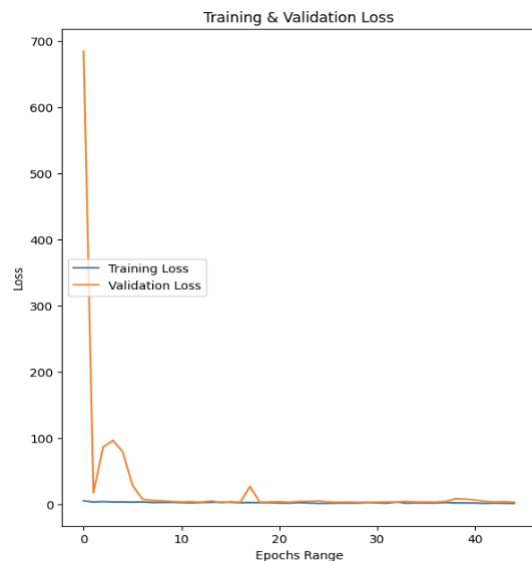


Fig. 6. Training and validation loss.

After evaluating the model’s performance, the model is used to predict the testing set. Some prediction results can be seen in Table III.

The last accuracy result for the validation process is around 32%, which causes unreliable prediction results for the testing set. From the table, it can be seen that the image with the name ISIC\_0024411 is predicted to be in Dermatofibroma. In reality, the image belongs to Basal Cell Carcinoma class. Moreover, the image with the name ISIC\_0024403 and ISIC\_0024431 is predicted to be Nevus when in reality, the image belongs to Basal Cell Carcinoma as well.

TABLE III. ACCURACY AND LOSS OF LAST EPOCH

N o.	ActinicKeratitis	Basal Cell Carcinoma	Dermatofibroma	Melanoma	Nevus	Image name	Highest Probability
1	0.27	0.05	0.41	0.10	0.17	ISIC_0024411	Dermatofibroma
2	0.21	0.58	0.18	0.00	0.03	ISIC_0024472	Basal Cell Carcinoma
3	0.00	0.02	0.01	0.00	0.97	ISIC_0024403	Nevus
4	0.32	0.26	0.03	0.10	0.29	ISIC_0024454	Actinic Keratosis
5	0.02	0.00	0.37	0.01	0.60	ISIC_0024431	Nevus

TABLE IV. CNN vs GCN

	CNN	GCN
Training Accuracy	96.55%	66%
Validation Accuracy	60.14%	32%
Training Loss	0.07	1.22
Validation Loss	1.93	3.10

When compared with the proposed model, convolutional neural network (CNN) performed better. A comparison of accuracy using the CNN model is shown in Fig. 7 and Table IV. The accuracy of the training process was 96.55% and the accuracy of the validation process was 60.14%. As shown in Fig. 8, the loss in the training process steadily decreased from epoch to epoch and did not change significantly from epoch 40 to epoch 50. However, the loss in the validation process was the other way around. From epoch 0 to approximately epoch 5, the loss of the validation process decreased significantly, and from there until the last epoch the loss increased significantly. A comparison of accuracy and loss in Table IV shows the better performance of CNN compared to the proposed model. The accuracy of the CNN model both in the training and validation process outperformed the proposed model by 30%. The gap between the training and validation processes' loss values is similar for both CNN and GCN models. However, the loss value of the proposed model is higher.

Even though it produced better accuracies and losses than the proposed model, the CNN model overfitted. Overfitting is a scenario that occurs when the predictive model fails to generalize the observed data properly in order to fit both training and testing data well. An overfitting condition takes place when the model attempts too hard in seeking the most suitable fit to the data it was trained on and adapts for noise in the data by retaining multiple training data characteristics rather than discovering a general prediction rule [33]. For CNN model, the accuracies and losses of the training process kept improving through each epoch or iteration, while the accuracy and loss of the validation process stopped improving after going through a certain amount of iteration.

### V. CONCLUSION

The accuracy and loss values of CNN model are higher than the GCN model. Images used in this study were taken at close range, where cancer lesions are clearly visible, and the cancer-to-skin area ratio is nearly balanced. However, the model using CNN is overfitted. The model did not seek to fit the data well by focusing only on cancerous areas, but also on normal skin areas.

When compared with CNN, the accuracy of the proposed model is terrible, with only 66% for the training process, and 32% for the validation process. On the other hand, the accuracy of training process generated from the CNN model is 96.55% and 60.14% for validation process. Furthermore, the last loss value from the training process is lower than the validation process. As the model performs better in the training process

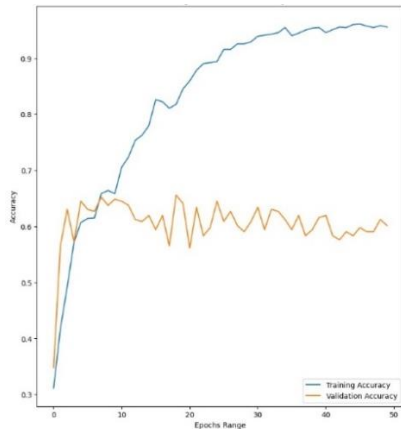


Fig. 7. Training and validation accuracy of the CNN model.

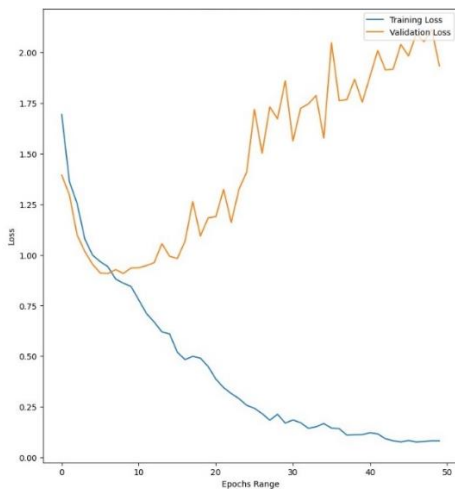


Fig. 8. Training and validation loss of the CNN model.

and poorly in the validation process, it can be concluded that the model is overfit. Consequently, when the test process was carried out, the prediction results were inaccurate.

There are several reasons that could lead the model to overfit, such as imbalance data, or even the data contain noise. Looking at the data proportion table from Table I, it could be clearly seen that the data distribution within the classes were imbalanced as the class Actinic keratosis was only represented by 8% of the total data, and class Dermatofibroma was only represented by 7% of the total data while the other classes were represented by 20% to 30% of the total data. Other than that, when conducting feature extraction using Delaunay triangulation method, it seems that for some images or data, the method could not map the point properly, ultimately giving inappropriate inputs for the model; hence, the terrible accuracy and loss value, and inaccurate predictions or diagnoses.

The last thing to be considered is insufficient features for reliable predictions. The data obtained from the Kaggle website itself has an imbalance data distribution within the classes, with "Pigmented Benign Keratosis" and "Melanoma" as the classes that has the highest number of data. As a result, the model could not learn properly from the classes that has too little data. The differences of the types of skin cancer are challenging to tell even for the human's eye. In this case, the same thing happen for the algorithm. When given to little data to learn from, the algorithm could not classify the type of skin cancer properly. This study paves the way for further in-depth future work to modify the algorithm so that it can perform better and guarantee that the algorithm performs acceptably and predict accurate diagnoses.

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# Fertigation Technology Meets Online Market: A Multipurpose Mobile App for Urban Farming

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**Abstract**—In a world where smartphones dominate the market and provide opportunities to a vast population, this work introduces an innovative application that enables users to order irrigated vegetable crops from urban farmers. The application utilizes simple fertigation system technology, which can be easily implemented in small areas such as homes. Currently, consumers and sellers rely on traditional methods like paper or other means to place orders for vertical farming. However, research shows that these methods are unreliable and only offer temporary relevance. Additionally, the traditional agriculture supply chain diminishes the appeal of urban farming as its benefits do not outweigh the disadvantages. The primary objective of this application is to promote the concept of urban farming by creating an online marketplace that bypasses traditional methods. This allows consumers to directly order from the farmers themselves, serving as an alternative to the agricultural supply chain. Furthermore, a monitoring system has been integrated into the application as an additional tool, enabling farmers to remotely monitor and control their farms. This feature is particularly beneficial for urban farmers with farms in multiple locations who may lack the time to physically visit each one.

**Keywords**—Vertical farming; mobile application; online market; farm monitoring; urban farmer; agriculture supply chain

## I. INTRODUCTION

Mobile applications have had a significant impact on today's world, exerting a large influence on the way communities think and on their goals and standards. In the economy, mobile applications have opened up numerous new opportunities for individuals to successfully earn money online. A catalyst for this success has been the emergence of M-commerce mobile applications. M-commerce mobile applications provide a platform where sellers can offer their products, allowing customers to browse and make purchases. Despite the growing popularity of M-commerce mobile applications, the agriculture sector has yet to fully embrace this tool to enhance farmers' profitability.

The agricultural sector requires significant improvements. Although farmers' income has steadily increased over the years [1] [2] [3] [4], they are often limited to selling their crops through middlemen. This traditional approach to connecting farmers with consumers makes it difficult for newcomers or individuals interested in farming to enter the agricultural sector. New farmers must find middlemen to ensure

profitability from their farms, as they lack a direct marketplace to sell their crops to consumers. Additionally, the agriculture supply chain has proven to be unreliable, particularly during the COVID-19 pandemic, which has caused disruptions and restrictions on movement [5]. As a result, crops have gone to waste due to the lack of middleman services for distribution. However, the challenges associated with crop distribution could be mitigated through widespread adoption of urban farming. Urban farming has the potential to improve access to healthy and nutritious food [6]. Urban farmers operate at various scales, ranging from small gardens to large-scale operations that incorporate systems like hydroponics for indoor farming. Currently, urban farming is not popular due to inefficiencies in farming practices within urban areas. Many medium to large-scale urban farmers do not reside near their farms, leading to inconvenience as they need to frequently travel to their farms located at a distance from their homes. However, constant monitoring is necessary for efficient crop production, leaving farmers with no choice but to visit their farms regularly. The trade-off between a farmer's time and crop production efficiency makes the concept of urban farming less appealing to urban dwellers.

Hence, the main goal of this work is to promote the idea of urban farming. To achieve this objective, an easy and approachable marketplace needs to be built. An online marketplace is perfect as it allows farmers to sell their crops without the need to meet anybody or be physically present. The concept of anyone being able to start farming indoors or in their garden and sell their produce through a mobile application makes urban farming more appealing to urban dwellers. Therefore, this project involves the creation of a mobile application that can host a marketplace for urban farmers to sell their crops. Additionally, a monitoring system is included in this application to reduce the frequency of farmers needing to be physically present at their farms. This saves a tremendous amount of time, especially for urban farmers. With these two functionalities in the application, along with the ability to generate profit, the concept of urban farming will become more and more popular. One significant advantage of urban farming is that it encourages people to buy fresh crops since the purchased crops are farmed near their location. This eliminates the need for preservatives used to prolong the shelf life of crops in traditional agricultural supply chains. In such chains,

some crops may no longer be fresh, resulting in waste as they lose their appeal for sale.

The remainder of this paper has been organized as follows: Section II discusses the background of the study. Then, Section III described the system implementation and testing. Section IV describes the results and discussion meanwhile the conclusion is described in Section V. Lastly, future works is mentioned in Section VI.

## II. BACKGROUND OF THE STUDY

In an article published on January 13, 2020, in The Malaysian Reserve, former two-time Finance Minister Tun Dr. Daim Zainuddin emphasized the importance of making agriculture more profitable and attractive to younger people. He highlighted that such a transformation would have significant benefits for Malaysia, including reducing the country's import bill, creating employment opportunities, and boosting federal revenue [7]. The consistent growth in demand for food supplies and vegetables further supports the viability of the agricultural sector as a solution for Malaysia's economy [8] [9] [10] [11]. In this context, vertical farming has emerged as a promising technology for sustainable food production in urban areas. With 80% of the global population residing in urban areas, where the demand for food supply is expected to become critical in the next 50 years, vertical farming offers a compelling solution [12]. By utilizing vertical spaces such as tall buildings and skyscrapers that are abundant in urban areas, this innovative approach enables the cultivation of crops. Vertical farming not only creates job opportunities in the agriculture and related industries but also addresses the issue of unemployment in urban areas. Additionally, it generates indirect employment through local distribution, community outreach, logistics, and delivery services [13] [14].

m-Commerce, also known as Mobile Commerce, has gained significant popularity as a method of conducting business and shopping using mobile devices [15]. The widespread use of mobile devices and the diverse intentions of users have contributed to its success. Demographic factors such as age, gender, and education play a crucial role in influencing consumers' inclination to use m-commerce applications. Overall, there is a positive consumer intention to utilize m-commerce, indicating that the development of mobile applications can attract younger generations to participate in agriculture by leveraging IoT technology [16]. Fig. 1 provides examples of mobile commerce applications that can be easily installed on smartphones. Moreover, there is a plethora of platforms and applications available that entrepreneurs can leverage to establish their own online businesses, even within the agricultural sector [17].



Fig. 1. Example of m-Commerce application in smartphone [17].

Moreover, various factors such as climate change, the overconsumption of Earth's resources [18], and population growth have emphasized the importance of adopting more sustainable agricultural practices. Traditional farming methods often face challenges due to their vulnerability to adverse weather conditions and a lack of technological advancements and marketing investments [19]. Despite efforts to enhance greenhouse farming, vertical farming still relies on manual order management systems, which are prone to errors and time-consuming mistakes [20]. By integrating a mobile application using m-commerce, these errors can be minimized by providing a backup system and a comprehensive order history, reducing the need for farmers to engage in face-to-face interactions with customers. Additionally, the m-commerce application enables the acceptance of a diverse range of crops, ensuring efficient fulfillment of food supply demands.

Moreover, the utilization of monitoring devices in agriculture is becoming increasingly prevalent and offers numerous advantages over manual monitoring methods. The industry is transitioning from traditional farming to modern, smart farming, which incorporates various technologies such as sensors, computing cores, machinery, and equipment. The integration of the Internet of Things (IoT) and cloud computing is driving this modernization, enabling farming operations with minimal human presence [21] [22]. This combination of technologies allows for real-time monitoring of crucial parameters such as temperature and soil moisture [23] [24]. Farmers can now remotely monitor their farms without the need for physical presence, which is particularly advantageous for those who reside far from their agricultural lands. Long-distance trips to check on farm conditions are no longer necessary. The monitoring system also assists farmers in maximizing crop production while utilizing the same inputs as conventional farming methods [25] [26].

Lastly, with all the benefits come to building mobile application around farming; numerous farming applications are available today, each with its unique functions tailored to specific farms or crops. For instance, there are applications designed to calculate the growth period of corn. However, these calculators are typically specific to corn and cannot be used to determine the growth of other plants.

### A. The Implementation of Smart Farming Application based on the Microcontroller and Automatic Sprinkler Irrigation System of Agricultural Land

Hasiri et al. [27] developed an Android-based application aimed at managing an automatic sprinkler system and monitoring the farm. The application consists of six pages, each offering different user interface (UI) functions. These functions include displaying the average temperature, moisture level, weather information, historical sensor data, scheduling activities such as watering and fertilization, manual watering mode, IoT setup, and application settings. The temperature and moisture levels are categorized into three conditions, and the watering activity can be either automated or manually controlled. Additionally, the application provides a settings page with options to enable or disable the automatic watering system and fertilization activities.

**B. Development of an Android Application for Smart Farming in Crop Management**

The research involves the utilization of unmanned aerial vehicles (UAVs) and an Android application to monitor paddy fields in Kampung Lundang Paku, Kereteh, Kelantan [28]. The Android application processes the images captured by the UAVs, analyzes them, and presents the information as a Normalized Difference Vegetation Index (NDVI) map, which helps monitor the health of the crops and assess the weather conditions. The application also provides the farmer with information regarding rice cultivation, planting schedules, field issues, and supplier details. The application is installed on a smartphone and requires an internet connection to update data in real time. The user interface is designed with user-friendly buttons that allow easy access to the information collected by the drones, and the NDVI map segments the paddy fields to indicate their health using an index ranging from -1 for unhealthy to 1 for healthy conditions.

**C. Mobile Application Development of Hydroponic Smart Farm using Information Flow Diagram**

The objective of this work is to develop an application for managing a hydroponic farm and visualizing data collected by sensors connected to a Raspberry Pi [29] [30] [31] [32]. The sensors are responsible for collecting various parameters such as temperature, humidity, sunlight, pH level, water level, and electrical conductivity. The system utilizes MongoDB as its database system and employs Message Queuing Telemetry Transport (MQTT) for seamless communication between the sensors, Raspberry Pi, and other devices. To access the farm status data, users are required to log in to the application. New users have the option to sign up and provide their Raspberry Pi's Wi-Fi information. The application comprises multiple pages, including a login page, as well as a dedicated page that displays the average values of the sensor data. Additionally, users can obtain further information by clicking on specific data points.

**D. Development of Soil Moisture Monitoring by using IoT and UAV-SC for Smart Farming Application**

The project utilizes both IoT and UAV technology to collect information about farmers' farms and present it through an application [33]. Ground sensors are deployed to gather data, such as soil moisture, which is then transmitted to a UAV drone. The UAV collects the data and stores it in a database. To avoid the need for lengthy cables, the sensor is powered by a solar panel. The UAV has a flight time of approximately 20 minutes. The application allows farmers to access real-time data and supports multiple users, ensuring that each farmer can only view information relevant to their own farm. The application provides detailed sensor data, including soil moisture levels categorized into three stages: "Dry" for moisture levels below 45%, "Humid" for moisture levels between 45% and 79%, and "Wet" for moisture levels exceeding 80%.

**E. Ma-Ease: An Android-based Technology for Corn Production and Management**

A mobile application has been developed specifically for corn farmers to conveniently manage and access information

using their smartphones [34]. The application is built using Java on Android Studio and is designed to be user-friendly. One of its key features is the ability to function without Wi-Fi, which is particularly beneficial for farmers operating in areas with limited internet connectivity, as it can be used offline. The application offers a simple and intuitive user interface (UI) with clear labeling and includes weather forecasts to assist farmers in making informed decisions. It also provides a calculator to estimate crop yield, enabling farmers to plan their farming activities effectively. Additionally, a pest control feature has been integrated into the application, allowing farmers to quickly contact pest control services in case of infestations, thereby helping to prevent crop loss.

The past related works are compared to the proposed method using these feature criteria: -

- a) Application displays sensor reading.
- b) Application is not limited to certain crops.
- c) Application can control device/automation.
- d) Application can work in long range scenario.
- e) Application provides general information about farming.
- f) Application allow user to monitor farm visually.
- g) Application can handle multiple users.
- h) Application has additional feature that have not been mentioned from a – g.

All the applications from the past related works will undergo a checklist to identify the presence of the mentioned criteria. If an application meets a specific criterion, it will be marked as 'Y'; otherwise, if the criterion is not present, it will be marked as 'N'. Next, the Y-Score will be calculated to determine which application has the highest number of 'Y' marks, using formula (1).

$$Y - Score(\%) = \frac{\text{Amount of Y}}{g} \times 100\% \quad (1)$$

The aim of the comparison table is to identify which application offers the most functionality that can effectively address the challenges faced by farmers, particularly those in urban areas. The table will allow for a comprehensive evaluation of the applications based on their features and capabilities, enabling the determination of which application is better suited to accommodate the specific needs of farmers.

TABLE I. COMPARISON BETWEEN EXISTING WORK

Feature REF	a	b	c	d	e	f	g	h	Y-Score
[27]	Y	Y	Y	N	N	N	N	N	37.5
[28]	Y	N	N	Y	N	Y	N	Y	50.0
[29]	Y	Y	Y	Y	N	N	N	N	50.0
[33]	Y	N	N	Y	N	N	Y	N	37.5
[34]	N	N	N	Y	Y	N	Y	Y	50.0
Purposed Work	Y	Y	Y	Y	N	N	Y	Y	75.0

Table I shows the feature comparison between previous works and this work. Based on the comparison table, it is evident that this work offers 25% more features compared to the highest percentage of features available in the previous works. However, to ensure the application remains streamlined and user-friendly, some features have been omitted. Despite this compromise, the application is still able to accommodate most of the needs of farmers, including those in urban areas. By providing a comprehensive set of features, it aims to address the challenges faced by farmers effectively.

### III. THE SYSTEM IMPLEMENTATION AND TESTING

#### A. Hardware Implementation

The necessary hardware components for developing this work include an ESP-32, an Electroconductivity (EC) sensor, and a temperature sensor. These components will be connected as depicted in Fig. 2. The hardware setup will be implemented in a selected hydroponic farm situated at Pertubuhan Kebajikan Villa Harapan in Taman Desa Molek, Melaka. The ESP-32 will be responsible for collecting data from the sensors and calculating the EC value, which will then be transmitted to the database. The formula (2), (3) and (4) is used to calculate the EC value.

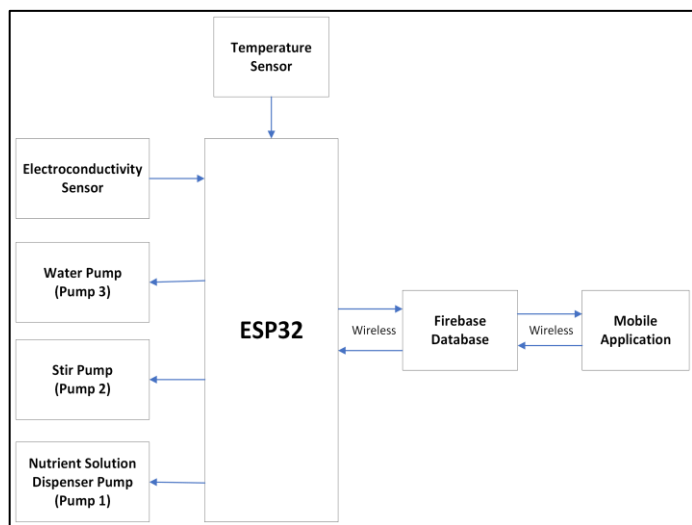


Fig. 2. Block Diagram of hardware system.

$$tempCoefficient = 1.0 + 0.0185 \times (temperature - 25.0) \quad (2)$$

\* 'temperature' is the reading of temperature sensor

$$voltageCoefficient = \frac{Voltage}{tempCoefficient} \quad (3)$$

\* 'Voltage' is the reading of EC sensor

$$ecCurrent = \begin{cases} voltageCoefficient \leq 448; 6.84 \times voltageCoefficient - 643.2 & \text{interface 6432} \\ voltageCoefficient \leq 1437; 6.98 \times voltageCoefficient - 643.2 & \text{temperature 25} \\ else ; 5.3 \times voltageCoefficient + 432.2 & \text{time.} \end{cases} \quad (4)$$

\*'ecCurrent' is the EC value that will be sent to the database

The EC value is crucial for monitoring the health of hydroponic crops, as it determines the conductivity and

nutrient levels in the water-nutrient solution. Maintaining the appropriate EC value is vital to ensure optimal growth and development of the plants. In the case of hydroponic farming, if the EC value of the water-nutrient solution is too high, it indicates a high concentration of salts or nutrients. This can lead to an imbalance in osmotic pressure, causing the water-nutrient solution to draw water from the roots of the crops. As a result, the plants may suffer from water stress and eventually wilt or die due to inadequate water supply. On the other hand, if the EC value is too low, it suggests a deficiency of salts or nutrients in the water-nutrient solution. In this scenario, the roots of the plants will primarily absorb water but not enough nutrients, leading to nutrient deficiencies and poor growth. For the selected hydroponic farm, maintaining a desirable EC value of 12.8 mS/cm is important. This value ensures an appropriate concentration of salts and nutrients in the water-nutrient solution, providing optimal conditions for the hydroponic crops to thrive and grow healthily. Regular monitoring and adjustment of the EC value will help maintain the desired nutrient balance and support the overall success of the hydroponic farming system.

The hardware system will operate in fully automatic mode, where the EC value will determine the functionality of the pumps, as shown in Fig. 3. Furthermore, to test the hardware, it has been run at various EC values to observe the intended operation of the ESP-32. The results of all the tests will be tabulated in a table to analyze the occurrences when different scenarios are presented to the hardware.

#### B. Software Implementation

The marketplace hosted in the application will utilize Firebase database to store all the information related to the crops, including price, pictures, descriptions, and more, for sale within the application. Firebase database also provides real-time functionality, allowing the mobile application to receive and display real-time data. Additionally, Firebase Authentication will be used to authenticate users who sign up or sign in to the application. The mobile application will be developed in Android Studio using Java as the programming language. The interface of the mobile application is designed according to Fig. 4. Farmers will have a slightly different interface where they can view their farm conditions and control the pumps and automation systems. On the other hand, customers will not be able to view the farm conditions to respect the privacy of the farmers, but they will have the ability to contact the farmers using the built-in interface within the application. To test the application and database, a series of simulations have been conducted to verify if the application interface is working as intended and if the monitoring interface updates the values of temperature and EC (Electroconductivity) accurately. During the simulations, different scenarios were presented to evaluate the performance of the application. The interface 6432 tested to ensure that it accurately displays the temperature and EC values retrieved from the database in real time. The goal of these tests was to confirm that the monitoring interface effectively tracks and updates the data, providing farmers with up-to-date information about their farm conditions. Additionally, the functionality of the application's interface was thoroughly tested to ensure that all features, such as crop information, pricing, pictures, and descriptions, are

properly stored and retrieved from the Firebase database. This testing aimed to ensure that the application operates smoothly and offers a user-friendly experience for both farmers and customers. By conducting these simulations, any potential issues or discrepancies were identified and addressed, ensuring that the application and database perform reliably and meet the intended objectives.

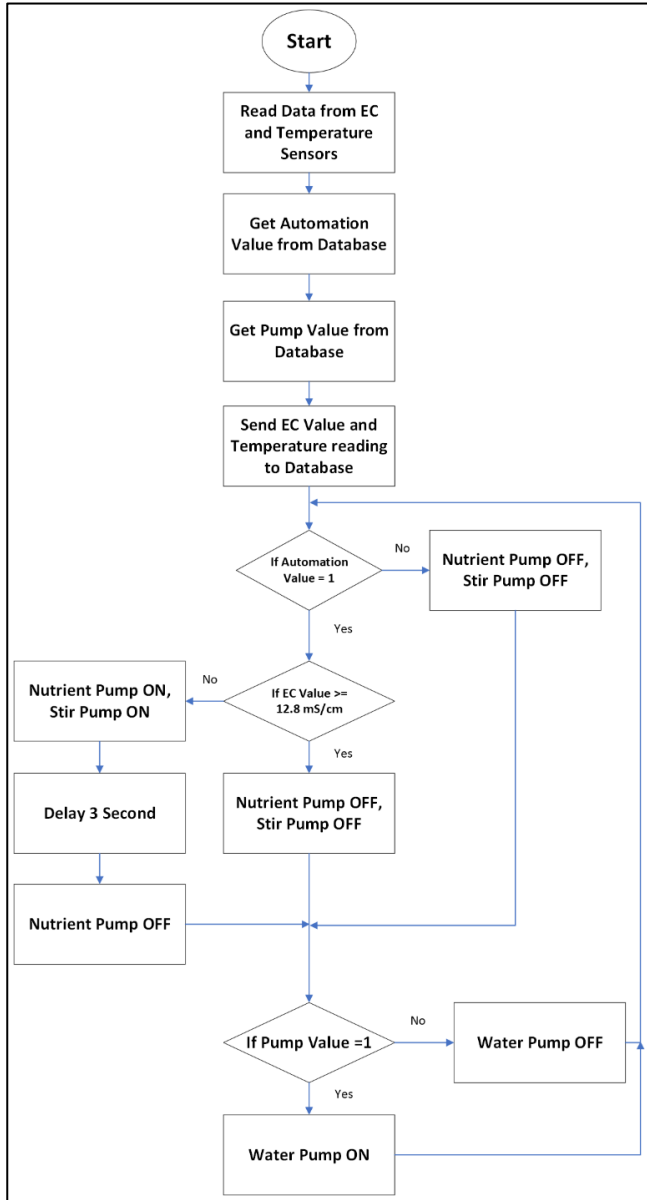


Fig. 3. Flowchart of automatic nutrient pump and monitoring system.

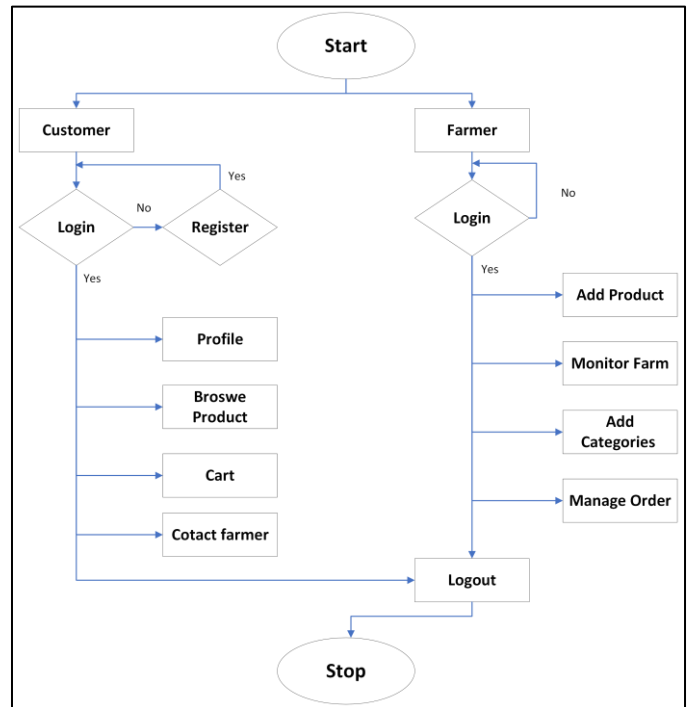


Fig. 4. Flowchart on function available in the mobile application for each type of user.

#### IV. RESULT AND DISCUSSION

##### A. Hardware Test Result

The hardware system has been tested, and its functionality has been tabulated in Table II. The ESP32 is capable of controlling the pumps based on the predetermined conditions set during the upload of EC and Temperature values to the Firebase Database. Additionally, the interval at which the mobile application updates the values has been captured and tabulated in Table III to determine any correlation between the distance between the mobile application and ESP-32 and the interval of information updates.

##### B. Hardware Result Discussion

Based on the test results, we can conclude that the fully automated system with monitoring is functioning as intended. The hardware successfully passed all the tests, achieving a 100% success rate. Thus, the farmer in Villa Harapan can trust the automation system to work as intended and allow them to not be needed in vicinity of their farm, majority of the time. The amount of time saved by not needing to be at their farm will make the concept of urban farming gain attraction.



TABLE II. AUTOMATIC NUTRIENT PUMP AND MONITORING SYSTEM HARDWARE TEST RESULT

Test ID	EC Value in Apps	Fully – Automate Switch in Apps	Pump Switch in Apps	Pump 1	Pump 2	Pump 3	Result
01	<12.8 mS/cm	OFF	Not Relevant	OFF	OFF	Not Relevant	Pass
02	<12.8 mS/cm	ON	Not Relevant	ON	ON	Not Relevant	Pass
03	>12.8 mS/cm	OFF	Not Relevant	OFF	OFF	Not Relevant	Pass
04	>12.8 mS/cm	ON	Not Relevant	OFF	OFF	Not Relevant	Pass
05	Not Relevant	Not Relevant	OFF	Not Relevant	Not Relevant	OFF	Pass
06	Not Relevant	Not Relevant	ON	Not Relevant	Not Relevant	ON	Pass

TABLE III. INTERVAL OF THE APPLICATION UPDATE THE INFORMATION AT DIFFERENT RANGE

Range (m)	Interval 1 (s)	Interval 2 (s)	Interval 3 (s)
5	1.54	1.45	1.37
10	3.47	3.05	3.83
20	2.74	3.38	1.48

Furthermore, the data gathered in Table III indicates that the range of the mobile phone to the farm does not have a significant impact on the time interval of information updates in the mobile application. The main factor causing the inconsistent time intervals is the stability of the network internet connection. The farm is located approximately 30m away from the internet router, which can result in intermittent connection issues for the ESP32, leading to inconsistent data updates in the database. Similarly, the mobile phone also requires a stable internet connection to ensure reliable and instant updates of the latest data in the application. In conclusion, to achieve a more consistent time interval for information updates in the mobile application, it is crucial for both the farm and the mobile application to be in close proximity to the network router or in a location with a stable and reliable internet connection. This will minimize the chances of the ESP32 experiencing connection losses and ensure a smooth and uninterrupted flow of data.

### C. Software Test Result

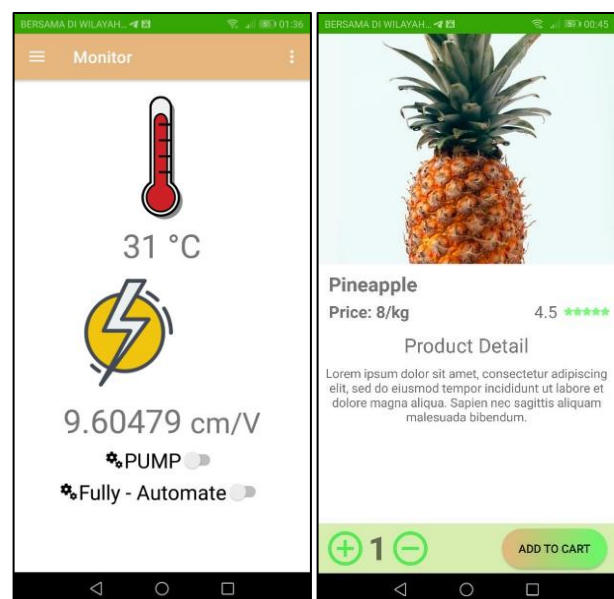
The software was subjected to testing, and the results have been compiled and presented in Table IV. The mobile application demonstrated its ability to handle multiple users simultaneously, enabling a marketplace where customers can search, browse, and purchase products. Additionally, customers have the option to contact the farmer to inquire about the status of their orders. The mobile application also provides access to farm information and allows users to control automation and pumps, as depicted in Fig. 5. Moreover, the application offers several other interfaces to enhance the user experience. This includes an interface where users can view product details such as descriptions, ratings, and prices. The home interface allows users to browse and search for desired products, while the sign-in interface enables registered users to log in to their accounts. Overall, the software has proven its capability to facilitate a user-friendly and feature-rich mobile application that accommodates multiple users and supports various functionalities, including marketplace access, farm information, and control of automation systems.

TABLE IV. BASIC NAVIGATION FOR APPLICATION SOFTWARE TEST RESULT

Test ID	Test Condition	Result
07	The user sign up customer account.	Pass
08	The user sign in into their account.	Pass
09	User search item in search bar.	Pass
10	User add item into the cart.	Pass
11	User check cart for the item	Pass
12	User buy the product.	Pass
13	User Delete Item in cart	Fail
14	User contact seller	Pass
15	Sign In using admin/farmer account	Pass
16	User Monitor farm	Pass

### D. Software Result Discussion

Based on the test results, it can be concluded that the mobile application is functioning mostly as intended. The application successfully passed 9 out of 10 tests, accounting for 90% of the overall testing process. Thus, the consumer can reliably browse the application and successfully create an order to purchase the crops from Villa Harapan. Since this application is still in development/testing stage, bug is expected, hence the failure one of the features. But with now option to generate profit on using the mobile application, the concept the urban farming surely getting more popular as the urban farmer can start their farm anywhere.



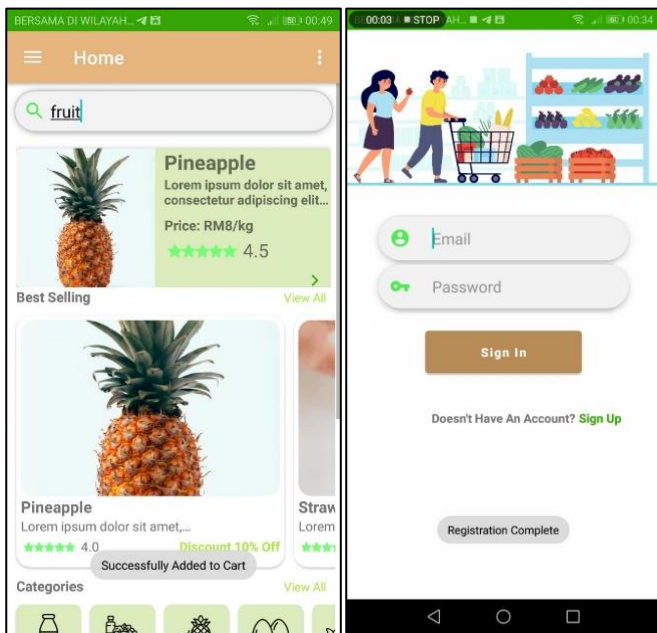


Fig. 5. Mobile application page for monitoring the browse item interface, home interface and sign in interface.

## V. CONCLUSION

This work was developed to help urban farmers to easily sell their crops directly to the customer without relying on traditional method of agriculture that is soon to be rendered obsolete. Furthermore, the work also developed to help urban farmers to monitor their farm wirelessly using the mobile application. With the implementation of IOT, farmers can anywhere check their farm condition even if they have their farms in multiple locations. By not needing to be in vicinity of their farm, it opens many opportunities especially for people in urban area to venture into agriculture sector, hence promoting the idea of urban farming. The chosen farm for testing and implementing this innovation has also reaped the rewards of state-of-the-art, fully automated pump system that can be easily controlled and monitored through a mobile application. Interestingly, according to Table III, the proximity of the farmer to the farm holds no bearing on the latency between updates in the interface, which varies greatly. This can be attributed to the fact that the farm is stationary and therefore, internet quality remains consistent. Essentially, the principal factor contributing to the latency between update intervals is the quality of the farmer's internet connection. The better the internet quality, the shorter the latency period between updates, enabling farmers to remotely control their farm from anywhere with a decent internet connection. Upon the crops reaching maturity, farmers can conveniently sell their produce through the in-built marketplace feature in the application. The introduction of this innovative application provides a practical solution to the growing need for sustainable urban farming and healthy food consumption. With the increasing use of smartphones and mobile applications, this technology offers a convenient and reliable platform for consumers, farmers, and other stakeholders to engage in indoor vertical farming. By incorporating features such as remote farm monitoring, the application enhances the efficiency and productivity of urban

farming, promoting sustainability and self-sufficiency. As more individuals turn to urban farming to address the challenges of food security and limited resources, this application provides a promising step towards a sustainable and equitable future.

## VI. LIMITATION AND FUTURE WORKS

This work has a limitation that can be improved with future works. The monitoring system built is tailor made to the selected farm in this work. So some monitoring features may not be of any use to other farms and thus some may request that feature is missing for other farm. For future work, more research can be conducted to gather data on the most common requested features in farm monitoring mobile application so that the feature can be widely used by variety of farmers especially urban farmers. Besides that, this approach of promoting the concept of urban farming also has a limitation where the user needs to be knowledgeable in technology to set up their online shop and monitoring system. This work only comes with mobile application since we assume user of this application already has his own monitoring system set up. So, if the users don't have the monitoring system set up, and they don't know how to, then the monitoring system feature will be useless to them, making the mobile application and urban farming less appealing in general. Next, the user interface can be improved much better to attract more consumers to use the application boosting the popularity of the application, simultaneously promoting the concept the urban farming to urban people. In future works, more appealed color scheme and modern design in user interface can be built. Lastly, the transaction for purchase in this application is still not diverse compared to other m-commerce applications in the market. In future work, the application can be built with more diverse options to complete the transaction making it more appealing to both consumer and seller. With improvement to this work, the goals to promote the concept of urban farming can achieve greater success.

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# Offensive Language Identification in Low Resource Languages using Bidirectional Long-Short-Term Memory Network

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**Abstract**—Offensive language identification is a critical task in today's digital era, enabling the development of effective content moderation systems. However, it poses unique challenges in low resource languages where limited annotated data is available. This research paper focuses on addressing the problem of offensive language identification specifically in the context of a low resource language, namely the Kazakh language. To tackle this challenge, we propose a novel approach based on Bidirectional Long-Short-Term Memory (BiLSTM) networks, which have demonstrated strong performance in natural language processing tasks. By leveraging the bidirectional nature of the BiLSTM architecture, we capture both contextual dependencies and long-term dependencies in the input text, enabling more accurate offensive language identification. Our approach further utilizes transfer learning techniques to mitigate the scarcity of annotated data in the low resource setting. Through extensive experiments on a Kazakh offensive language dataset, we demonstrate the effectiveness of our proposed approach, achieving state-of-the-art results in offensive language identification in the low resource Kazakh language. Moreover, we analyze the impact of different model configurations and training strategies on the performance of our approach. The findings from our study provide valuable insights into offensive language identification techniques in low resource languages and pave the way for more robust content moderation systems tailored to specific linguistic contexts.

**Keywords**—Offensive language; natural language processing; low resource language; machine learning; deep learning; classification

## I. INTRODUCTION

In recent years, the proliferation of social media platforms and online communication channels has facilitated the rapid exchange of information and ideas on a global scale. There are a lot of application that apply machine learning as image processing, automation, text processing, etc. [1-3]. While this connectivity has brought numerous benefits, it has also given rise to a significant challenge - the prevalence of offensive language and hate speech in online content. Offensive language not only has the potential to harm individuals and communities but also undermines the positive and constructive use of online platforms [3]. Consequently, there is a pressing need to

develop robust and effective systems for offensive language identification and content moderation.

Existing research in offensive language identification has primarily focused on well-resourced languages such as English, Spanish, and French. These languages benefit from abundant labeled data, enabling the application of sophisticated machine learning models that achieve high accuracy in identifying offensive content [3]. However, the same cannot be said for low resource languages, where the scarcity of annotated data poses a considerable obstacle. Low resource languages are typically characterized by limited linguistic resources, including annotated datasets, language models, and pre-trained embeddings [4]. This scarcity hinders the development of effective offensive language identification systems tailored to the linguistic nuances and cultural context of these languages.

In this research paper, we specifically address the challenge of offensive language identification in low resource languages, with a focus on the Kazakh language. Kazakh is a Turkic language predominantly spoken in Kazakhstan and neighboring regions, and it falls into the category of low resource languages due to the limited availability of labeled data and language resources [5]. Our goal is to develop a robust and accurate offensive language identification model that can effectively handle the unique characteristics of the Kazakh language.

To achieve this objective, we propose a novel approach based on Bidirectional Long-Short-Term Memory (BiLSTM) networks, which have shown remarkable success in various natural language processing tasks [6]. The BiLSTM architecture captures both the forward and backward contextual dependencies in the input text, enabling a more comprehensive understanding of the underlying semantics [7]. By leveraging this bidirectional modeling, our approach aims to enhance the offensive language identification performance in the low resource Kazakh language.

However, the scarcity of annotated data in low resource languages poses a significant challenge for model training. To mitigate this issue, we adopt transfer learning techniques,

leveraging pre-trained language models trained on large-scale datasets from high resource languages [8]. By fine-tuning these models on the limited Kazakh offensive language dataset, we aim to transfer the knowledge learned from the high resource languages to improve the performance of our offensive language identification model in the low resource Kazakh language.

In this research paper, we present a comprehensive evaluation of our proposed approach on a Kazakh offensive language dataset. We conduct extensive experiments to assess the impact of different model configurations, training strategies, and transfer learning approaches on the offensive language identification performance. Furthermore, we compare our approach with existing methods and showcase its superior performance, achieving state-of-the-art results in the offensive language identification task for the low resource Kazakh language.

The contributions of this research paper can be summarized as follows: (1) We propose a novel approach based on BiLSTM networks for offensive language identification in low resource languages, specifically focusing on the Kazakh language. (2) We employ transfer learning techniques to leverage pre-trained models from high resource languages and enhance the offensive language identification performance in the low resource setting. (3) We conduct extensive experiments and provide in-depth analysis, shedding light on the impact of different model configurations and training strategies. (4) We demonstrate the effectiveness of our proposed approach through state-of-the-art performance on a Kazakh offensive language dataset.

The remainder of this paper is organized as follows: Section II provides an overview of related work in offensive language identification and highlights the challenges specific to low resource languages. Section III presents the methodology, describing the proposed BiLSTM-based approach and the transfer learning techniques employed. Section IV discusses the evaluation metrics. Section V presents the experimental results. Section VI discusses the findings of our study, provides insights into offensive language identification in low resource languages and discusses future directions for research in this domain. Finally, Section VI concludes the paper.

## II. LITERATURE REVIEW

Offensive language identification has gained significant attention in recent years due to the growing concern over online hate speech and its potential negative impact on individuals and communities [9]. Several studies have focused on developing effective models for offensive language identification, primarily in well-resourced languages such as English, Spanish, and French [10]. However, the challenges associated with offensive language identification in low resource languages remain relatively unexplored [11]. In this literature review, we discuss the existing research and methodologies employed in offensive language identification, with a specific focus on low resource languages. Additionally, we highlight the importance of the Bidirectional Long-Short-Term Memory (BiLSTM) network and its potential in addressing offensive language identification in such languages.

Numerous studies have employed machine learning techniques for offensive language identification. Wulczyn et al. (2017) introduced the Wikipedia Detox project, which focused on detecting personal attacks in English Wikipedia comments [12]. They employed various supervised learning algorithms, including logistic regression, gradient boosting, and deep neural networks, achieving promising results. Similarly, Djuric et al. (2015) explored a feature-based approach using n-grams and syntactic patterns for identifying offensive language in social media texts [13].

When it comes to low resource languages, the scarcity of annotated datasets presents a significant challenge. Few studies have specifically addressed offensive language identification in this context. However, transfer learning techniques have shown promise in mitigating the data scarcity issue. Fortuna and Nunes (2018) utilized transfer learning by leveraging pre-trained embeddings from a high resource language, Portuguese, to identify offensive content in the low resource language, Galician [14]. Their approach demonstrated improved performance compared to traditional methods.

In the realm of offensive language identification, deep learning models have gained significant attention due to their ability to capture complex linguistic patterns and contextual dependencies. Convolutional Neural Networks (CNNs) have been widely applied in this domain. Park et al. (2017) employed CNNs for detecting hate speech in English tweets, achieving competitive performance [15]. Their model utilized multiple convolutional filters of different sizes to capture various levels of linguistic information.

Another notable approach is the use of ensemble models. Davidson et al. (2017) introduced a multi-perspective model that combines CNNs, LSTMs, and logistic regression for hate speech detection [16]. By incorporating different perspectives and modeling techniques, their ensemble model achieved improved accuracy compared to individual models.

Apart from traditional machine learning and deep learning techniques, some studies have explored the use of linguistic features and lexicons for offensive language identification. Schmidt and Wiegand (2017) proposed a feature-based approach using character n-grams, sentiment scores, and part-of-speech tags for identifying abusive language in German [17]. Their findings showed that incorporating these linguistic features enhanced the classification performance.

Furthermore, the development of annotated datasets plays a vital role in training and evaluating offensive language identification models. Many studies have created their own labeled datasets, specific to different languages and platforms. For instance, Founta et al. (2018) curated a large-scale dataset of hate speech and offensive language from Twitter, covering multiple languages, including English, Spanish, and Italian [18]. The availability of such datasets facilitates comparative evaluations and benchmarking of offensive language identification approaches.

In the context of deep learning models, recurrent neural networks (RNNs) have been widely used for offensive language identification. Chen et al. (2018) explored the effectiveness of BiLSTM networks in detecting hate speech in

Chinese social media platforms. Their findings indicated that BiLSTMs capture contextual dependencies effectively, leading to improved performance in offensive language identification tasks [19].

Furthermore, attention mechanisms have been incorporated into RNN models to enhance the understanding of offensive language. Nobata et al. (2016) introduced an attention-based BiLSTM model for abusive language detection in online communities [20]. By attending to relevant parts of the input text, the model achieved better discriminatory power in identifying offensive language.

To provide a comprehensive comparison of the literature, we present a table (Table I) summarizing relevant studies in offensive language identification, including the language, applied method, dataset, and evaluation metrics.

TABLE I. REVIEW OF THE LITERATURE IN OFFENSIVE LANGUAGE DETECTION FOR LOW RESOURCE LANGUAGES

Literature	Language	Applied Method	Dataset	Evaluation
Wulczyn et al. (2017)	English	Logistic Regression, Gradient Boosting, Deep Neural Networks	Wikipedia Comments	Accuracy, Precision, Recall, F1-Score
Djuric et al. (2015)	English	Feature-based approach (n-grams, syntactic patterns)	Social Media Texts	Accuracy, Precision, Recall, F1-Score
Fortuna and Nunes (2018)	Galician	Transfer Learning, Pre-trained Embeddings	Social Media Texts	Accuracy, Precision, Recall, F1-Score
Chen et al. (2018)	Chinese	BiLSTM Networks	Social Media Texts	Accuracy, Precision, Recall, F1-Score
Nobata et al. (2016)	English	Attention-based BiLSTM Networks	Online Communities	Accuracy, Precision, Recall, F1-Score
Hassan et al. (2019)	Arabic	Deep Learning Models	Social Media Texts	Accuracy, Precision, Recall, F1-Score
Imran et al. (2018)	Urdu	Feature-based Approach, SVM	Twitter Data	Accuracy, Precision, Recall, F1-Score
Choubey et al. (2019)	Hindi	Deep Learning Models	Social Media Texts	Accuracy, Precision, Recall, F1-Score
Jha et al. (2018)	Bengali	LSTM, Word Embeddings	Social Media Texts	Accuracy, Precision, Recall, F1-Score

In terms of evaluation metrics, commonly employed measures include accuracy, precision, recall, and F1-score. Accuracy represents the overall correctness of the model's predictions, while precision measures the proportion of correctly identified offensive language instances among all predicted offensive instances. Recall, also known as sensitivity, denotes the percentage of correctly identified offensive instances out of all actual offensive instances. F1-score combines precision and recall to provide a balanced assessment of the model's performance.

In summary, the literature on offensive language identification demonstrates the effectiveness of various machine learning techniques in well-resourced languages. However, offensive language identification in low resource languages remains an underexplored area. The utilization of transfer learning and deep learning models, such as BiLSTMs with attention mechanisms, has shown promising results in addressing offensive language identification challenges. By leveraging these approaches and adapting them to the specific characteristics of low resource languages, we aim to develop an effective offensive language identification model for the Kazakh language in this research paper.

### III. MATERIALS AND METHODS

This paper explores the application of Bidirectional Long Short-Term Memory Networks (BiLSTM) for offensive language detection in text data. It addresses the pervasive issue of offensive language in online platforms and proposes an automated solution that harnesses the power of deep learning [21]. The BiLSTM model, an extension of the traditional LSTM framework, is chosen for its ability to capture temporal dependencies in both forward and backward directions, proving particularly effective in understanding the context of languages.

#### A. BiLSTM

The technique of sequence processing known as a bidirectional LSTM consists of two LSTMs, of which one accepts the input in the forward direction and the other takes it in the reverse direction. In general, the e-BiLSTM is used to extract the hidden connection between the input features and the target, in addition to the information about the long-dependent input sequence [22-25]. Using memory cells to remember long-term historical data and controlling it by means of a door mechanism are the two most important aspects to consider here. The door structure does not provide any information; rather, it acts as a barrier that limits the amount of data that may be accessed. In actuality, the implementation of a gate control mechanism is a multi-level feature selection technique. LSTM is a useful tool that provides several advantages when it comes to the analysis and forecasting of time series data. This is a particular kind of RNN [26]. Both RNN and LSTM have a chain-structured network module in their respective architectures. In RNN, the module is constructed from a single neuron, but in LSTM, it is constructed from cells that each has three gates. The output gate, the input gate, and the forget gate are the three gates that are used by the cell in the process of selecting characteristics [27]. The LSTM loop body is shown in Fig. 1, which may be



found here. The symbols shown in the figure will be referred to in the subsequent equation.

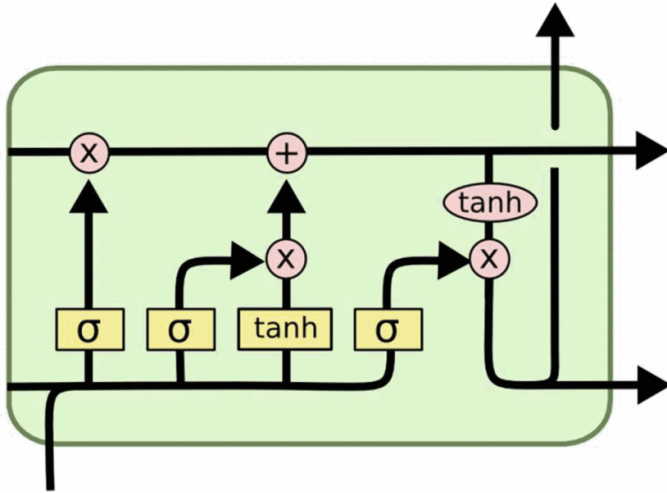


Fig. 1. BiLSTM network.

Fig. 2 illustrates the structure of the cell, which consists mostly of the output gate, the input gate, and the forget gate. The following are some examples of computing methods that may be used with these three different types of gates:

$$input(t) = \sigma(W_i x(t) + V_i h(t-1) + b_i) \quad (1)$$

The equation (2) provides a description of the computing mechanism used by the forget gate in the cell.  $W_f$  and  $V_f$  in the equation are forgotten gate weights, and this gate governs which of the data in the cell must be destroyed. In other words,  $W_f$  and  $V_f$  are forgotten gate weights.

$$forget(t) = \sigma(W_f x(t) + V_f h(t-1) + b_f) \quad (2)$$

The computation procedure of the input gate in the cell is described by Equation (1), where  $h(t-1)$  is the previous cell's output,  $x(t)$  is the current cell's input,  $\sigma$  denotes the sigmoid function, and  $W_i$  and  $V_i$  are the input gate's weights.

$$\tilde{C}(t) = \tanh(W_c x(t) + V_c h(t-1) + b_c) \quad (3)$$

$$C(t) = forget(t) \cdot C(t-1) + input(t) \cdot \tilde{C}(t) \quad (4)$$

The update procedures are described by equations (3) and (4), where (3) denotes the candidate memory unit that creates alternate update data and (4) denotes the updating process of the cell's status. The update data is merged with the information from the forgetting gate to generate a new state, where  $W_c$  and  $V_c$  denote the alternate new state's weights, and  $\cdot$  denotes the Hadamard product.

$$output(t) = \sigma(W_o x(t) + V_o h(t-1) + b_o) \quad (5)$$

$$h(t) = output(t) \cdot \tanh(C(t)) \quad (6)$$

The procedure for calculating the output gate is outlined by equations (5) and (6) respectively. In the first step, the sigmoid layer is used to determine whether or not the cell is in the

output state. The second step involves applying the tanh function to the updated cell status [27]. The third and final step involves multiplying the current cell status by  $output(t)$  to yield  $h(t)$ .  $V_o$  denotes the weight of the output gate. The cell that is mentioned up top serves as the hub of the LSTM neural network. This topology is used as the foundation for the construction of a bidirectional LSTM network, which is then used to extract data properties. Traditional LSTM is superior than bidirectional LSTM in terms of the amount of context data it can extract [28]. The forward and backward time series are used to offer information about the past and future timestamps, which enables the network to more accurately predict time series. Because there is no direct connection between the forward and backward layers, the structure may be described as being acyclic. In the event that the input layer does include data, the results of the backward and forward layers are combined at the output layer in order to form the output. After each feature has been processed by the bidirectional LSTM and has passed through the fully connected layer, all of the features are blended together using the merged layer. Fig. 2 depicts the primary architecture of both the bidirectional LSTM (BiLSTM) and the LSTM neural network.

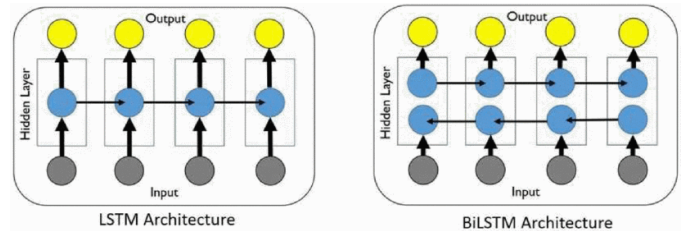


Fig. 2. BiLSTM network.

Fig. 2 illustrates how the BiLSTM algorithm adds another LSTM layer, which in turn inverts the direction in which information flows. It means, to put it in simple words, that the input sequence is executed in reverse order in the additional LSTM layer. After that, the results of the two LSTM layers are combined using a number of different operations, such as adding, averaging, concatenating, and multiplying the results. Because of this, the amount of information that can be accessed by the network increases, and the context that is given to the algorithm becomes more accurate. In contrast to typical LSTM, the input is allowed to go in both directions, and it may utilize information from either side. Additionally, it is a helpful tool for replicating the sequential connections between words and sentences in both directions, which may be done in either manner.

#### IV. EVALUATION METRICS

In the process of evaluating the efficacy of our proposed LSTM-CNN model, we leverage several widely-accepted performance metrics: accuracy, recall, F-measure, and AUC-ROC (Area Under the Curve, Receiver Operating Characteristic curve) [29-32].

Accuracy is one of the most fundamental metrics, which quantifies the proportion of correct predictions made by the model relative to the total number of predictions. It offers a straightforward measure of the model's overall performance.

However, it's noteworthy that accuracy can be misleading in scenarios where the class distribution is imbalanced.

$$accuracy = \frac{TP + TN}{TP + FN + TN + FP} \quad (7)$$

Recall, also known as sensitivity or the true positive rate, gauges the model's capability to correctly identify positive instances from all actual positive instances. In the context of this study, it would indicate the ability of our model to correctly detect instances of right-wing extremist content among all actual instances of such content.

$$recall = \frac{TP}{TP + FN} \quad (8)$$

F-measure, or F1-score, provides a harmonic mean of precision and recall. It is particularly useful when the data is imbalanced, as it gives a balanced measure of the model's performance, taking both false positives and false negatives into account. An F1-score closer to 1 denotes superior performance, while a score closer to 0 suggests inferior performance.

$$F1 = \frac{2 \cdot precision \cdot recall}{precision + recall} \quad (9)$$

Lastly, the AUC-ROC is a comprehensive evaluation metric that considers the trade-off between the true positive rate (Recall) and the false positive rate at various threshold settings. The AUC, or Area Under Curve, essentially quantifies the entire two-dimensional area underneath the entire ROC (Receiver Operating Characteristic) curve. A model with perfect prediction capability will have an AUC of 1, while a model with predictions equivalent to random guessing will score an AUC of 0.5.

Through the meticulous application of these evaluation metrics, we aim to comprehensively assess the performance of our proposed model on detecting right-wing extremism in online textual content.

### V. EXPERIMENTAL RESULTS

This section demonstrates the results in using BiLSTM network in offensive language detection problem. Fig. 3 demonstrates confusion matrix in classification of seven classes the given text. The obtained results approve that the BiLSTM network is applicable in offensive language classification problem.

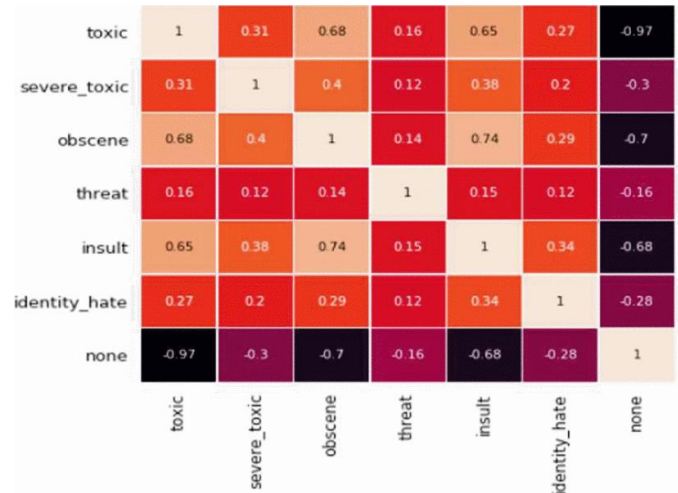
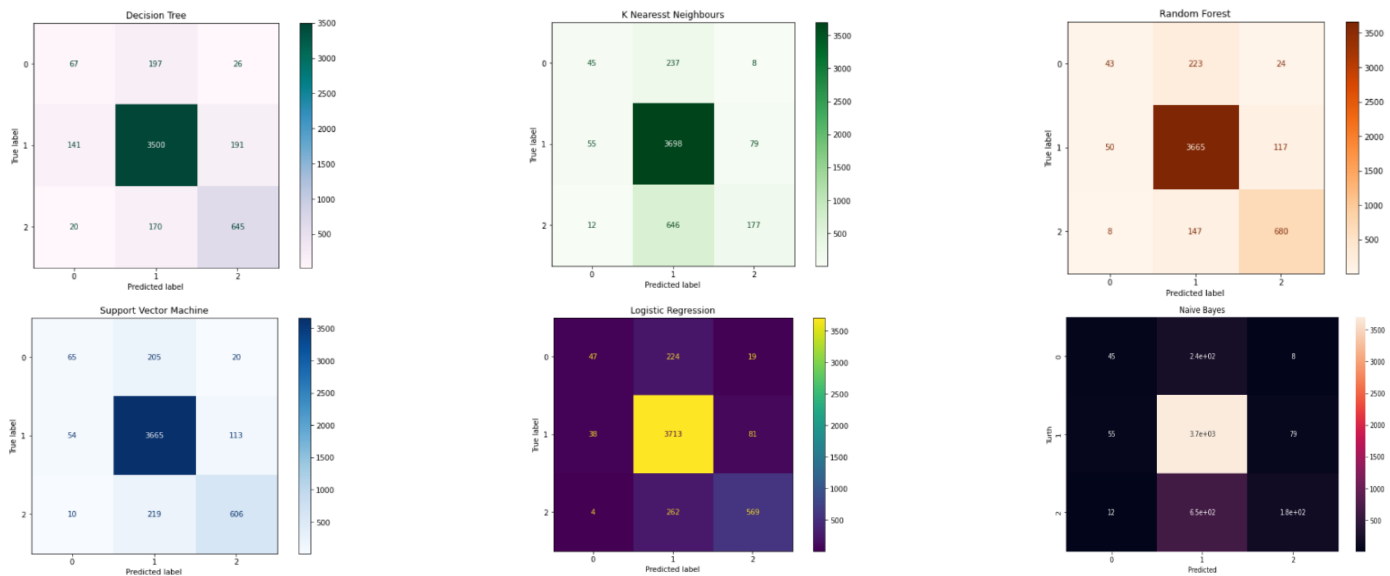


Fig. 3. Confusion matrix in classification of 5 classes.

Fig. 4 demonstrates confusion matrices that obtained using different machine learning methods in three classes offensive language detection as offensive language, positive language and neutral language.



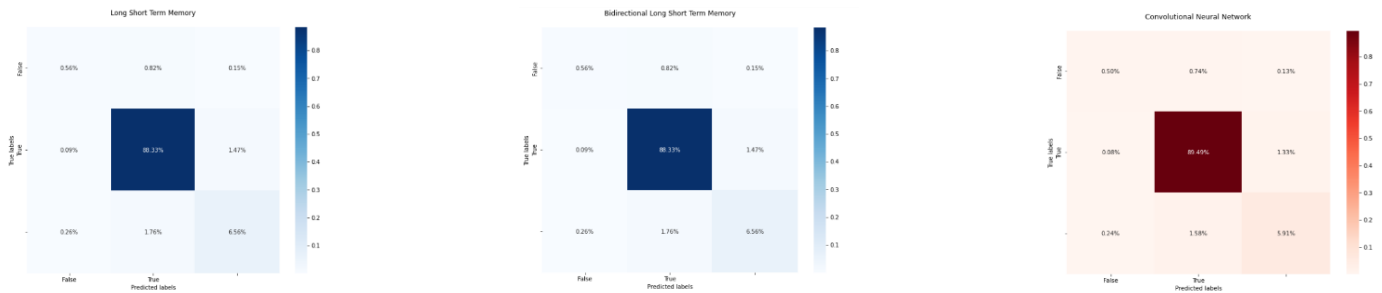


Fig. 4. Confusion matrix using the other models.

Fig. 5 compares AUC-ROC curves of different machine learning algorithms including the explored bidirectional long-short term memory network in binary classification of offensive language. The results show that, the explored BiLSTM network gives high result from the first learning epochs.

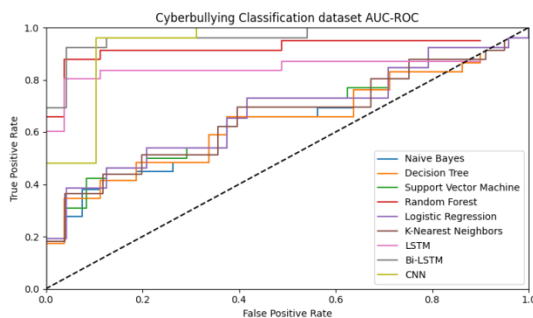


Fig. 5. AUC-ROC curve in offensive language detection.

## VI. DISCUSSION

This section discusses the bidirectional long-short-term-memory network in terms of different categories as practical use of the BiLSTM network, advantages of the BiLSTM network, limitations of the BiLSTM network, and future perspectives of the explored model in offensive language detection problem.

### A. Practical Use

The application of BiLSTM for offensive language detection has far-reaching implications in many sectors, particularly in social media moderation and digital community management. One of the significant challenges faced by these platforms is managing the vast volume of user-generated content, which often contains offensive, hateful, or toxic language. The manual moderation of such content is time-consuming, expensive, and prone to inconsistencies. Implementing a BiLSTM-based model can significantly enhance the efficiency of these moderation processes, as it can automatically and continually screen the content for offensive language [32]. This could help in early detection and removal of such content, thereby creating a safer and more inclusive online environment. Furthermore, this model can also be useful for other digital platforms such as news portals and e-commerce websites, where user reviews and comments are often left unchecked. Given the expanding digital landscape, the practical use of this approach is vast and largely untapped.

### B. Advantages of The BiLSTM in Offensive Language Detection

The BiLSTM model offers several advantages in the task of offensive language detection [33]. Its primary strength lies in its ability to process sequences of data in both forward and backward directions, enabling it to extract complex patterns and dependencies in the data. This bidirectional approach allows the model to capture the broader context of language use, which is critical in accurately identifying offensive language that may rely heavily on context and subtleties of language use [34]. Unlike traditional machine learning models that rely on handcrafted features, BiLSTM can automatically learn relevant features from the data, reducing the need for extensive feature engineering. Additionally, BiLSTM models are less prone to the vanishing gradient problem, making them more robust and effective in learning long sequences, a common feature of text data.

### C. Limitations

Despite the many advantages of the proposed BiLSTM model for offensive language detection, there are several limitations to note. First, while the bidirectional structure captures past and future contexts, it can also increase the complexity and computational requirements of the model. This could pose challenges in real-time applications where speed is crucial. Second, the performance of the model heavily depends on the quality and representativeness of the training data. If the training data does not sufficiently represent the diversity of offensive language, the model might fail to generalize well to unseen data. Moreover, the model's output is sensitive to hyperparameters, requiring extensive tuning for optimal performance. Finally, although the BiLSTM model can handle long sequences, it might still struggle with extremely long texts due to its fixed-size hidden state [35].

### D. Future Perspectives

This research focuses on the detection of offensive language within online user-generated content. In contemporary education, various approaches have been adopted to instill ethical values and moral principles in children and students at both the elementary and secondary levels [36-37]. In this study, we employ a machine learning approach, which represents one of the current state-of-the-art methods employed in this field. Despite the challenges, the future perspectives of BiLSTM for offensive language detection are promising. One potential area for improvement is the integration of attention mechanisms, which can allow the model to focus on the most informative parts of the sequence,

potentially improving accuracy and efficiency [38]. Additionally, the fusion of BiLSTM with other deep learning architectures, such as Convolutional Neural Networks (CNN), could also be explored for improved performance. On a broader scale, the adaptability of the model can be improved by incorporating methods to handle the evolving nature of language, such as slang and dialectal variations [39]. Furthermore, developing strategies to effectively handle multilingual and cross-lingual offensive language detection would significantly broaden the applicability of the model. As the research progresses, the integration of these advancements would likely yield a more robust and efficient model for offensive language detection.

## VII. CONCLUSION

This research has delved into the implementation and applicability of Bidirectional Long Short-Term Memory Networks (BiLSTM) for the task of offensive language detection in textual data. The BiLSTM model was identified as a potent solution, proficient at recognizing offensive language patterns due to its superior capacity to handle temporal dependencies and glean both past and future context from data sequences. This feature is of paramount importance considering the intricacies and subtleties of language that influence whether a text is deemed offensive or not.

The proposed model serves as a highly valuable tool for content moderation in digital platforms, promising efficiency and consistency in filtering out offensive content, thereby contributing to safer and more respectful online environments. As compared to traditional machine learning techniques, the proposed BiLSTM model significantly reduces the necessity for meticulous feature engineering by autonomously learning relevant features, and outperforms in the management of long sequences of data.

However, it is equally important to consider the model's limitations. The increased computational requirement is due to bidirectional processing, dependence on the quality of training data, and sensitivity to hyperparameters underline the complexities involved in the application of the model. Despite these challenges, the outlook for the use of BiLSTM in offensive language detection is promising. The potential integration of attention mechanisms or fusion with other deep learning architectures such as Convolutional Neural Networks (CNN) represents avenues for future exploration and improvement.

Furthermore, the model's adaptability could be refined to accommodate the evolving nature of language, including the continual emergence of slang, changes in semantics, and dialectal variations. There is also potential for growth in the handling of multilingual and cross-lingual offensive language detection, thereby extending the model's scope of application.

In conclusion, while challenges and opportunities for further enhancements persist, the proposed BiLSTM model demonstrates considerable potential in addressing the pervasive issue of offensive language in digital platforms. It highlights the potency of deep learning techniques in understanding the complexities of human language, providing automated solutions to challenges that could not be effectively handled

with traditional methods. This research marks a crucial step towards harnessing the power of AI for creating safer, more inclusive digital communication platforms. Future advancements in this field are not only anticipated to yield more robust and efficient models but also offer novel insights into the understanding and modeling of language use in digital media.

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# Query-Focused Multi-document Summarization Survey

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**Abstract**—With the exponential growth of textual information on the web and in multimedia, query-focused multi-document summarization (QFMS) has emerged as a critical research area. QFMS aims to generate concise summaries that address user queries and satisfy their information needs. This paper provides a comprehensive survey of state-of-the-art approaches in QFMS, focusing specifically on graph-based and clustering-based methods. Each approach is examined in detail, highlighting its advantages and disadvantages. The survey covers ranking algorithms, sentence selection techniques, redundancy removal methods, evaluation metrics, and available datasets. The principal aim of this paper is to present a thorough analysis of QFMS approaches, providing researchers and practitioners with valuable insights into the field. By surveying existing techniques, the paper identifies the challenges and issues faced in QFMS and discusses potential future directions. Moreover, the paper emphasizes the importance of addressing coherency, ambiguity, vague references, evaluation methods, redundancy, and diversity in QFMS. Performance standards and competing approaches are also discussed, showcasing the advancements made in QFMS. The paper acknowledges the need for improving summarization coherence, readability, and semantic efficiency, while balancing compression ratios and summarizing quality. Additionally, it highlights the potential of hybrid methods and the integration of extractive and abstractive techniques to achieve more human-like summaries.

**Keywords**—Text summarization; query-based extractive text summarization; multi-document; graph-based approach; clustering-based approach

## I. INTRODUCTION

Computers and human interaction have significantly impacted on Natural Language Processing (NLP). The evolution of NLP has a direct influence on numerous fields and serves a wide range of applications. Most importantly, it assists computers in recognizing and understanding human language. Recently, there has been a rapid growth of available documents online. As a result, retrieving helpful information from the vast amount of electronically accessible documents available has become a big challenge. Text summarization can be effectively used to reduce this issue.

Automatic summarization can be categorized based on different factors. Extractive and abstractive summaries are the two major categories [1]. An extractive summary is created by linking some chosen sentences from the input document to form a summary. The output summary presents these selected sentences precisely as they appear in the original text without any changes. In contrast, language-generation algorithms are used to produce an abstractive summary automatically. This

usually requires the system to do sentence compression, paraphrasing, and reformulation to make the summary look more human-like.

Moreover, depending on the number of input documents, summarization can be generally classified as either a single-document or multi-document system [2]. Early studies dealt with a single document where the system presented that document in a shorter form while retaining the most essential information. The use of multi-document summarization has become more critical with the growth of the internet. Given the massive volume of redundant content on the web, summarization can be more beneficial if they offer a concise summary of numerous papers on the same subject.

Summarization can be either a generic or query-focused [2]. A general summary gives an overview of the critical information from the input document to help the reader to understand its contents quickly. In this regard, the content of the entire input document determines the significance of the information. When the summary is generated based to a query, instead, the query itself chooses what data is essential and ought to be included in the output summary.

Query-focused multi-document text summarization (QFMS) is a relatively active automatic summarization subfield with many applications. It is a quick and efficient approach to navigating and grasping web texts, including news, articles, blogs, and data analysis. Search engines use query-focused text summarization methods to produce a summary of retrieved data, which helps the users to grasp the critical content quickly. These techniques save consumers' time, improving the search engine's service.

Moreover, in many sectors nowadays, chatbots automatically respond to users' inquiries and requests made through chat interfaces. A natural-language search query, such as "Return an item," is often the first step in using a chatbot on a shopping website, for example. The chatbot answers by displaying a summary of the results. Additionally, it is crucial for marketing since, through user inquiries, companies may learn more about what attracts customers and save this information through some data collection techniques. As a result, essential business choices may be made by examining and analyzing these unstructured data. Organizations may thus be proactive with their strategies and enhance their poise and confidence.

While existing text summarization surveys have mainly focused on generic summarization, query-focused summarization has received limited attention. To the best of



our knowledge, there are no state-of-the-art surveys investigating query-based summarization problems, such as extracting query-relevant sentences and reducing redundancy. Therefore, the primary motivation of this study is to provide a comprehensive review of existing studies on query-focused multi-document summarization, aiming to assist researchers in improving query-based summaries. This survey delves into two main QFMS approaches, their algorithms, sentence extraction techniques, similarity scoring methods, redundancy removal techniques, evaluation metrics, standard datasets, existing challenges, and future research directions.

The remainder of this paper is structured as follows: Section II presents a detailed description of the QFMS problem. The third section introduces the QFMS approaches and reviews the different methods proposed in the literature for each approach. The discussion of findings, open research problems, and future directions are presented in Section IV. Finally, Section V concludes the paper.

## II. PROBLEM STATEMENT

QFMS resolves the problem of extracting useful information from an extensive amount of data, which improves the effectiveness of obtaining and utilizing information. However, automatic text summarization has many challenges, particularly query-focused ones. Relevancy, diversity, and redundancy are the three main bottlenecks.

A summary must be relevant and provide information based on a given query. Query-based summarization is complicated because the user's query must evaluate the relevance of sentences and choose the ones suitable for inclusion in summary. In addition to selecting the most important information from all document sets, the system is supposed to ensure that the information is based on the specified query. As a result, the query's specific features should be included throughout the summarizing process by calculating the similarity measure between the query and each sentence from the input text and, then sorting the sentences based on the generated scores [3]. Taking into account only the precise match between the query's terms and the terms in the sentences does not provide the best measure. Additionally, doing that to multi-documents sets makes the process potentially more complicated since we have to deal with the variations and similarities across document sets.

Another crucial factor of a robust query-based summary is the diversity [4]. To ensure user satisfaction, different aspects of the question should be considered in the summary to the greatest extent possible. This task is difficult because it demands recognizing and modeling the connections between the sentences and how they relate to the query. Therefore, it is founded that diversity is the most essential and challenging task in QFMS that has interested many researchers lately [4].

Additionally, redundancy is a typical issue that practically all methods of multi-documents automatic summarization encounter [5]. A good summary should be more informative and less repetitive. In single-document summarization, every phrase is distinct and doesn't often contain redundant data. In contrast, information from multi-documents will overlap. In

fact, the information can be repetitive, or it can represent the same concepts in multiple ways without adding any new data. This issue makes the automatic summarization more difficult, as it involves finding and analyzing the connections among the sentences in all texts to remove redundant and repeated data.

The diversity of automatic summarization methodologies comes from different ways of tackling the ranking and selection issues. A ranking problem is a process of ranking all sentences in the input documents. This needs an algorithm that evaluates the importance of each sentence in accordance with the input inquiry. The selection problem is how to choose some of those ranked sentences to create the summary [6]. This requires a model that increases the diversity and decreases the redundancy to form an informative summary under a limited length. Fig. 1 shows a general architecture of a QFMS, which consists generally of the following steps:

1) *Pre-Processing*: This step is done for both input documents and the query. The objective is to reduce noisy and unfiltered text, decrease calculation time, and allow diverse term variants to be treated equally. This can be done using several NLP methods. The following techniques are used in the surveyed literature:

a) *Normalization*: Extends acronyms, lowercase all words, eliminates digits, or changes them to terms, etc.

b) *Tokenization*: Converts each sentence into a list of individual words [2].

c) *Stop-Word Removal*: Stopwords are the commonly used terms in a language, such as: how, are, to, etc. Removing such words drives attention to the important ones. They are irrelevant for search purposes, and they can disturb the result [7].

d) *Stemming*: From a text summarization aspect, stemming is the process of returning the words to their root form [8].

e) *Part-of-Speech Tagging*: Categorizes the terms into nouns, verbs, adjectives, and adverbs [9].

f) *Named Entity Recognition*: Classifies words as item names such as person name, location name, etc.

2) *Processing*: this includes the following:

a) *Creating text representation*: Generating a proper representation of the input documents to simplify the subsequent ranking process and selection. This representation can be graphs, clusters, topic models, etc.

b) *Ranking algorithm*: The input sentences are ranked according to relevance to the query, and they are then arranged from highest to lowest. This step varies depending on the approach being used.

c) *Selecting algorithm*: Choosing the best-ranked sentences considering the limited length. That length can be computed as a number of sentences, number of terms, or a ratio.

3) *Post-Processing*: This can include reordering the sentences, redundant sentence reduction, etc.

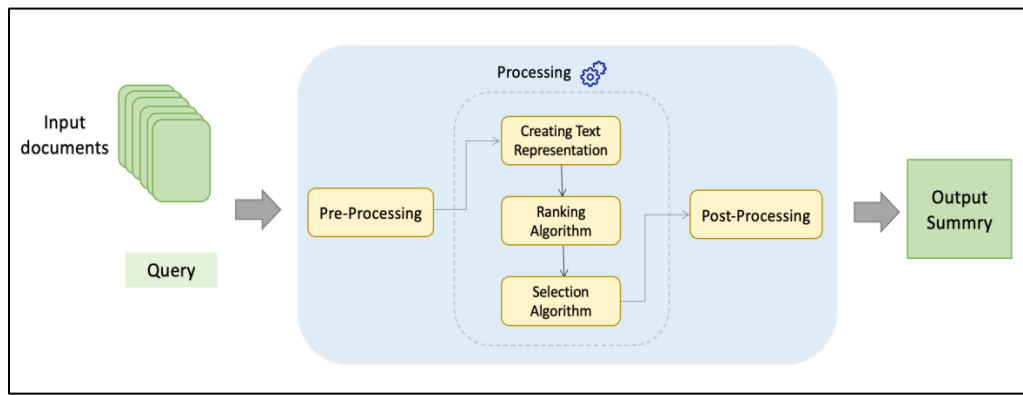


Fig. 1. General architecture of a query-focused multi-document summarizer.

### III. LITERATURE REVIEW

#### A. QFMS Approaches

Different approaches have been applied to QFMS, such as graph-based, clustering-based, machine learning-based, statistical-based, semantic-based, optimization-based, etc. [8]. In this survey, two main approaches will be reviewed separately in respective subsections. Fig. 2 presents a classification of the reviewed QFMS approaches.

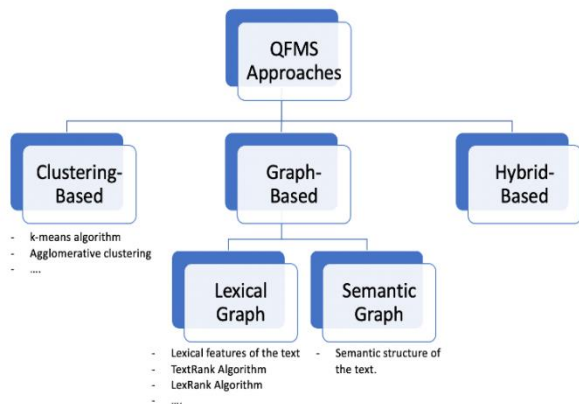


Fig. 2. A classification of the reviewed QFMS approaches.

1) *Graph-based approach*: The graph-based approach has been a commonly used approach for extractive text summarization because of its capacity to create sentence linkages within one document and linkages with sentences on other documents [10]. Particularly, it is best suited to extract a list of the essential query-related sentences from the documents [11]. A graph is a data structure that contains a set of nodes connected with edges. It is a domain-independent [2] and language-independent and can enhance the coherency [8], and reduce the redundancy [5], [12]. In QFMS, to display the input, a graph is employed such that each sentence from the input text is a node, and the weighted edges between nodes and the query measure the similarity between each respective pair. Then, the nodes are ranked using ranking algorithms such as PageRank [13], TextRank [14], and LexRank [15] algorithms to assess each sentence's significance. Finally, the summary is produced by selecting high-ranked sentences [8].

Lei and Zeng [16] used a manifold-ranking algorithm [17] to create a graph where edges represented the degree of similarity to the query and the vertices represented the sentences and the query. According to their study, the manifold ranking system, which used a graph-based placement algorithm, can quickly determine the most relevant and prestigious phrases to answer the query. Their model produced unique top-ranked sentences by modifying the iteration operation, and these sentences were utilized to build a review without the need for extra procedures. In comparison to earlier query-focused summarizing techniques, their method produced high-quality summaries. Wan and Xia [18] also created a multi-modality system that considered both intra-document relevance and other documents' similarities to improve the manifold-ranking algorithm. Their method outperformed the standard manifold-ranking algorithm.

Similarly, Wei et al. [19] argued that the inter-document links (i.e., the edges that link sentences from different documents) are more significant than the intra-document links (i.e., the edges that connect sentences from the same documents). They are supposed to be more comprehensive and able to capture more relevant information from the whole document set. Hence, they assigned the inter-document edges an additional weight compared to the intra-document edges. The results of the proposed approach outperform the best-performing systems in DUC2005. As aforementioned, redundancies are challenging in multi-document summarizations. Balaji et al. [5] presented a graph-based technique for QFMS that effectively minimized redundancies. In this study, graph matching was used to create a global semantic graph, which decreased the number of repeated sentences appearing in the summary.

Mohamed and Rajasekaran [20] created a document graph to represent the text document which has two forms of relations, "is a" and "related to." They made three tries, each time slightly altering the centric graph to include a generic summary. Then they expanded their work to include query-based summaries and finally introduced the query modification technique to incorporate additional query information. Although their solution outperforms many baseline systems in terms of performance, it is ineffective when the query contains a variety of hidden subtopics.

Due to the insufficient information that a query can express, query expansion is proposed [21]. Abdi et al. [22] expanded the terms in the query and the sentences using the Content Word Expansion (CWE) approach. The CWE is based on semantic similarity. Also, Jia et al. [21] proposed a query expansion technique that used -including the query itself- some external resources, which are: WordNet, mean, variance, and TexRank algorithm to expand the query. Better performance was found using their approach.

QFMS has effectively utilized the hypergraph-based concept. . It can provide more precise similarity calculations [27]. Xiong and Ji in [26] developed a vertex-enhanced hypergraph approach. Using the cosine similarity metric, they used a topic model to group sentences according to the probability distribution of their topic. Then they expressed these distributions and the relationship between phrases using the hypergraph. A random walk algorithm determined the score of the sentences on the graph. Experiments on datasets showed an improvement.

Similarly, two summarization approaches are integrated by Akhtar et al. in [28] to benefit from both topic model-based and graph-based approaches. Their scoring technique used only common words for sentence ranking. They would like to enhance their work by considering semantic similarities in future work. Notably, Lierde and Chow [23] pointed out the two critical issues in graph-based summarization. First, the fact that each sentence covers multiple topics. Second, the joint relevance of sentences can't be measured by each sentence's individual relevance score, and this scoring tends to produce redundant summaries. To address these issues, they proposed a new summarizer based on hypergraph transversals, in which the nodes are sentences and the hyperedges are themes (topics). The hyperedge weights reflect both its importance and its relevance to the query. Hence, each hyperedge is associated with a specific topic, each node should belong to multiple hyperedges, and the themes may overlap. A summary is produced by generating a transversal of nodes in the hypergraph. Experiments on DUC 2007 dataset showed that their method outperforms the related graph and hypergraph-based approaches by at least 6% of the ROUGE-SU4 score. However, this approach is restricted to topical similarities between sentences. Authors would like to involve some linguistic features and discourse relations to enhance their model. Similarly, the same authors, Lierde and Chow [24] extended their work to develop a fuzzy hypergraph model where each node represents a sentence and fuzzy hyperedge is a topic. Sentences are scored according to how closely they relate to the query and how central they are to the hypergraph. In future work, the authors would like to improve the readability of their generated summaries.

One of the main drawbacks of the graph-based approach is that it doesn't consider the semantic structure of the sentence [29]. However, some researchers tried to handle this issue by taking into account additional language-dependent parallels, like semantic similarity [30]. Abdi et al. [31] also proposed a query-based summary method that combines sentiment analysis and summarization approaches. The proposed method has two main phases: 1) sentiment analysis, which calculates the sentiment score of each sentence and selects sentences that

have the same sentiment orientation of the opinion of the correlated query and passes them to the next phase 2) summarizer phase, it calculates the total score that combines the query-relevant score with the sentence sentiment score and rank them using a graph-based ranking algorithm. Although using a semantic graph gave good scoring, it required external knowledge sources. In the same manner, several statistical and semantic scoring techniques have been used by Krishna et al. [32] to assess how closely the user query matches the document's sentences, which are Word form similarity, N-gram similarity, Word Order Similarity, and Semantic similarity. Instead of applying a weighted scoring method (where each value has a predefined weight) to determine the overall score, they base it on the average (mean) value obtained using the abovementioned techniques. To avoid redundancy, an iterative clustering process is employed.

Conversely, three statistical features were proposed by He et al. [33] for sentence scoring. Similarity and Skip-Bigram co-occurrence are the first two query-dependent features. The third feature is a text graph's query-independent feature that is used to extract sentences with high information density. However, their approach might not be able to identify semantically equivalent sentences.

To support the assertion that multiple approaches in combination can improve text summarization, Murarka and Singhal [34] developed a hybrid system that combines the Latent Semantic Analysis (LSA) technique [35] and an enhanced PageRank algorithm to address the challenges of QFMS. The results showed a better performance of their hybrid model than many graph-based and semantic-based methods. In fact, PageRank [13] is a well-known graph-based technique to assess the relevancy of web pages by evaluating their related keywords, sentences, and reputable links. It commonly appears in text-summarization methods due to its capacity to extract meaning from texts. The PageRank method is suitable for giving significance to any collection of units with mutual references [36]. PageRank [37] and graph-based relevancy methods are used widely [38]. These graph-based methods emphasize global relevance and PageRank-inspired recursive scoring for phrase relevance. Generally, the model has a simple implementation, fast computation, and is language independent. However, they have reduced readability. Nastase [39] applied a summarization of Wikipedia and heavily relied on PageRank as a mechanism for measuring significance in the process. By utilizing the spreading activation technique in a graph, he visualized the relationship between the query and the documents. To identify the most crucial sentences, topic-expanded terms and activated nodes in the graph were used. Comparing the outcome of this experiment to 30 DUC systems was positive. Thakkar et al. [40] used TextRank in their PageRank-based system. They created a tightly connected graph for the text and applied the TextRank method to extract the relevant terms and assess their importance throughout the entire manuscript. Then they used the shortest path technique to get the sentences for the summary. They claimed that this provided the most diversified summary possible.

2) *Clustering-based approach*: Clustering-based or Sentence Centrality methods for QFMS are used in several

systems [2]. These methods use predefined features to assign scores for all sentence in the input text. After that, the sentences with similar contents will be grouped together in one cluster. In the end, the summary is generated by choosing representative sentences from each cluster. Various methods were developed to define the similarity measure between two objects in the text clustering [41]. The clustering-based approach is suitable for multi-document summarization since it groups different sentences by their topic. However, it requires prior specification of the clusters' amount, and top-ranked sentences may be similar. Hence, redundancy removal techniques are required [42].

Wang et al. [25] defined a clustering-based hypergraph where sentences are nodes and hyperedges are clusters. The sentences are scored using a semi-supervised ranking algorithm. To avoid redundancy, each extracted sentence is compared to previously selected ones before adding it to the generated summary. Chali and Joty [43] used k-means and expectation maximization techniques to determine the relevancy of sentences. Different features were used for weighting, such as lexical, lexical-semantic, statistical, and cosine similarity. Their work showed promising results that could be extended to consider more features, such as a fundamental element, tree kernel-based syntactic features, and shallow-semantic features [44]. Likewise, Naveen and Nedungadi [45] combined the Potential-based Hierarchical Agglomerative clustering algorithm and the k-means algorithm. Cosine similarity was employed to calculate the query-relevant score of each sentence, and the TextRank algorithm was used for ranking the sentences.

For the purpose of enhancing the similarity score between input text and user query, Chandu et al. [46] developed a hierarchical hybrid similarity measure with two tiers to check the similarity between input text and user query. The first tier uses cosine similarity with a threshold of 0.7. Then, for all the sentences passing this threshold, semantic and word order similarities are combined and applied to score the sentences. Redundant sentences are removed by using the DBSCAN and Agglomerative clustering algorithms. Similarly, Rahman and Borah [9] proposed a word sense disambiguation (WSD) method to improve the accuracy of the score for the sense-oriented sentence semantic between the input sentences and the query. The general method used to calculate this score between two sentences includes 1) calculating the Semantic Relatedness score. 2) calculating the Sense Relatedness score, 3) calculating the Word Order Similarity score. 4) finding the final Sense-Oriented Sentence Semantic relatedness score. Furthermore, they measured the informativeness of any sentence based on the presence of five features listed proper noun, numerical data, sentence length, thematic word, and cue phrase. Thus, any sentence that carries these features must be informative. The k-Mean clustering algorithm is employed to create clusters depending on the frequency of the five abovementioned features. Each cluster contains query-relevant sentences. To extract redundancy-free sentences, they established a cutoff point at which one of the sentences will be eliminated if the sense-oriented semantic relatedness score between the two sentences is higher than this cutoff point.

This algorithm achieved competitive results for all best participating models on DUC datasets as well as the current state-of-art QFMS systems.

Integrating various approaches to improve the final summary has received attention from many scholars. Bhaskar and Bandyopadhyay [11] used both graph-based and clustering-based approaches. The graph was reduced to include only seed nodes, which had a total score of all outgoing edges above a threshold. Such a reduction in a dense graph led to an effective execution time. The new graph was clustered to identify shared topical nodes. Each sentence was given a weight that represents the number of query words and keywords covered by that sentence. After using sentence compression, top-scored sentences in each cluster were selected for the summary. The approach gave commendable experimental results on a standard dataset. The performance of their method mainly relied on the selection of seed nodes, and since it is a query-based approach, their method could be enhanced if they consider the query during this reduction. Also, their ranking method is simplified; they just considered the exact match between each sentence and the query in terms of words and keywords. Likewise, clustering and a graph were merged by Canhasi and Kononenko for the summarization [47]. To combine the needed information from the query context and broaden the result options, an archetypal analysis was used. The sentences are grouped into various criteria depending on the type of analysis. The sentence that needs to be evaluated is plotted out on a graph, a score is given based on the relation to the query, which reflects its significance to the query. The weighted method, hence, weighted archetypal analysis, was designed to advance earlier archetypal analysis techniques.

For instance, a system that combines a topic model with graph-based semi-supervised learning was proposed by Li et al. [48]. The topic and sentence layers were the basis for the created graph. The relationship between the topic and sentence vectors was normalized after computing the cosine similarity between them. Sentence clustering was accomplished using a topic modeling technique. They took into account various data, including background and document-specific data. After evaluating this method, the summarization was greatly enhanced. Many scholars found that considering topic-level information might greatly enhance the output summary's quality [49]. He et al. [50] advocated a learning-based strategy that used content terms to rank sentences. They worked with both richness and relevant features, which resulted in a suitable choice of content terms. They used relevance features to give a relevance score to the query. And information richness feature was used to determine the significance of the phrase in the document collection. The scores from the aforementioned features were accumulated to determine the quality of the content term. On test data, their methodology produced promising results. Markedly, many methods have been developed for determining the significance of a sentence based on a query by considering other sentences' features.

These techniques integrated a variety of sentence features with the query's information to rate sentences. These features include term frequency of query, the log-likelihood ratio [6], the term overlap feature, sentence location, and the length of

sentence [26]. Wu et al. 's [1] query-focused summarization method was produced using an unsupervised two pattern-enhanced model. Using LDA topic modeling, the first pattern indicated the topic relevancy of the sentence while the relevance of the query to sentences was presented using the second. The sum of the two patterns for each sentence results was used to determine its importance score to the query. Moreover, to control redundancy during selection, they included a diversity penalty technique named maximal marginal relevance. They claimed that their results outperform state-of-the-art approaches.

The difficulty of scoring several sentences according to a query motivates the development of an interactive learning-to-rank technique to address it by Zhu et al. [53]. The model was initially defined as a sentence ranking issue. The ranking process then considers the connections between the previously chosen sentences and the current sentence in addition to the pertinent context of that specific sentence. The Plackett-Luce model was applied to minimize the likelihood of loss in the ranking function. The sentences in the summary are then chosen using the greedy selection technique based on the defined ranking function. Results from this approach are remarkably positive. An interesting method was proposed by

Woodsend and Lapata [54]. They used particular predictors to construct a model that learnt crucial summary elements independently from training data and then combined them optimally using integer linear programming. The system modeled less redundant content, content's critical and poor places, and stylistic norms, using bigram and positional information along with language modeling. The assessments of the expert learners were then combined using hard and soft constraints by ILP. A considerable improvement in text summarization was obtained using the approach. On the hand, the text-summarization method proposed by Yasuda et al. [55] adds the requirement that at least some terms from the query must appear in the summary. As a result of including that constraint, this optimization challenge was resolved via Lagrangian relaxation. By adding the constraints on the inclusion of query words, both ROUGE-1 and ROUGE-2 scores were increased and thereby increasing the relevance of summaries.

Table I provides an overview of the surveyed QFMS papers, highlighting their main characteristics, approach for selecting query-relevant sentences, redundancy removal techniques, and performance measures on datasets.

TABLE I. OVERVIEW OF A SET OF QFMS PAPERS

Ref/ Year	Approach	Selecting of query-relevant sentences	Redundancy removal technique	Performance
[9],2021	Clustering-based	Sense-oriented sentence semantic relatedness score to score the sentences. Extracted features: proper noun, numerical data, sentence length, thematic word, and cue phrase. Then, K-Means clustering algorithm is applied.	Cluster-based method: If the similarity between two sentences is >60%, then one of them will be removed.	+ The proposed algorithm obtained highest ROUGE score for all three datasets: DUC2005: Rouge1: 0.3951, Rouge2: 0.0893, RougeSU4: 0.1563. DUC2006: Rouge1: 0.5679, Rouge2: 0.1242, RougeSU4: 0.2181. DUC2007: Rouge1: 0.5735, Rouge2: 0.1367, RougeSU4: 0.2371.
[21], 2021	Semantic-graph-based	Sentence scoring= TF-ISF cosine similarity+ word overlap + proximity similarity Manifold Ranking algorithm	Cosine similarity threshold	+ The performance of using expansion of query is better than that using the original query DUC2006: Rouge1: 0.41674, Rouge2: 0.09202 , RougeSU4: 0.15071, Rouge-W: 0.14279. DUC2007: Rouge1: 0.43982, Rouge2: 0.11185, RougeSU4: 0.16870, Rouge-W: 0.15159.
[34], 2020	Semantic-graph-based	1) Jiang-Conrath measure is used to measure the semantic similarity between sentences. 2) Each sentence's cosine similarity to the query is determined. 3) the sentences are ranked using TextRank Algorithm	A similarity function is used to reduce similar sentences.	- Two evaluation metrics were used: ROUGE-N/L and human-based metrics. - They do not cover multi-documents summarization.
[23],2019	Hypergraph-based and topic model-based	Topics are modeled as hyperedges of a hypergraph. Hyperedge weights reflect their relevance to the query.	Hypergraph transversal is generated to capture the information jointly covered by a group of sentences.	+ Ability to produce non-redundant summaries that better cover the relevant topics of a corpus. DUC2005: Rouge2: 0.077392, RougeSU4: 0.12869. DUC2006: Rouge2: 0.10779, RougeSU4: 0.15854. DUC2007: Rouge2: 0.12997, RougeSU4: 0.17995 + It has low time complexity $O(N^2)$ , N is the total number of sentences. - Limitation: Restriction to purely topical similarities. - Authors would like to take the polysemy of terms into account.
[1], 2019	Topic model-based	- Query expansion technique is applied. - Sentence scoring = query-relevance score+ topical- relevance score + sentence position+ sentence length.	Maximal marginal relevance (MMR)[51] + Greedy algorithm [52]	DUC2006: Rouge1: 0.40551, Rouge2: 0.09228 , RougeSU4: 0.14966 . DUC2007: Rouge1: 0.43404, Rouge2: 0.11683, RougeSU4: 0.17026.

[46],2019	Clustering-based, semantic-based	A hierarchical hybrid similarity measure: 1. cosine similarity 2. a weighted sum of word order and semantic similarities. Then, DBSCAN and Agglomerative clustering algorithms are used.	Clustering methods	+ The generated summaries have shown 86% accuracy. - After the redundancy removal phase, their model removes some relevant sentences in their displayed examples. - Collected data from Amrita School of Engineering websites is used as a dataset.
[28],2019	Graph-Based and Topic model-Based	Similarity score: Normalized common words. 1. TextRank algorithm is applied to rank the most important sentences. 2. Two-Tiered topic used to sample query-relevant sentences.	NA	- The proposed method uses only common words for sentence scoring. - The scoring method should be enhanced to include both topical information and linguistic features.
[31], 2018	Semantic-graph-based	1) Sentence Scoring for each sentence = sentiment score + query relevant score . 2) graph-based ranking algorithm is applied to select top ranked sentences.	A Greedy algorithm in [52] is used.	- QMOS approach outperforms other existing methods. - DUC2006: ROUGE1: 0.4123 , ROUGE2: 0.0985, Average ROUGE Score:0.2554 - Used datasets: TAC 2008 and DUC 2006. -The authors would like to distinguish between active and passive sentences before comparing them.
[22],2017	Semantic-graph-based	1- Content word expansion (CWE) method to expand the words in the query and the sentence. 2. Combine: semantic similarity + Word order. 3. a graph-based ranking model is used to ranking the sentences.	A Greedy algorithm in [52] is used.	+ According to the experimental results, the proposed method performs well when compared to other methods. DUC2006: Rouge1: 0.4287, Rouge2: 0.0968, RougeSU4: 0.1673. - The authors intend to enhance their approach by considering recognizing passive and active sentences as well as increasing the semantic knowledge base.

### B. Text Summarization Datasets and Evaluation Metrics

This is an overview of the basic resources used to evaluate and compare QFMS systems presented in the literature review. These resources include standard datasets besides evaluation tools.

1) *Datasets*: Several conferences and workshops have been organized for automatic summarization. To enable progress in this field, these conferences have made available datasets used in extensive research experiments. These datasets have undergone extensive work to prepare them to act as a standard text for summarizing while evaluating various methodologies.

- The Document Understanding Conferences (DUC): is a series of conferences for automatic summarization that are held by the National Institute of Standards and Technology (NIST) [56]. DUC-2005, DUC-2006, and DUC-2007 datasets are designed for extractive QFMS testing. Each data set contains several topics, including various related documents. Reference summaries are available for each topic for evaluation. Filling out some application forms found on the DUC website is needed to access these datasets. Table II shows a summary of these datasets.
- Text Analysis Conference (TAC) [57] : TAC is a group of evaluation workshops that aim to advance research in Natural Language Processing and related applications. It gives access to a massive test collection, standardized evaluation methods, and a platform to share their findings. The tasks from TAC-8 until TAC-15 support the query-based models.

2) *Evaluation metrics*: A system's produced summary can be accurately assessed for readability, succinctness, consistency, and compliance with information requirements using human assessments. Manual examination, however, is infeasible and takes much time. Consequently, it is necessary

to evaluate a summary automatically. Automatic evaluation of a system's generated summary can be done using ROUGE scoring [58]. This acronym means Recall-Oriented Understudy for Gisting Evaluation. It is a set of performance measures used to automatically calculate the quality of a summary. ROUGE compares the output summary to a set of summaries that were manually constructed by counting the number of intersecting units [59]. The intersecting units can be computed using n-grams, word pairs, or word sequences, which correspond to the ROUGE model.

TABLE II. SUMMARY OF USED DATASETS FOR QFMS

	DUC-2005	DUC-2006	DUC-2007
# of Topics	50	50	50
# of documents related to each topic	32-43	25	25
Data source	TIPSTER-TREC	AQUAINT	AQUAINT
Reference summaries for each topic	4 for each of 30 of the topics and 10 for each of 20 of the topic	4 summaries written by 4 different NIST assessors	4 summaries written by 4 different NIST assessors
Size of summary	250 words	250 words	250

## IV. DISCUSSIONS

This section discusses the finding and current challenges that can lead the researcher in future directions.

### A. Findings

This paper surveyed literature related to QFMS techniques. It is an active and attractive variant of automatic summarization due to its wide applications. Furthermore, they are less complicated, more affordable, and typically produce grammatically and semantically accurate summaries.

1) *QFMS approaches*: According to the different approaches for QFMS discussed previously, each approach



has distinct advantages and drawbacks. Most surveyed studies use the graph-based approach, which has shown effectiveness in QFMS due to its ability to enhance coherency and language-independent approach. However, it does not pay attention to the importance of the words in the document, as it assumes that the weights of the words are similar. As well as may be unable to identify semantically equivalent sentences. Consequently, the resulting summary can be less relevant and more redundant. However, some selected studies made different improvements to this approach by considering more language-dependent similarities like semantic similarity that enhanced the caliber of the summaries that were produced.

The clustering-based approach was successfully used to enhance the summaries' diversity and guarantee that all aspects of the needed information from the query were captured. It is appropriate for multi-document summarization because it groups several sentences about the same topic in the documents. Hence, each cluster contains highly related sentences. However, the highly scored sentences may be similar and thus have high redundancy. Therefore, there should be a mechanism for choosing sentences from each cluster that balances diversity, relevancy, and redundancy. Besides, it requires prior specification of the number of clusters. Another issue, some sentences may express more than one topic, but each sentence has to be assigned to only one cluster. The hypergraph-based approach is proposed in [23] to alleviate this issue. Each hyperedge is connected to a particular topic, and each sentence may be tagged with several different topics. Then, each sentence can be a member of various hyperedge.

According to the semantic-based approach, considerable performance has been provided from hybrid approaches that combine semantic-based and graph-based approaches. Some studies argued that QFMS couldn't be solved completely using only one method of the two methods, namely semantic-based and graph-based approaches.

Moreover, some of the overviewed articles have shown the effectiveness of combining topic model-based and graph-based approaches for QFMS to balance the three characteristics of summarization relevance, significance, and diversity. We found that most of the studies that were done concentrated on relevancy to the query by analysing the content of individual sentences depending on the query. Some research employed clustering to diversify the summary, although these algorithms only considered basic lexical similarity clustering [11], [47]. Other scholars are attentive to the diverse selection of the sentences while utilizing a straightforward Manifold method to assign relevancy score [60].

Generally, combining the previously mentioned approaches (graph-based, statistical-based, semantic-based, and clustering-based) would generate better summaries that benefit from their advantages and overcome the drawbacks of every single method.

2) *Extracting query-relevant sentences*: Many extraction techniques have been proposed in the surveyed systems. Most of them used statistical techniques such as TF-IDF and cosine similarity. However, these methods failed to capture semantic

similarities, thus decreasing the relevancy of the generated summary. At the same time, some studies boosted the statistical methods by introducing linguistic methods. The Word sense disambiguation (WSD) technique is proposed in [9] to determine each content word's appropriate meaning in a sentence. Their algorithm gained the highest ROUGE score for all three DUC query-based summarization datasets (DUC 2005, DUC 2006, and DUC 2007). However, the proposed WSD can only accurately determine a word sense if presented in WordNet.

Moreover, expanding query words has effectively solved mismatch problems in sentence comparison by extracting more relevant and essential sentences based on user demand. Hence, enhance the summaries' quality.

Furthermore, it is evident from the previous research that although they all seek QFMS, query-dependent features are given less attention by most of them. Without these query-dependent properties, their variation in speed is minimal.

3) *Redundancy removal techniques*: There are several redundancy removal techniques used in the surveyed literature. Most studies used a greedy algorithm in [52] as a post-processing step to force a diversity penalty on the sentences, which decreases the score of the less informative sentence before adding it to the final summary. Other approaches used the Maximum Marginal Relevance (MMR) [51] method to control redundancy. Moreover, the cosine similarity is calculated between each top-ranked sentence and the previously selected sentences to avoid redundancy. Sentence clustering algorithms are also used to prevent redundant information. In general, most of the redundancy-removal techniques under study rely on lexical similarity across sentences, which leaves semantic redundancies in the resulting summary unaffected. The Maximum Relevance and Coverage (MRC) [24] is suggested as a solution to this problem to maximize the relevancy and joint topical coverage. It showed enhancement compared to other redundancy removal techniques.

## B. Open Research Problems

Any QFMS system should be able to produce summaries of texts based on a query that are as near as possible to those produced by humans. Although many various strategies have been employed for the goal of QFMS, several concerns remain unresolved:

1) *Coherency*: The majority of summary techniques work by selecting the most important sentences to the query and presenting them verbatim. The reader must sense the flow of ideas rather than simply moving from one to the next. It can be beneficial to transfer one sentence to another due to their similarities. Therefore, sentence reordering is crucial, especially in multi-document summarization, since the sentences are from many sources with different flows of ideas. More post-processing techniques can be developed to tackle this issue, making it an active research problem.

2) *Ambiguity*: When determining the degree to which two content terms are semantically connected, sense plays a significant impact. Therefore, ambiguity in terms matters when summarizing statements. The quality of QFMS is indeed diminished by ambiguous words since they can reduce the number of sentences that can be found relevant to the query. Various kinds of ambiguity are known, such as word sense, local ambiguity, form class, structural, syntactical, and form factors [61]. In QFMS, removing ambiguity senses is a rising challenge that can interest many researchers.

3) *Vague reference*: In the multi-document summarization [62], a proper noun may appear in one sentence, and a pronoun may appear in the following sentence to refer to the proper noun. The summarizer will provide an ambiguous reference if it chooses the sentence with the pronoun but not the proper noun. This can open ideas for creating more pre-processing steps to resolve this issue and similar ones to enhance the overall generated summary.

4) *Evaluation*: Another critical challenge is the evaluation procedure. As aforementioned, existing evaluation in automatic summarization works by comparing the automatically generated summary to a human-generated one. This is admirable yet insufficient. Although reference summaries are created by expert humans, we cannot declare with certainty that this is the best summary due to the individual variation in writing and evaluation of the summary. Proposed techniques for QFMS are affected by the evaluation methods and the datasets available. It requires a lot of tools and corpora resources to create a powerful automatic text summarizer. DUCs, for example, produce a summary with 250 terms only. This is challenging for a system to generate a summary of just 250 words that is accurate and consistent with man-made summaries. More efficient ways to evaluate the summary would greatly help the researchers. Moreover, automated quality evaluations for grammar, reference clarity, readability, and coherence are still missing in this field [9].

5) *Redundancy*: Since the input is a multi-document that can share the same sentences and ideas, redundancy has been the main bottleneck when extracting query-relevant sentences. Although many techniques have been developed to reduce this issue, it is still an active and scalable domain.

6) *Diversity*: Designing a QFMS system not only requires extracting the essential sentences from the input but also demands diverse sentences to cover all aspects of the query. Only the sentences directly related to the query's primary request will be selected by a summarizer, leaving out any sub-request. As a result, the summary will concentrate more on the main point and neglect any supporting points that might be equally significant. Employing semantic analysis can help since it takes into account the meaning of every sentence and word. More techniques to handle this problem are open in this area.

### C. Future Research Directions

One of the most interesting issues is how a model can mimic a human's ability to summarize. The sentence information should be coherent, along with being concatenated. The summary's coherence has been a long-standing problem. Existing methods primarily seek to produce informative summaries; nevertheless, future research will be needed to improve the summary's readability by developing coherence scores between pairs of sentences and enhancing the order of sentences in the summary.

In addition, developing novel QFMS methods to generate query-related, higher-quality, and robust summaries under human criteria is a priority. More research needs to be done to improve and discover semantic, linguistic, and statistical features for terms in sentences. This will help systems to process natural language most effectively and to remove redundancy [7]. Additionally, choosing the appropriate query-relevant weights for various features is crucial because the final summary's quality depends on it. Studying new features and their effect on performance can be an eminent research domain.

A higher quality summary can be generated by making the system more intelligent by combining it with hybrid methods and other techniques. Important sentences can be chosen, combined, or compacted, or some information can be removed to provide better quality. A hybrid approach can be developed by combining extractive and abstractive techniques. Research can go on to generate a hybrid approach that combines extractive and abstractive methods to produce a more human-like generated summary.

Moreover, an effective balance between readability, compression ratio, and summarizing quality must be achieved. For QFMS of lengthy materials such as novels and books, larger compression ratios are needed. However, current systems struggle to meet this need [63]. Therefore, it is imperative to provide a more persuading and balanced method.

Automatically evaluating summaries is difficult since it is challenging to develop and apply a good criterion to determine whether the summaries produced by the systems are sufficient and satisfy the query [2]. Additionally, it is challenging to define the optimal summary since systems might produce effective summaries that differ from those produced by humans. Research can be conducted in automatic evaluation, creating new approaches and solutions to assess the query-related summary based on the data it includes, user satisfaction, how it is presented, and the level of readability and coherences.

An interesting future direction was suggested by [7]. The majority of QFMS systems work with text for both input and output. It will be beneficial if new summarizers can accept the input in a format of meetings, videos, audio, etc. Although this kind of input data is a valuable source for information extraction and knowledge discovery, users find it very challenging to track down or identify its occurrences due to their quantity and diversity. Moreover, the output can be in the form of statistics, graphs, tables, visual score measures, etc.

Users will obtain the necessary content faster with the aid of such summarizer systems that enable the summaries' visualization. There have been few works in the video summarization [64]; however, development in this important area is slow and requires more research efforts in the future.

The English language material is the main focus of most QFMS systems. There is a need to dedicate some future efforts to other languages. It is necessary to create and enhance NLP tools such as POS tagging, syntactic and semantic parsing, stemming, and NER that can be used for non-English languages [65]. Moreover, the absence of resources, such as annotated corpora and evaluation tools, is one of the most complicated issues that these types of summarizers must overcome.

Finally, developing a semi-supervised model for QFMS can be a potential future direction. This model can incorporate the user-required phrases to improve the semantic efficiency of the summary while incorporating a higher level of data's feature set. Thus, it may provide a query-based, more intelligent, and useful summary.

## V. CONCLUSIONS

In the last few years, there has been a huge expansion in the volume of text material on the internet. The research area of QFMS is intriguing and has many potential uses. It is a task of returning a concise and coherent response to a query entered by a user from multi-documents input.

This paper reviewed studies based on the main QFMS approaches: graph-based and clustering-based. It discusses their summarization process, advantages, and disadvantages. The findings show that hybrid approaches have been receiving increasing attention due to the satisfactory level of advanced performance. However, the currently generated summaries require further enhancements as they are still far from the quality of the human-generated summaries. Simultaneously, increasing research interest and rapid technological advancements could evolve QFMS and make summaries more relevant, significant, and less redundant.

The paper also underlined multiple open research problems and current challenges in QFMS. Furthermore, it presents future directions that may assist researchers in identifying crucial aspects that require deep investigation and more development.

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# Ensuring Information Security of Web Resources Based on Blockchain Technologies

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**Abstract**—This project examines how blockchain technology can enhance data security and reliability for web applications. In this article, ways to improve data security on online course platforms that utilize blockchain technology are explored. To clarify, online course platforms are web-based applications that enable users to access course materials online. These platforms often deal with sensitive data which, if compromised, can cause significant harm to users. Unfortunately, this information is often the target of fraudulent operations and illegal actions aimed at stealing personal data that can be used for authentication on various platforms. This article identifies the weaknesses of these sites and discusses the importance of using complex technologies to safeguard web resources effectively. This research explores how blockchain technology can protect from common web application attacks, which are often aimed at the user authorization process involving the transmission of identification and authentication data from the user to the website database. The study outlines the key components of blockchain technology, including hash function, hash value, data structure, and blockchain classification. Additionally, the study presents a transaction block model for a web course developed using blockchain technology.

**Keywords**—Information security; data security; website protection; blockchain; network attacks; hash functions; web applications

## I. INTRODUCTION

Websites store confidential information such as personal data like email addresses, names, birth dates, and credit card numbers [1]. Therefore, protecting information confidentiality is fundamental for most information compliance regulations today. It is concerning to know that hackers target at least 50,000 websites daily, especially since almost every business has an online presence. Small and medium-sized companies are not exempt as about 43% of attacks are directed towards them [2]. Although there are programs and firewalls available to prevent unauthorized access, there is no foolproof way to protect against hackers as they are always on the lookout for new vulnerabilities and once found, they launch an attack.

This article explores the use of blockchain technology to enhance the security and dependability of data in web applications, specifically the methods employed in online course platforms to safeguard data using blockchain

technologies. Online course platforms are web applications that grant access to online course content. Therefore, a significant concern is preventing theft, unauthorized access, and duplication of online course content belonging to others. Unfortunately, scammers and plagiarists can be a common issue for creators of online training courses [3]. Providing expert knowledge in online courses can be a great way to earn a steady income, but protecting your content from theft is essential. Attackers use various methods to steal content from online course websites such as hacking the server or recording video from the screen to distribute online [4].

It is essential to ensure that your online course platform has top-notch security to prevent these unauthorized activities. Utilizing blockchain technology can effectively safeguard data and avoid unauthorized usage and copying of online course content. There are many ways to protect content from cyber-attacks and unauthorized access. However, with the development of information technology, it is necessary to use relevant methods and models for ensuring data protection, including blockchain technology. Blockchain is a data storage system that operates in a decentralized manner and guarantees the security and reliability of information. The technology creates a chain of blocks where data is stored, and each block is linked to the previous one, enabling easy verification and preventing unauthorized alterations.

By utilizing blockchain technology, it is possible to establish a decentralized registry for content rights, ensuring protection against infringements. In addition, the blockchain system enables users to manage access to information and establish usage guidelines safeguarding content from unauthorized use. With blockchain technology, it is developed to develop a register of content rights and a change control system, which protects against cyber threats. Another benefit of using blockchain technology for content protection is the potential for transparency and clarity in storing and transmitting information. This implies that every block, including information on content rights, will be visible to all users, allowing for monitoring of any changes in data and safeguarding content against potential violations.

One effective method of safeguarding content from cyber-attacks and remote access is using blockchain technology. This



technology provides a decentralized registry for storing information about content ownership and rules for appropriate use. With such measures in place, unauthorized content use is prevented, ensuring that content creators can confidently use their content online without fear of infringement.

The paper discussed various methods of information protection, their mechanisms and structures, and their weaknesses. Finally, the article demonstrated the efficacy of blockchain technology in safeguarding content against cyberattacks and unauthorized access.

## II. RELATED WORK

We reviewed the work of scientists who conducted other studies before using blockchain technology. Sathya A. et al., in their research papers, conducted research on cryptography and blockchain technology and discussed how combining the two technologies could ensure data security. This article deals with various cryptographic attacks on the blockchain and the various security services offered on the blockchain. Blockchain security issues are also analyzed and briefly presented in this article [5]. Ahmed A. et al., in their research work, made a comprehensive analysis of the current new and large-scale level tasks based on the blockchain used in the Internet of Things domain. They have proposed a scalable assessment system in IAR environments, including essential criteria such as bandwidth, latency, and block size for information threats. They also evaluated and differentiated the Most Outstanding Large solutions, highlighting six complex scalability problems for blockchain-based solutions in IoT [6]. Sabri H. et al., in research work, analyzed SHA and MD5 and developed analytical work on the comparative analysis of algorithms and their velocities. SHA-2 and SHA-3 have become industry norms. In this paper, hash methods proposed by other scientists are considered. As a result of the study, it was decided that hash performance plays a vital role in the blockchain and IoT [7]. Naresh K. et al. provided a comprehensive overview of how Blockchain technology is used to ensure Internet security and counter current threats, as well as growing cybercrime and cyberattacks. During the review, they studied how blockchain affects cyber data and information over the Internet. In this paper, they first compiled blockchain architecture and cybersecurity models, classified and discussed the latest and most relevant anti-cybersecurity work, and identified the main challenges and barriers to blockchain technology in response to cybersecurity [8].

## III. WEBSITE PROTECTION MECHANISMS AND ITS ANALYSIS

The World Wide Web is a collection of websites residing in various domains. A segment of the Internet comprises websites hosted within one or multiple domains. Therefore, the Internet can be seen as a compilation of these segments [9][10].

The average security of a segment of the Internet is defined as the ratio of the number of "protected" websites in the studied part to the total number of sites in the studied component.

$$W_i = \frac{s_i}{n_i} \quad (1)$$

where  $W_i$  - security indicator of the  $i$ -th segment of the Internet,

$s$  - the number of secure websites in the  $i$ -th segment,

$n$  - the total number of websites in the  $i$ -th segment,

$i$  - segment number  $i=1,2,..,C$ ,

$C$  - total number of Internet segments.

And the average security of the entire Internet  $W$  is defined as the average security of all its segments:

$$W = \frac{1}{c} \sum_{i=1}^c W_i \quad (2)$$

The security level of a website is evaluated based on a specific method. Websites face risks such as unauthorized access to locally stored information and unauthorized access or modification during data transmission over communication channels [10]. The classification of website protection mechanisms that prevent these types of threats is shown in Fig. 1.

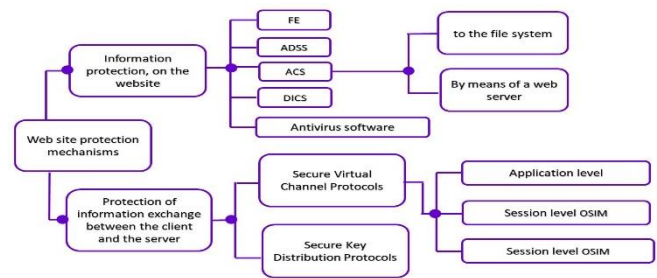


Fig. 1. Website protection mechanisms.

ACS (access control system).

DICS (Data Integrity Control System).

FE (firewall).

ADSS (attack detection system).

OSIM (Open Systems Interaction model).

Any commercial site is at risk of external influence by default – attackers use dozens of ways to hack web pages, regardless of the platform they are made on [11].

The list of "classic" types of attacks [12]:

- SQL injections;
- Cross-site Scripting (XSS);
- Remote Code Execution (RCE);
- Cross-site Request Forgery (CSRF);
- Local and remote inclusion (LFI, RFI);
- Authorization bypass options;
- Automated password selection (Bruteforce).

It is concerning that 85% of websites that use PHP (Hypertext Preprocessor) [13] are at a high risk of dangerous attacks. Even conventional technology websites can be vulnerable to hacking or "dropping" if they don't have enough protection. All websites are at risk of attacks unless they have special safeguards - but even those safeguards have limitations

[14]. Therefore, it's not surprising that attackers are continually improving their tactics and targeting both individuals and corporations.

This research work analyzed the website (www.aliyaschool.kz), which serves as the subject of the study. Due to the pandemic and self-isolation measures, traditional education shifted to online education, making it a crucial part of many fields. Unfortunately, there has been an increase in copyright infringement cases where content is used without permission. To prevent potential material and moral losses, it's essential to safeguard against plagiarism and fraud even before the online course is launched for sale. Therefore, it's necessary to prioritize the security of online course content to prevent theft, distortion, and unauthorized access.

A web course site review was conducted, and Webrate [15] presented statistics revealing a daily traffic volume of 219 unique visitors and 1228 page views. Fig. 2 displays general information about the site.

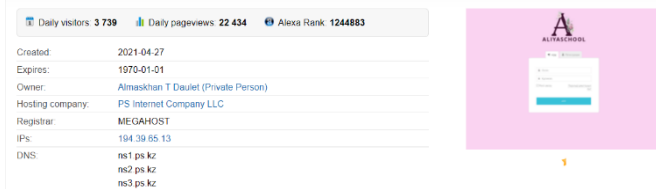


Fig. 2. General information of the studied web course.

Each visitor makes an average of about 3739 page views (Fig. 3). According to the Alexa Rank statistical ranking system [16], aliya.school.kz traffic occupies 49,006 positions worldwide, while the most significant number of its visitors is from Kazakhstan (Fig. 4), which occupies 211th place. According to these data, there is a demand for web course resources. Therefore, there is a reason to attack it.

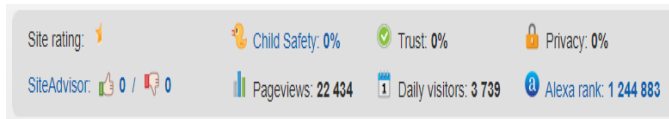


Fig. 3. Web course statistics information.

Fig. 5 shows how many visitors visited the website daily for the past 90 days. The last record was on Oct 4, 2022, and about 3,400 visitors visited this site.

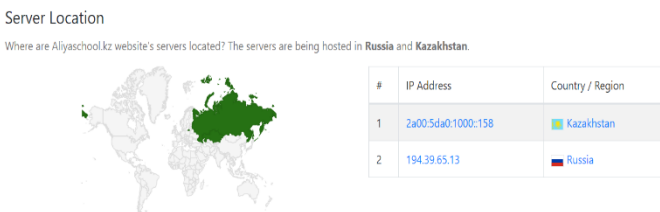


Fig. 4. Server location.

In Yandex.Metrica, a sharp surge in direct visits to the site was detected for the area under study, and mobile traffic also increased sharply - direct visits during the day are distributed evenly over time. Therefore, we analyzed the web browser and monitored the data, and concluded that the site was under attack (Fig. 6).

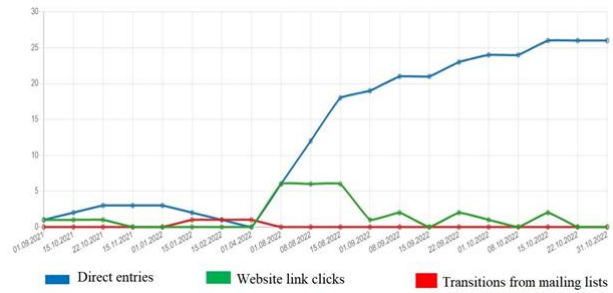


Fig. 5. Web course attendance information.

DDoS attacks (Distributed Denial of Service) are one of the most prevalent and damaging forms of cyberattacks on the internet today. Hundreds of thousands of websites, including government institutions, businesses, media outlets, and non-profit organizations, fall victim to these attacks daily. Unfortunately, attackers continue to develop sophisticated methods to disrupt and block access to internet resources and servers. While there are several effective methods for protecting against DDoS attacks, the increasing complexity of these attacks and the decreasing cost of computing resources means that more than basic protection is required.

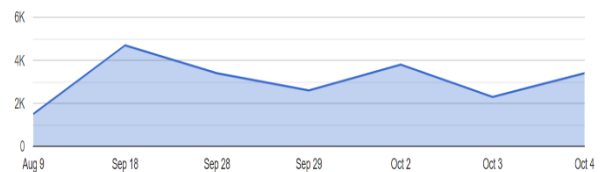


Fig. 6. Web course traffic analysis.

#### IV. BLOCKCHAIN TECHNOLOGIES

Initially, blockchain technology was only associated with cryptocurrency. However, over time, this method of data storage has found various applications since the blockchain can contain any digital information about transactions, legal documents, and media files, including photos, video, and audio.

Blockchain technology, as a decentralized environment for storing and executing programs, ensures the immutability of stored data, protecting web applications from unauthorized changes to site scripts and database contents [17]. The load is distributed over devices with identical data, protecting against DDoS attacks [18]. Special libraries track and automatically block malicious requests, protecting servers from unauthorized access [19]. Blockchain technology can protect web applications from cyber-attacks and data leaks. Blockchain technology can be used to build decentralized and distributed networks that can provide DDoS protection and high availability for web applications.

To begin, let's examine the process of constructing a blockchain. Blockchain technology is a decentralized, distributed database governed by many contributors and available to all [20]. It is not a collection of several large databases managed centrally. Data related to each batch of confirmed transactions is stored in a separate block. Each such block is connected to the previous one, as shown in Fig. 7. As information is added, new blocks are created. To include them

in the chain, it is necessary to confirm all participants of the entire network [21].

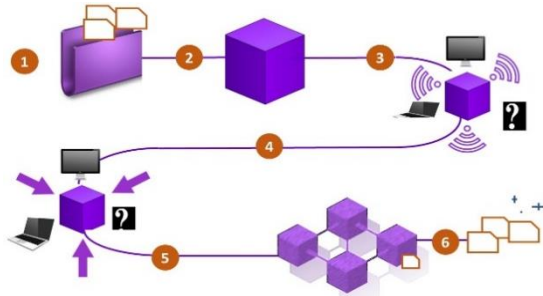


Fig. 7. Blockchain structure.

- 1) A wants to send money to B.
- 2) Transactions are transferred to the network and collected in a new "block".
- 3) Blocks are sent out for verification to all participants of the system
- 4) Each participant writes a block to their database instance.
- 5) The block falls into the "blockchain", which contains information about all transactions.
- 6) The transaction is completed.

2008 marked a significant turning point for the internet when an individual or group, using the pseudonym Satoshi Nakamoto, released a White Paper detailing a decentralized peer-to-peer electronic payment system called Bitcoin. Satoshi Nakamoto, the creator of blockchain technology, remains unidentified to this day. Recently, Bloomberg corroborated claims that Satoshi is Hal Finney. It's worth noting that Bitcoin is the first iteration of blockchain technology.

It works as a decentralized payment system with simple, smart contracts - conditions for a transaction. The problem is that they need more capabilities.

The second generation is Ethereum [22]. It began with the launch of the eponymous network in 2015. Then, for the first time, developers implemented the advanced functionality of smart contracts [23]. The history of development is shown in Fig. 8.

Blockchain today consists of various cryptocurrencies, NFT tokens [24], crypto exchanges and wallets, stock markets where virtual assets are traded, and much more [25] (see Fig. 8). It is easy to forge paper documents with a hand signature because the source code, a ballpoint pen, and a desire are enough. Electronic documents are stored centrally in one extensive archive, and people enter information into registers, causing them to be susceptible to changes [26]. Legal norms are not sufficient for ensuring document authenticity. The only viable solution is to develop a technical solution.

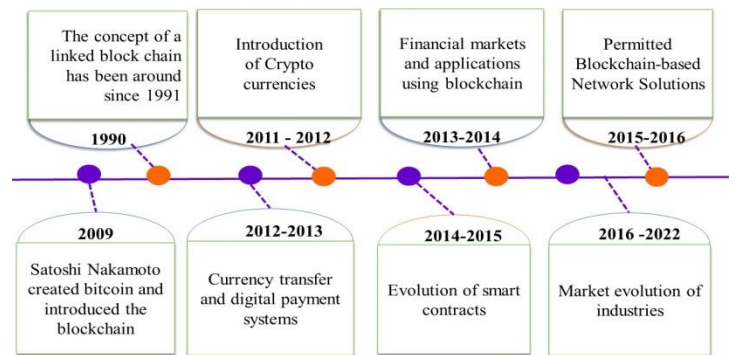


Fig. 8. Blockchain history.

In 1991, American cryptographers Stuart Haber and Scott Starnet came up with an idea to put time stamps on electronic documents, making them impossible to issue retroactively or forge [27]. The documents were sorted by the same marks and collected into one block, forming the prototype of the blockchain. A year later, the technology was improved, including Merkle trees, which made it possible to store more documents in one block.

Another technology that contributed to the emergence of blockchain is a decentralized peer-to-peer network [28]. In such a network, there are typically no dedicated servers, and each node performs the server and client functions. Based on the characteristics and functional features of the blockchain, three types of networks are distinguished: public, private, and consortium, as shown in Fig. 9 [29].

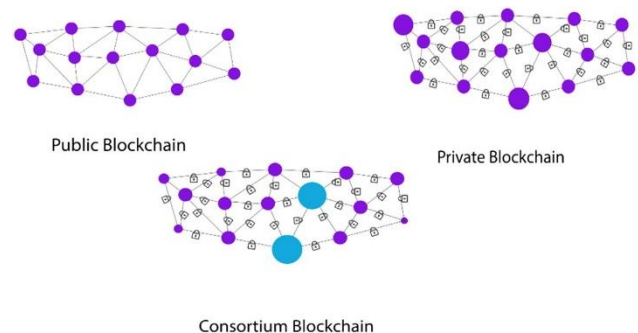


Fig. 9. Types of blockchain network.

According to the source [30], a public blockchain allows any internet user to join or leave the blockchain network without providing identification forms or seeking permission.

A private blockchain [31] assumes that all network participants are known and trustworthy; belong to a controlled community. Subjects can be individuals, such as employees, customers, and organizations (companies or departments within companies). Private network users can have certain types of access to write to the registry. Private Blockchain contains the majority of corporate, industrial, and government projects. Various other actors may have different personal read-only representations of the data (e.g., regulatory officials).



The consortium's blockchain combines elements of a public and private blockchain [32]. An authorized group functions as a validator; validators or authorized persons can limit the network's visibility or have no restrictions.

An essential innovation of the Blockchain protocol is the consensus matching algorithm, which allows you to build an open distributed network where all actors can agree [33]. This mechanism ensures overall reliability in a distributed network of registers. It is assumed that 51% coordinates the content stored in the registers network.

Public Blockchain agreement algorithms for "Proof of Work" (PoW) are shown in Fig. 10 [34].

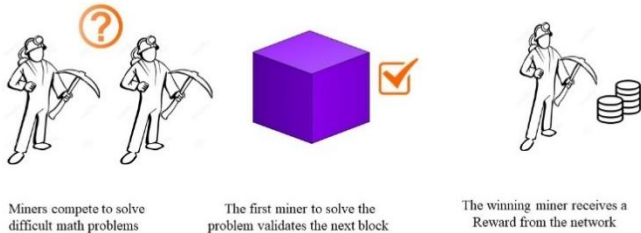


Fig. 10. Proof of work.

"Proof of Stake" is shown in Fig. 11 (Proof of Stake (PoS) is the most common and popular consensus algorithm.

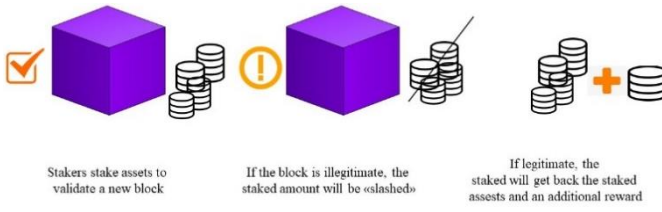


Fig. 11. Proof of stake.

The Proof-of-Work (PoW) algorithm is designed to require all nodes in the network to compete for a reward when adding a block of records to the end of the chain. This competition involves finding a one-time number using computing power [35].

This creates an incentive model in which the winning node that adds a block to the blockchain is rewarded with digital tokens – bitcoins. To hack the network, an attacker must fight for the right to add a block and compete to create the longest chain.

This undermines the economic incentives of attacks, making them financially costly (the type of attack is Sybil's attack). The Proof of Stake (PoS) algorithm assumes that the miner or validator who creates a new block is chosen deterministically depending on his wealth or share [36].

Open-type blockchains are suitable for a broad community and mainly for solving private tasks, such as exchanging cryptocurrency between users or concluding small transactions using smart contracts [37]. For corporate networks, it is advisable to use a closed type, which allows you to hide certain information. Consensus algorithms are vital for blockchains to remain fully decentralized. Due to the decentralized nature of the blockchain, there will never be a centralized authority that

checks and updates the register with transactions and new data. Therefore, stakeholders in the network should decide on an equal basis which transactions should be added to the blockchain.

For corporate networks, it is advisable to use the closed type, which allows you to hide certain information. Consensus algorithms are vital for blockchains to remain fully decentralized. Due to the decentralized nature of the blockchain, there will never be a centralized authority to verify and update the ledger with transactions and new data. Therefore, the stakeholders in the network must decide on an equitable basis which transactions should be added to the blockchain.

A. Hashing is the Basis of Blockchain Functioning

Cryptographic hash functions are prevalent [38]. They store passwords during authentication, protect data in file verification systems, detect malicious software, and encode information in the blockchain (the block is the central primitive processed by Bitcoin and Ethereum). This article will review hashing algorithms: what is it, what types are there, and what properties they have.

A significant contribution to the development was made by Hashcash, the proof—of—work algorithm developed by Adam Back. It worked like this: each email user added a text stamp to the email header, indicating that the sender had spent some of his time and resources calculating this stamp. The algorithm significantly complicated spam and DDoS attacks on mail servers [39].

A hash function is called any function h:

$X \rightarrow Y$ , easily computable and such that for any message, M is the value;

$h(M) = H$  (convolution) has a fixed bit length;

X is the set of all messages;

Y is a set of binary vectors of fixed length.

As a rule, hash functions are built based on the so-called one—step compression functions  $y = f(x_1, x_2)$  of two variables, where  $x_1, x_2$ , and  $y$  are binary vectors of length  $m, n$ , and  $n$ , respectively, and  $n$  is the convolution length, and  $m$  is the length of the message block.

To obtain the value of  $h(M)$ , the message is first divided into blocks of length  $m$  (in this case, if the message length is not a multiple of  $m$ , then the last block is supplemented to the full in some unique way), and then the following sequential convolution calculation procedure is applied to the resulting blocks  $M_1, M_2, \dots, M_N$ :

$$H_0 = v,$$

$$H_i = f(M_i, H_{i-1}), i = 1, \dots, N,$$

$$h(M) = H_N$$

Here  $v$  is some constant, it is often called an initializing vector. It is chosen for various reasons and can be a secret constant or a set of random data (for example, a date and time sample). With this approach, the properties of the hash function

are entirely determined by the properties of the one-step compression function [40].

There are many cryptographic algorithms out there these days. They vary in complexity, digit capacity, cryptographic reliability, and operation features. However, hashing algorithms are a familiar idea. They appeared more than half a century ago, and there have been little changes from a fundamental point of view for many years [41-42]. However, because of its development, data hashing has acquired many new properties, so its application in information technology has already become universal. In our study, we analyzed cryptographic hash functions.

Comparison of Cryptographic hash functions:

The Secure Hash algorithms are a family of cryptographic hash functions published by the National Institute of Standards and Technology (NIST) as the U.S. Federal Information Processing Standard (FIPS), including [43]:

- SHA-0: A retronym applied to the original version of the 160-bit hash function published in 1993 under the name "SHA". It was withdrawn shortly after publication due to an undisclosed "significant flaw" and replaced with a slightly modified version of SHA-1.
- SHA-1: 160-bit hash function, reminiscent of the earlier MD5 algorithm. This was developed by the National Security Agency (NSA) as part of a digital signature algorithm. Unfortunately, cryptography weaknesses were discovered in SHA1, and after 2010 the standard was no longer approved for most cryptographic applications.
- SHA-2: A family of two similar hash functions with different block sizes, known as SHA-256 and SHA-512. They differ in word size; SHA-256 uses 32-byte words, and SHA-512 - 64- byte words. There are also truncated versions of each standard known as SHA-

224, SHA-384, SHA-512/224, and SHA-512/256. The NSA also developed them.

- SHA-3: A hash function, formerly Keccak, was selected in 2012 after an open competition among non-NSA designers. It supports the same hash length as SHA-2, and its internal structure differs significantly from the actors of the SHA family. Table I compares general and technical information for several cryptographic hash functions.

In blockchain technology, all blocks are interconnected by a complex cryptographic signature called a hash - it is created using complex mathematical algorithms, looks like a generator of letters and numbers, and contains 1024 characters. After the transaction is completed and written to the block, all network nodes receive data about it. In simple terms, a node is a separate computer where the complete and most up-to-date copy of the blockchain is stored [44]. Whenever a new block appears on the network, all nodes update their blockchain.

Most of the current classes of attacks on websites fall on the stage of user authorization, namely the process of transferring identification and authentication data from the user to the website database [45].

In our study, we show login and password hashing using several algorithms and compare their parameters shown in Fig. 12.

Currently, only SHA2 and SHA-3 groups are considered secure. At the same time, it should be regarded that the more characters in the resulting hash in Fig. 12, the more difficult it is to select it. Results of algorithm security analysis hashing against attacks are shown in Fig. 13, which shows the speed of various hashing functions based on the experimental studies of the authors. For hash rate comparison, we use the Intel Iris Xe Graphics G7 96EUs laptop graphics system, which belongs to the Tiger Lake GT2 family and is currently the most powerful integrated graphics.

TABLE I. COMPARISON OF SHA FUNCTIONS

Algorithms	Output size (bits)	Internal state size (bits)	Block Size (bits)	Round	Operations	First published
MD5	128	128	512	64	And, Xor, Rot, Add (mod 2 32), or	1992
SHA-0	160	160	512	80	And, Xor, Rot, Add (mod 2 32), or	1993
SHA-1						1995
SHA-224 SHA-256	224 256	256	512	64	And, Xor, Rot, Add (mod 2 32), Or, Shr	2004 2001
SHA-384 SHA-512	384 512	512	1024	80	And, Xor, Rot, Add (mod 2 64), Or, Shr	2001
SHA-512/224 SHA-512/256	224 256					2012
SHA3-224 SHA3-256 SHA3-384 SHA3-512	224 256 384 512	1600	1152 1088 832 576	24	And, Xor, Rot, Not	2015
SHAKE 128 SHAKE 256	d (arbitrary) d (arbitrary)		1344 1088			

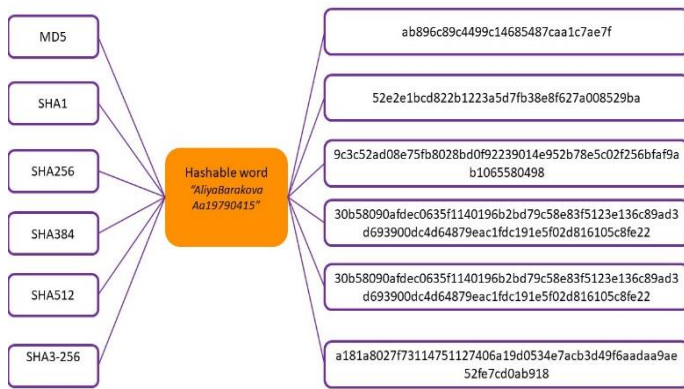


Fig. 12. The result of hashing the username and password.

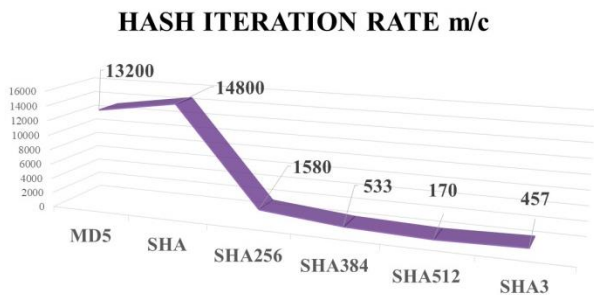


Fig. 13. Hash brute force values on a modern video card INTEL R IRIS R XE GRAPHICS.

As shown in Fig. 13, SHA512 and SHA3 algorithms and algorithms based on block encryption are the best among the given values regarding hashing speed. With different implementations, the absolute values of hashing rates may vary, but the ratio between their speeds will be maintained.

Hashing functions are widely used to verify data integrity [46]. For example, many software vendors publish their checksums together with the software. After downloading the file, you need to feed it to the hash function and then compare the produced hash with what the software developer published.

In the blockchain, a hash guarantees the block's integrity [47]. Unfortunately, the input data for the hashing algorithm contains the hash of the previous block, which makes it impossible (or at least very difficult) to change the block in the chain: you will have to recalculate the hash of the block itself, as well as the hashes of all the blocks following it.

### B. Securing Web Course Transactions

Using blockchain technologies for online course transactions can significantly increase the trust and attractiveness of these courses in users' eyes. Blockchain technologies provide unique opportunities to ensure the security of web course transactions. They allow you to guarantee the integrity of data and their reliable protection against cyber-attacks and fraud. Furthermore, due to transparency and decentralization, the blockchain facilitates the payment process and is convenient for storing information about participants and their achievements.

The use of blockchain technology for web course transactions has many advantages. It allows you to ensure the

security and transparency of buying and using courses, simplifies the payment process, and improves the ability to manage finances and monitor the use of the course.

Consider building a transaction block model based on blockchain technology for the web course under study. This article proposes to build a block model using lines of code in Node JS. Node (or, more formally, Node.js) is an open-source, cross-platform runtime that allows developers to create server-side tools and applications using JavaScript.

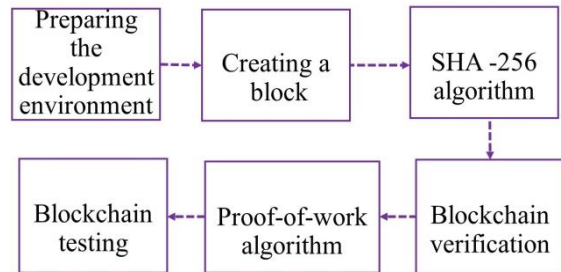


Fig. 14. The general structure of our blockchain.

Our blockchain (see Fig. 14) will be a chain of blocks, and every block will include the following:

- block number [index];
- timestamp [timestamp];
- the value of the hash sum of the previous block [previous hash];
- the value of the hash sum of the current block [hash].

We will include in the transaction content the sender of the funds [sender], the name of the recipient of these funds [recipient], and the amount of funds transferred [amount]. We will include information about only one transaction to the block for simplicity.

A new Blockchain.js file is used to create the block class, here, we create a block class. This work uses the SHA 256 algorithm. First, a hash function is created. Next, to implement the hashing process, it is necessary to use the built-in crypto package from Node.js.

```

class Block {
  constructor(timestamp = " ", data=[]) {
    this.timestamp = timestamp;
    this.data = data;
    this.data = this.getHash();
    this.prevHash = ""; }
  getHash() {
    return SHA256(this.prevHash + this.timestamp +
JSON.stringify(this.data)); }
  const crypto = require('crypto'), SHA256 = message =>
crypto.createHash("SHA256").
update(message).digest('hex');
  class Blockchain{
  constructor () {
    this.chain = [new Block(Date.now().toString()); }
    getlastblock() {
      return this.chain[this.chain.length - 1];}
  addBlock(block){
    block.prevHash = this.getlastblock().hash;
    block.hash=block.getHash();
  }
}
  
```



```
this.chain.push(Object.freeze(block));  
isValid(blockchain = this) {  
  for(let i = 1; i < blockchain.chain.length; i++) {  
    const currentBlock = blockchain.chain[i];  
    const prevBlock = blockchain.chain[i-1];  
    if(currentBlock.hash !==currentBlock.getHash() ||  
prevBlock.hash  
    !==currentBlock.prevHash) {  
      return false; } }  
    return true;} }  
module.exports = {Block, Blockchain}
```

Timestamp is a sequence of symbols or encoded information showing when a particular event occurred. Usually indicates the date and time, respectively. With some data, we will get a hash, and we will also have the hash of the previous block. To do this, we will create a const crypto. If something changes every time, then SHA 256 will give us something completely different, and this can guarantee us immutability. In this case, the PrevHash property also plays a significant role in constancy. It ensures that the blocks will remain unchanged throughout the life of our blockchain. Accordingly, if the previous hash does not match, this block will not pass validation, respectively.

Next, let's move on to the next class, and we will create a blockchain class. The first thing we need is a genesis block. The Genesis block is our first block, and technically we have the main first block. Next, we also need to create a function with the last block. There are several functions here. Firstly, this function is for getting the previous block and also a process for adding a block to our blockchain. Finally, we need to know if our chain is valid and a method to check the validation.

Do we have a chain if the block's hash is equal to what its hashing method returns and the prevHash property of the block should be similar to the previous block? Accordingly, we check whether our blockchain is valid and coincides with our expectations. To do this, we export everything. Now let's go to another file stored in the same folder. Let's call it Index.js, and we need to add some data here. This is, firstly, the block, the blockchain that we exported, and the path to this file.

Next, we need to create the blockchain itself. Let's call it TEST. Then we will create an object of our blockchain. Next, we will create a block using this function.

```
const test = new Blockchain();  
test.addBlock(new Block(Date.now().toString(), {from: "Alia", to:  
"Olga", amount: 10}));  
test.addBlock(new Block(Date.now().toString(), {from: "Zhazira",  
to: "Aliya", amount: 20}));  
test.addBlock(new Block(Date.now().toString(), {from: "Asel", to:  
"Baglan", amount: 15}));  
test.addBlock(new Block(Date.now().toString(), {from: "Alma", to:  
"Marat", amount: 25}));
```

Here we will indicate certain data. Here we will have from whom this or that transaction comes, for example, Aliya, then there is a value to whom this block goes, for example, "Olga". Next, write down the number of transactions. In this case, we have created four blocks. And further, we need to add a console to display everything from our block.

```
console.log(test.chain)  
В данном случае мы видим на наш блокчейн  
PS C:\Blockchain> node index.js  
[  
  Block {  
    timestamp: '1666506048577',  
    data:  
'fd4b1de75b9fb1ac48eb12f3f306a2fd4c6227857b3f96deb2974e13974b86',  
    prevHash: "  
  },  
  Block {  
    timestamp: '1666506048577',  
    data:  
'0013e76e5a7dc2a11c7caa2a0dff5e62e7557f831860f514581b8b8d616e2445',  
    prevHash: undefined,  
    hash:  
'785d2b99afa9f2a13cf646a6a9e7d8366c523d39c0551bbd021a2e8b9e8d9d3a'  
  },  
  Block {  
    timestamp: '1666506048577',  
    data:  
'eeae9571d9e0af0aa408ccfa5e94c495c3d66b8f7d80d273a47cad90f00e2884',  
    prevHash:  
'785d2b99afa9f2a13cf646a6a9e7d8366c523d39c0551bbd021a2e8b9e8d9d3a',  
    hash:  
'9170bfe54dc9b7b70870edc403558f2f8f6222367ceb5a87790f91efd99777e'  
  },  
  Block {  
    timestamp: '1666506048577',  
    data:  
'f3f9760c6f28dff8401da4003c3b7b2ccc8d26f62fb23b0b1036c3d3f3415959',  
    prevHash:  
'9170bfe54dc9b7b70870edc403558f2f8f6222367ceb5a87790f91efd99777e',  
    hash:  
'661c470d5bc849d9d51cdeb41d73cb3d83fccc2a2a77ecde28f309114d1c0db4'  
  },  
  Block {  
    timestamp: '1666506048577',  
    data:  
'f510198c0fc3ede70add6b98bf288dd4bba5584a9027a5eed94af73ec6e846df',  
    prevHash:  
'661c470d5bc849d9d51cdeb41d73cb3d83fccc2a2a77ecde28f309114d1c0db4'  
  },  
  Block {  
    timestamp: '1666506048577',  
    data:  
'700a5215a94fa8088cb061349c5605aa4616257c4c2e9d550852f61fbb863e38'  
  }  
]
```

## V. RESULT AND DISCUSSION

As a result, there is a hash and a previous hash of the last block, respectively. We can compare it with the genesis block, which is shown in Fig. 15. The genesis block is the very first block in the blockchain. We can imagine a blockchain as a series of blocks where each block is connected to its previous block and replicated all over the blocks. The fundamental benefit of this replication is that, in case one of the replicated blocks becomes corrupted, other copies are available to ensure the integrity of the information contained in the data structure. Furthermore, replication provides assurance of the reliability of the data, conveyed as a guarantee that the different computers involved in the blockchain [48,49] platform are running appropriate calculations to ensure the consistency and reliability of the data. In general, our blockchain will look like this. Therefore, blockchain is one of the ways to store data and protect it by making it immutable.

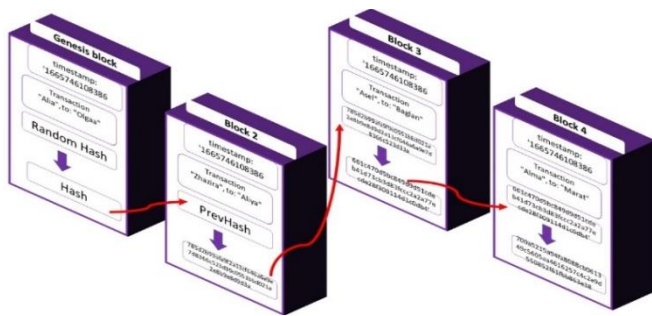


Fig. 15. Type of created blockchain.

## VI. CONCLUSIONS

This research paper provides statistical data from analyzing the studied web course as an experiment. In addition to the standard methods of protecting websites, blockchain technology was studied, and a comparative analysis of hashing algorithms was given for further use when modifying an authentication system. Finally, a model of the transaction block of the analyzed web course based on blockchain technology was built.

In conclusion, it can be noted that most of the current classes of attacks on websites occur during the user authorization stage, namely the process of transferring identification and authentication data from the user to the website database. Although blockchain technology has great potential in authentication systems and provides high security against fraud and forgery, making it especially attractive to provide web resources, it is essential to address technical and organizational issues such as scalability, standardization, and regulation to enable widespread use of blockchain technology in authentication systems. Nevertheless, blockchain technology in authentication systems promises significant benefits for all stakeholders and may become one of the essential cybersecurity trends in the near future.

Further research should focus on developing an authentication system based on blockchain technology using a modified hashing algorithm.

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# A Hybrid Multiple Indefinite Kernel Learning Framework for Disease Classification from Gene Expression Data

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**Abstract**—In recent years, Machine Learning (ML) techniques have been used by several researchers to classify diseases using gene expression data. Disease categorization using heterogeneous gene expression data is often used for defining critical problems such as cancer analysis. A variety of evaluated factors known as genes are used to characterize the gene expression data gathered from DNA microarrays. Accurate classification of genetic data is essential to provide accurate treatments to sick people. A large number of genes can be viewed simultaneously from the collected data. However, processing this data has some limitations due to noises, redundant data, frequent errors, increased complexity, smaller samples with high dimensionality, difficult interpretation, etc. A model must be able to distinguish the features in such heterogeneous data with high accuracy to make accurate predictions. So this paper presents an innovative model to overcome these issues. The proposed model includes an effective multiple indefinite kernel learning based model for analyze the gene expression microarray data, then an optimized kernel principal component analysis (OKPCA) to select best features and hybrid flow-directed arithmetic support vector machine (SVM)-based multiple infinite kernel learning (FDASVM-MIKL) model for classification. Flow direction and arithmetic optimization algorithms are combined with SVM to increase classification accuracy. The proposed technique has an accuracy of 99.95%, 99.63%, 99.60%, 99.51%, and 99.79% using the datasets including colon, Isolet, ALLAML, Lung\_cancer, and Snp2 graph.

**Keywords**—Gene expression; optimized kernel principle component analysis; multiple indefinite kernel learning; flow direction algorithm based support vector machine; arithmetic optimization algorithm

## I. INTRODUCTION

The integration of data tends to be an emerging topic, whereas decision making based on metabolomics and genomic requires better prediction or diagnosis rather than the utilization of clinical data alone [1]. The prediction or classification of diseases dependent upon the medical data requires appropriate methodologies [2]. Machine learning has been widely playing a huge role, especially in biomedical researchers, over the past decades [3]-[4]. This process is partially because of greater advancements in data collection

that have enabled the study of biomedical mechanisms of various diseases, particularly cancer [5]. When the gene expression data are adopted from microarrays comprising high density oligonucleotide arrays (HDOA) or complementary Deoxyribonucleic acid (CDNA), the classification methods are utilized for data examination and interpretation.

Disease classification using heterogeneous gene expression data is greatly utilized for determining fundamental issues like disease analysis and drug detection [6]-[7]. The gene expression data collected from DNA micro arrays are characterized through diverse evaluated variables known as genes [8]. An exact classification of the gene data is very important in order to be able to treat sick people appropriately [9]-[10]. The molecular founded connections over a scale can be analyzed through gene expression data, which can be examined by a significant tool called microarray [11]. A huge amount of genes from the collected data can be observed simultaneously. Still, there are certain drawbacks in processing these data as they comprise noises, redundant data, often prone to errors, increased complexity, smaller sample with large dimensionality, complex interpretation, etc.

Several researches were conducted previously using machine learning approaches to classify diseases using gene expression data [12]-[13]. The major reason behind searching for effective approaches is to predict the survival rates to grab better treatment. The feature selection approaches are highly efficient in eradicating the noisy features, redundant data and are significant in describing the biological features when minimizing the model complexity [14]. The chief focus of the feature selection approach is to reduce the data dimensionality, which improves the overall system performance [15]-[16]. The kernel is generally used to indicate a kernel trick, an approach of utilizing a linear classifier to solve non-linear issues [17]. The Kernel learning transforms linearly inseparable heterogeneous data over separable data. The kernel approaches are better, but parametric assumptions cannot be made and sensible over outliers.

Even though multi-task learning improves accuracy performance, a similarity measure between tasks is highly

required, which is not a priority for many diseases [18]-[19]. The utilization of transcriptomics subjects possesses diverse challenges in interpretation. To overcome this, multiple kernel learning (MKL) permits the combination of pathway data into prediction models that utilize transcriptomics, whereas the interpretation and accuracy can be enhanced. Several studies have been developed through the application of MKL over genomic data. Every MKL method can render an ordering for data type significance that delivers appropriate information [20]. The MKL aims to determine the kernel's best convex integrations to generate the best classifier. Diverse feature components of heterogeneous data with various kernel functions can be mapped to expose the data better in the new feature space.

#### A. Motivation

Predicting and classifying the disease from gene expression data is an extremely challenging task due to the intrinsic nature of the data. Heterogeneous data involves large differences between traits, making predictions difficult for any learning model. In addition, the size of the data is extremely large, leading to several complications. A prominent solution identified to this problem is using meta-heuristics that can optimally tune the parameters, resulting in higher accuracy. In order to achieve better performance of multiple kernel learning, machine learning models are generally adopted, among which the SVM model is highly preferred. Considering all the problems, this proposal focuses on developing a hybrid multi-core learning framework with the hybridization of an effective meta-heuristic with an SVM model to achieve a higher percentage of accuracy in disease classification. The main contributions of the proposed work are:

- To analyze the gene expression microarray data to attain higher accuracy in disease classification, an effective multiple indefinite kernel learning based model is proposed.
- A new approach of optimized kernel principal component analysis (OKPCA) is presented to decrease the dimensions of microarray data by eliminating the unimportant features from the feature space.
- In order to achieve higher accuracy in disease classification using gene expression data, several kernel functions such as radial basis function, sigmoid kernel, polynomial kernel and linear kernel are introduced and integrated into the hybrid flow-directed arithmetic SVM-based multiple infinite kernel learning (FDASVM-MIKL) classification frameworks.
- In order to validate its efficiency against the existing methods, extensive simulations of the proposed method are performed using different metrics.

The proposed research work is organized into various sections. The literature survey of disease classification from gene expression data directed by various researchers is described in Section II. The discussion of the proposed methodology for disease classification from gene expression data is described in Section III. Section IV discusses the simulations performed using simulation tools to analyze the outcomes of the proposed technique. Finally, the conclusion

and the future scope of the proposed technique are provided in Section V with references.

## II. RELATED WORKS

Most researchers have applied various methods to reduce dimensionality across heterogeneous gene expression data. Some of the prominent adopted models are examined as follows.

Liu et al. [21] presented a dimension reduction algorithm to enhance the classification performance and minimize the dimensionality. The dimensionality minimization was carried through a Weighted Kernel Principal Component Analysis (WKPCA) that builds the weights of the kernel function in accordance with the kernel matrix Eigenvalues. The feature dimensions were minimized through the multiple kernel functions combination. The t-class kernel functions were built to further enhance the efficacy of dimensional reduction. The classifiers like random forest, naive Bayes and Support Vector Machine were used to examine six real gene expression datasets. The major limitation faced in this approach was the non-flexibility of kernel function selection and the degraded embedding ability.

Rahimi *et al.* [22] presented a multi-task multiple KL approach with task clustering and developed a greatly time-effective solution. The proposed solution approach in this research was dependent upon the benders decomposition and clustering issue treatment through the determination of given tree structures in the graph. The method is called forest formulation and has been used to differentiate early and late stage cancers through the adoption of gene sets and genomic data. When the number of tasks and clusters gets maximized, the forest formulation approach is highly favorable due to computational performance. The time consumed in solving large scale instances was too high in the case of a multi-task multiple KL approach and clustering.

The microarray data was utilized for training deep learning approaches using extracted features. Almarzouki et al. [23] established an effective feature selection approach to maximize accuracy and minimize the classification time. The most significant genes were picked by eradicating the superfluous and duplicate information. Artificial Bee Colony (ABC) method using bone marrow pyruvate carboxylase gene expression data was employed in this research work. The features selected using the ABC algorithm were made as a wrapper based features selection system. The datasets of lung, kidney and brain cancer were utilized during testing and training. The characteristics of data were not effectively examined, and there was a greater possibility of losses.

The seven cancer datasets were collected initially from the Broad Institute GDAC Firehose comprising of isoform expression profile, survival information, gene expression profile and expression data of DNA methylation, respectively. Feng et al. [24] recommended kernel principal component analysis (KPCA) to extract the relevant features for every expression profile. The features are then fed over three similar kernel matrices through a Gaussian kernel function combined as a global kernel matrix. Finally, the features were applied over the spectral clustering algorithm to obtain clustering

outcomes. Due to the collection of abundant datasets, the dimensionality issue was not solved effectively.

To overcome the limitation of the increased computational effort of using a huge data set, Wani et al. [25] proposed an efficient method. The MKL founded gene regulatory network (GRN) inference method was presented in this research in which numerous heterogeneous datasets were combined together using the MKL paradigm. The GRN learning issue has been formulated as a supervised classification issue in which the genes are directed through a specified transcription factor differentiated from other non-regulated genes. In order to learn a huge scale GRN, a parallel execution construction was devised. Better accuracy rates and speedups can be obtained, but the data quality and redundancy issues were not solved effectively. Table I describes the major contribution with its corresponding merits and demerits of existing methods.

TABLE I. REVIEW OF EXISTING METHODS WITH THEIR MERITS AND DEMERITS

Author name and Reference	Technique	Contribution	Merits	Demerits
Liu et al. [21]	WKPCA	To develop a dimension reduction algorithm for enhancing the classification performance.	Minimization of dimensionality with less computational complexity.	Non-flexible and degraded embedding capability.
Rahimi et al. [22]	Forest formulation method	To distinguish late and early stage cancers using genomic data.	Better computational performance in aggregation.	Higher consumption of time.
Almarzouki et al. [23]	ABC algorithm	To develop an effective feature selection approach to eliminate the superfluous and duplicate information	The computational time can be minimized by using relevant features.	Ineffective characterization of gene data and high error possibilities.
Feng et al. [24]	KPCA	To extract the relevant features and obtain clustering results using a spectral clustering algorithm	An effectual global kernel matrix can be attained.	Greater dimensionality issue due to huge dataset.
Wani et al. [25]	MKL with GRN	To combine numerous datasets using the MKL paradigm and to revise a parallel execution framework.	The computational cost can be minimized.	Data quality and redundancy problems cannot be solved.

Based on the related work of the existing methods according to disease classification using gene expression data, various limitations negatively impact the performance of the method. Due to the disadvantages, such as the use of lesser datasets, non-flexible embedding capability, higher consumption of time, lower data quality, redundancy problem and lower classification accuracy, an effective proposed FDASVM-MIKL approach is developed. The additional limitations such as noises, redundant data, frequent errors, increasing complexity, smaller samples with high dimensionality, difficult interpretation, etc. This limitation can be reduced in appropriate feature extraction method, here in this research OKPCA proposed for analyzing expression data based on multiple indefinite kernel learning with and hybrid flow directed arithmetic SVM for gathering effective results to overcome the current limitations and increase classification accuracy.

### III. PROPOSED METHODOLOGY

The heterogeneous nature of the data is a very difficult to process, predict and classify the disease utilizing gene expression data. The fact that the gene expression data are quite heterogeneous has been identified as one of the main challenges. In general, heterogeneous data have a wide range of feature variations, making it difficult for any learning model to make predictions. A model must be able to accurately distinguish between the characteristics of heterogeneous data in order to make reasonable predictions. Utilizing meta-heuristics to optimize the tuning of the parameters and increase accuracy has been proposed as one prominent solution to this problem. The support vector machine (SVM) model is highly preferred among the machine learning models when the task of multiple kernel learning is accomplished. This approach aims to consider all issues and create a hybrid multiple-kernel learning framework that combines an efficient meta-heuristic with an SVM model to increase the accuracy of disease classification. The Fig. 1 demonstrates the overall architecture for the proposed methodology.

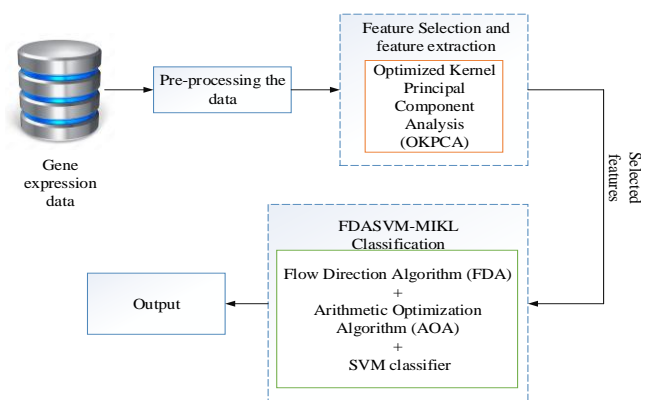


Fig. 1. Overall architecture of the proposed method.

The proposed framework comprises three major steps pre-processing, feature selection and classification. The dataset is initially brought through various processes to make it suitable for classification because it is diverse and has a large dimension. To improve the quality of the dataset, the outliers



are first eliminated. The missing values are then filled with mean values once the dataset has been examined for any missing values. After this step, the data set is then passed to the feature selection phase, in which the main features are extracted. The proposed study introduces the optimized kernel principal component analysis to identify the dataset's best features (OKPCA). The proposed hybrid flow directed arithmetic SVM based multiple indefinite kernel learning (FDASVM-MIKL) classification framework is then given the features chosen using the OKPCA technique. This proposed framework is associated with the SVM classifier, flow direction algorithm (FDA), and Arithmetic Optimization Algorithm (AOA). To increase overall performance, the SVM framework incorporates some kernels, containing the linear kernel, sigmoid kernel, polynomial kernel, and radial basis function.

#### A. Pre-processing

Pre-processing is a very essential step utilized to provide data cleansing that is useful for further analysis. Here, a standard pre-processing method is used. The dataset is then examined for non-value reduction processes, and the missing values are then filled with mean values. Outliers are removed to increase the quality of the data set. The dataset is then given to the feature selection stage, where the main features are extracted after this step.

#### B. Feature Selection and Extraction

The proposed study introduces the optimized kernel principal component analysis to identify the dataset's best features (OKPCA). This technique chooses the most important features from the dataset and ignores the rest, designed to decrease the dimensionality of the data.

1) *Optimized kernel principal component analysis:* Principal component analysis, which finds recurring patterns in the dataset with little information loss, is frequently used to reduce complex spectral datasets into understandable information. The strength and flexibility of principal component analysis are greatly enhanced by its clarity and conciseness. The important factor when using PCA is that it is a linear transformation and it can be written in the simple matrix form, which is given below:

$$B = HA \tag{1}$$

Where,  $B$  is a transformed data matrix,  $A$  is an original data matrix, and  $H$  is a transformation matrix. The corresponding eigenvectors  $v_i, 1 \leq i \leq n$ , and the necessarily non-negative eigenvalues  $(v_i)$  arranged in decreasing order. The transformation matrix is obtained by stacking the eigenvectors which is shown in equation (2).

$$H = \begin{bmatrix} \overleftarrow{v_1} \overrightarrow{\phantom{v_1}} \\ \vdots \\ \overleftarrow{v_n} \overrightarrow{\phantom{v_n}} \end{bmatrix} \tag{2}$$

The enhanced version of PCA, known as kernel principal component analysis (KPCA), can handle non-linear correlations between variables. It employs a non-linear function to translate the observed data into high dimensional space (kernel function). KPCA uses a non-linear mapping function  $\omega(x)$  to translate an observed data matrix  $datametics \in R^{M \times N}$  with  $N$  columns (variables) and  $M$  rows (observations). This can be calculated mathematically as shown in equation (3),

$$datametics \in R^{M \times N} \rightarrow \omega(x) \in R^f \tag{3}$$

Where  $f$  is the feature space. In kernel technique, kernel function and kernel matrix are known as  $K(x_i, x_j) = \omega(x_i)^T \omega(x_j)$  and  $K$ , respectively. The appropriate kernel parameter is best discovered using this kernel-based strategy by generalizing the problem to an eigenvector one. The scatter error metric is used as the objective function of the problem.

The defined goal function computes the gradient and Hessian matrices, and the kernel parameter of the method is tweaked using the gradient values. Gradient  $(\nabla f)$  and Hessian  $(\nabla^2 f)$  matrices are the popular optimization technique, as the search direction as it approaches the optimum that moves in the opposite direction of the positive gradient. Gradient and Hessian matrices for optimization are given in the equation below.

$$\nabla f = \begin{bmatrix} \frac{\partial f}{\partial x_1} \\ \frac{\partial f}{\partial x_2} \\ \vdots \\ \frac{\partial f}{\partial x_N} \end{bmatrix} \tag{4}$$

$$\nabla^2 f = \begin{bmatrix} \frac{\partial^2 f}{\partial x_1^2} & \frac{\partial^2 f}{\partial x_1 \partial x_2} & \dots & \frac{\partial^2 f}{\partial x_1 \partial x_N} \\ \frac{\partial^2 f}{\partial x_2 \partial x_1} & \frac{\partial^2 f}{\partial x_2^2} & \dots & \frac{\partial^2 f}{\partial x_2 \partial x_N} \\ \vdots & & \ddots & \vdots \\ \frac{\partial^2 f}{\partial x_N \partial x_1} & \frac{\partial^2 f}{\partial x_N \partial x_2} & \dots & \frac{\partial^2 f}{\partial x_N^2} \end{bmatrix} \tag{5}$$

This kernel-based approach best discovers the appropriate kernel parameter by generalizing the problem to an eigenvector. The scatter error metric is used as an objective function to solve the problem. The gradient and Hessian matrices are produced by the defined objective function, and

the gradient values are used to control the algorithm's kernel parameter. The hybrid flow directed arithmetic SVM based multiple indefinite kernel learning (FDASVM-MIKL) classification framework is then given to the features chosen using the OKPCA technique.

### C. Classification using FDASVM-MIKL

The proposed hybrid Flow Directed Arithmetic SVM based multiple indefinite kernel learning (FDASVM-MIKL) frameworks are used for classification purposes. This framework combines an SVM classifier, a FDA and AOA which are described in below sections.

1) *SVM based multiple indefinite kernel learning*: Various kernels are incorporated into the SVM architecture to improve overall performance, containing the polynomial kernel, linear kernel, sigmoid kernel, and radial basis function. The input layer, hidden layer, SVM kernel layers, SVM output layer, and the voting layer form an original SVM based multiple indefinite kernel learning. An additive kernel model enhances the functionality of a standard kernel model. This model is obtained using the weighted linear sum of kernels.

a) *Radial basis function (RBF)*: RBF kernels are the most usually utilized kinds of kernelization due to their similarity to the Gaussian distribution. The degree or similarity of proximity among two points  $X_1$  and  $X_2$  is determined by using the RBF kernel function. The mathematical representation of kernel is given in the following equation:

$$K(X_1, X_2) = \exp\left[-\frac{\|X_1 - X_2\|^2}{2v^2}\right] \quad (6)$$

Where  $v$  is the variance or hyperparameter, and  $\|X_1 - X_2\|$  is the Euclidean distance between two points  $X_1$  and  $X_2$ .

b) *Sigmoid kernel*: The sigmoid kernel function is an activation function for artificial neurons and is similar to a two-layer perceptron neural network architecture. It is defined as equation (7):

$$K(X_1, X_2) = \tanh\left[\frac{X_1 \cdot X_2 + \text{coeff}}{2v^2}\right] \quad (7)$$

The hyperbolic tangent,  $\tanh$  is used to define this kernel. It can express intricate non-linear interactions when utilized with correctly calibrated parameters. However, this does not represent a true kernel since the sigmoid function might not be positive definite for some parameters.

c) *Polynomial kernel*: The kernel function is used with SVMs and other kernel models is termed as polynomial kernel, to represent the similarity of vectors (training samples) in a feature space via polynomials of the original variables machine learning can be used, allowing the learning of non-linear methods.

$$K(X_1, X_2) = \left[\frac{X_1 \cdot X_2 + \text{coef}}{2v^2}\right]^P \quad (8)$$

Where  $P$  is the kernel parameter. It shows the similarity of vectors in the training dataset in a feature space over polynomials of the original variables that is utilized in the kernel.

d) *Linear kernel*: Linear kernels are used when the data can be linearly separated.

$$K(X_1, X_2) = X_1^T \cdot X_2 \quad (9)$$

When the data is linearly separable or can be divided along a single line, a linear kernel is utilized in SVM. When a given data set contains many features, it is typically employed.

### D. Hybrid Flow Directed Arithmetic SVM

The SVM classifier categorizes diseases in the data, and the hybrid FDA with the AOA method is used to optimize each kernel parameter. Performance evaluations are then conducted to determine the effectiveness of the proposed methods across a variety of datasets. Furthermore, analyses of gene expression data in various forms demonstrate the heterogeneity of the method. Support Vector Classification (C), known as Regularization Parameter, has a strictly positive value. This regularization parameter is optimized using a hybrid FDA-AOA.

1) *Flow direction algorithm*: FDA is evaluated using the direct runoff flow in basins, which is the main focus. The FDA calculates flow velocity based on each individual slope, which falls steeply toward its near neighbors. The FDA introduces new tools for performing optimization. The neighborhood radius decreases from high to low values by defining a washbasin filling technique that helps in escaping local solutions. The FDA algorithm applies the relationship below to determine the initial position of flows:

$$\text{flow}[X(i)] = mc + \mathfrak{R}(vc - mc) \quad (10)$$

Where,  $\text{flow}[X(i)]$  denotes the location of the flow  $i^{\text{th}}$ ,  $mc$  and  $vc$  denote the lower and upper limits of the decision variables, and  $\mathfrak{R}$  denotes a uniformly distributed random number between zero and one. Additionally, it is assumed that each flow is surrounded by one or more neighborhoods, whose positions are determined by the relationship shown in below equation:

$$\text{neighbor}[X(j)] = \text{flow}[X(i)] + \mathfrak{R}(n) \cdot \kappa \quad (11)$$

The normal distribution with a mean of 0 and standard deviation of 1 where,  $\mathfrak{R}(n)$  is a random variable.

$\text{neighbor}[X(j)]$  represents the neighbor at the  $j^{\text{th}}$  position. The large numbers for this parameter shows the searching in a large range, while small numbers ( $\kappa$ ) limit searching to a small range.

$$\kappa = (\mathfrak{R} * X\mathfrak{R} - \mathfrak{R} * (\text{flow}[X(i)])) * \|\text{best}(X) - \text{flow}[X(i)]\| * G \quad (12)$$

Where,  $G$  is a non-linear weight,  $\mathfrak{R}$  is a random number between  $0$  and  $\infty$ ,  $X\mathfrak{R}$  is a random location and  $\mathfrak{R}$  is a random number with uniform distribution. This relationship's first term demonstrates that  $flow[X(i)]$  shifts to a random position  $X\mathfrak{R}$ . The Euclidian distance between  $best(X)$  and  $flow[X(i)]$  is lowered to zeros for the second term when iteration is increased, closing the gap between the two. Thus, the local search is not working. In the third term, the  $(G)$  is determined as follows:

$$G = \left( \left( 1 - \frac{itr}{itr_{max}} \right)^{2 * \mathfrak{R}(n)} \right) * \left( \overline{\mathfrak{R}} * \frac{itr}{itr_{max}} \right) * \overline{\mathfrak{R}} \quad (13)$$

Where, the random vector with uniform distribution is represented as  $\overline{\mathfrak{R}}$ . The following relationship determines the new place of the flow.

$$newflow[X(i)] = flow[X(i)] + v * \frac{flow[X(i)] - neighbor[X(j)]}{\|flow[X(i)] - neighbor[X(j)]\|} \quad (14)$$

$$neighbor[X(j)] = flow[X(i)] + \mathfrak{R}(n) * \kappa \quad (15)$$

$$v = \mathfrak{R}(n) * M_0 \quad (16)$$

$$M_0(i, j, z) = \frac{fitnessflow[X(i)] - neighbor[X(j)]}{low[X(i, z)] - neighbor[X(j, z)]} \quad (17)$$

Where,  $fitnessflow[X(i)]$  and  $neighbor[X(j)]$  are the substitute for the objective value of the  $neighbor(j)$  and the  $flow(i)$ . The  $(z)$  component reflects the size of the issue.

$newflow[X(i)]$  displays the updated position  $flow(i)$ . Fig. 2 shows the flowchart based on the FDA.

This FDA method starts with the initial population of the search space or drainage basin. The flows then shift to a low height position by achieving best outcome or output point with lowest height.

2) *Arithmetic Optimization Algorithm (AOA)*: AOA is a meta-heuristic algorithm that uses the distribution behavior using four major arithmetic operators in mathematics, such as multiplication, subtraction, division and addition. To carry out the optimization processes in various search areas, AOA is arithmetically modeled and placed into action. This meta-heuristic technique uses population data to solve optimization problems without finding their derivatives. Initialization, exploration, and exploitation are the three important phases of the optimization process.

a) *Initialization phase*: The best optimized solution is regarded as the best candidate solution in each iteration of the AOA optimization process. The optimization procedure in AOA starts with a collection of candidate solutions  $(S)$ , as shown in the matrix, which is generated randomly.

$$S = \begin{bmatrix} X_{1,1} & \cdots & \cdots & X_{1,k} & X_{1,m-1} & X_{1,m} \\ X_{2,1} & \cdots & \cdots & X_{2,k} & \cdots & X_{2,m} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ X_{M-1,1} & \cdots & \cdots & X_{M-1,k} & \cdots & X_{M-1,m} \\ X_{M,1} & \cdots & \cdots & X_{M,k} & X_{M,m-1} & X_{M,m} \end{bmatrix} \quad (18)$$

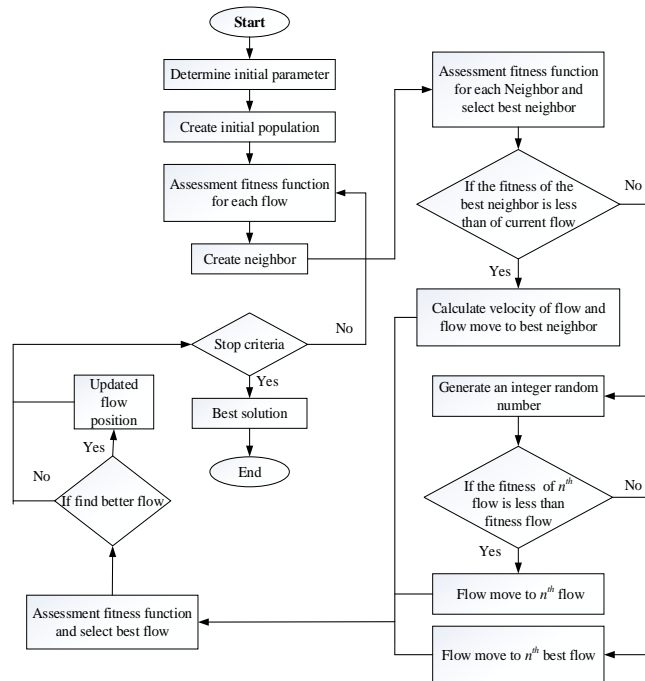


Fig. 2. Flowchart based on flow direction algorithm.

The search phase before it starts to function (i.e., exploitation or exploration), AOA should be select. Math Optimizer Accelerated (MOA) function is the coefficient derived from equation (18) and provided in the subsequent search phases.

$$MOA\_current_{itr} = \mu + current_{itr} \times \left( \frac{\eta - \mu}{\eta_{itr}} \right) \quad (19)$$

Where, the function value at the  $i^{th}$  iteration is represented as  $MOA\_current_{itr}$ . The  $current_{itr}$  stands for the current iteration ( $\eta_{itr}$ ) between 1 and the maximum number of iterations. The minimum and maximum values for accelerated function are indicated by the  $\mu$  and  $\eta$ , respectively.

*b) Exploration phase:* This section introduces the exploring behavior of AOA. To determine the better outcome, two major search processes (division search approach and multiplication search approach) are used by AOA's exploration operators to randomly explore the search area at different positions. This is the most basic rule that can approximate the actions of arithmetic operators. For the condition  $a > MOA$  ( $a$  is a random number), the exploration search is accomplished by the MOA function. The exploratory phase is evaluated using the position updating equation given below:

$$X_{i,k}(current_{itr} + 1) = \begin{cases} \frac{Best(X_{i,k})}{(MOP \cdot \epsilon)} \times ((UB_{value(k)} - LB_{value(k)}) \cdot \gamma + LB_{value(k)}), & b < 0.5 \\ (Best(X_{i,k}) \cdot MOP) \times ((UB_{value(k)} - LB_{value(k)}) \cdot \gamma + LB_{value(k)}), & otherwise \end{cases} \quad (20)$$

Where,  $Best(X_{i,k})$  indicates the  $k^{th}$  result in the next iteration,  $X_{i,k}(current_{itr})$  represents the  $k^{th}$  location of the  $i^{th}$  solution at the existing (current) iteration, and  $X_i(current_{itr} + 1)$  denotes the  $i^{th}$  solution in the following iteration. ( $\epsilon$ ) is a tiny integer number,  $LB_{value(k)}$  and  $UB_{value(k)}$  stand for the lower bound and upper bound values of the  $k^{th}$  position. The control parameter ( $\gamma$ ), which is fixed equal to 0.5, is used to alter the search process.

$$MOP(current_{itr}) = 1 - \frac{current_{itr}^{1/\beta}}{\eta_{itr}^{1/\beta}} \quad (21)$$

Where,  $current_{itr}$  stands for the current iteration,  $\eta_{itr}$  stands for the maximum number of iterations, and MOP is a coefficient. The  $MOP(current_{itr})$  function value at the  $i^{th}$  iteration is signifies the parameter,  $MOP(current_{itr})$ . The term ( $\beta$ ) specifies the exploitation accuracy over the iterations, and it is a key parameter.

*c) Exploitation phase:* The exploitation approach of AOA is described in this section. According to the arithmetic operators, the mathematical representation utilizing any subtraction or addition produced very high dense outcomes related to the exploitation search process. As a result, the exploitation search finds the almost ideal answer that can be determined after numerous attempts (iterations). The exploitation operators (Addition and Subtraction) of AOA investigate the search area systematically in some dense regions and take a method to determine the better result. According to two major search approaches (i.e., Addition search strategy and Subtraction search strategy), modeled below:

$$X_{i,k}(current_{itr} + 1) = \begin{cases} (Best(X_{i,k}) - (MOP)) \times ((UB_{value(k)} - LB_{value(k)}) \cdot \gamma + LB_{value(k)}), & c < 0.5 \\ (Best(X_{i,k}) + (MOP)) \times ((UB_{value(k)} - LB_{value(k)}) \cdot \gamma + LB_{value(k)}), & otherwise \end{cases} \quad (22)$$

A deep search is used to fully use the search space. The other operator addition will not be considered till the first operator subtraction in this phase (first rule in equation (22)), which is conditioned by  $c < 0.5$ . If not, the subtraction will be replaced with the second operator addition to complete the current task. The partitions from the previous phase methods are analogous to those in this phase.

Pseudo-code for AOA:

```

1. Initialize the AOA parameters, where  $\beta, \gamma$ .
2. Initialize the positions of the solution, ( $i=1, \dots, N$ )
3. while ( $current_{itr} < \eta_{itr}$ ) do
4.     Compute the fitness function for the solution given.
5.     Find the best solutions.
6.     Update the MOA value from equation (19).
7.     Update the MOP value using (21).
8.     for ( $i=1$  to  $solutions$ ) do
9.         for ( $k=1$  to  $positions$ ) do
10.            Create random values between [0,1] ( $a, b$  and  $c$ )
11.            if  $a > MOA$  then
12.                Exploration phase
13.                if  $b > 0.5$  then
14.                    Use division math operator (" $\div$ ").
15.                    Update the  $i^{th}$  position of the solution using
equation (20)
16.                else
17.                    Use multiplication math operator (" $\times$ ").
18.                    Update the  $i^{th}$  position of the solution using
equation (20)
19.                end if
20.            else
21.                Exploitation phase
22.                if  $c > 0.5$  then
23.                    Use Subtraction math operator (" $-$ ").
24.                    Update the  $i^{th}$  position of the solution using
equation (22)
25.                else
26.                    Use Addition math operator (" $+$ ").

```

```

27.         Update the  $i^{th}$  position of the solution using
equation (22)
28.         end if
29.     end if
30.     end for
31. end for
32.      $current_{itr} = current_{itr} + 1$ 
33. end while
34.     Return the best solution ( $X$ ).
    
```

In AOA, generating a randomized set of populations is the first step in the optimization process. Every solution improves its position in relation to the best solution found. The parameter  $MOA$  is similarly increased from 0.2 to 0.9 to emphasize exploitation and exploration. When,  $a > MOA$  the candidate solutions effort to diverge from the near-optimal result, and when  $b < MOA$  they attempt to meet to the near-optimal result.

#### IV. RESULTS AND DISCUSSION

This section describes the experimental outcomes of the proposed FDASVM-MIKL classification. The proposed work performance is evaluated by using a simulation tool in PYTHON. Some of the simulation parameters are given in the Table II.

TABLE II. SIMULATION PARAMETERS

Parameters	Values
Regularization Parameter	1.0
Kernel functions	Linear kernel, Sigmoid kernel, Polynomial kernel and Radial Basis Function
Iteration	1000
Intercept scaling	1.0
Fit intercept	True
Random state	None

Several current approaches are examined to assess the proposed categorization performance. The next subsections provide descriptions of the dataset, representations of various performance metrics, analyses, and comparisons.

##### A. Dataset Description

The data utilized for assessing the performance of gene expression classification through the FDASVM-MIKL based approach is gathered from the datasets Colon, Prostate\_GE, Isolet, Lung\_cancer, ALLAML, snp2graph and the download link of each dataset is given below:

1) *Colon dataset* (<http://biogps.org/dataset/tag/colon/>): It is a well-known dataset for expression data analysis (cancer). Seven criteria and 90 samples are included. Dataset based on the human species.

2) *Prostate\_GE* (<https://wiki.cancerimagingarchive.net/display/Public/QIN+PROSTATE>): This dataset includes multi-parametric data gathered for staging or detecting prostate cancer.

3) *Isolet* (<https://archive.ics.uci.edu/ml/datasets/isolet>): Real characteristics (genetic variation) with several variables are present. There are 697 attributes and a total of 7797 instances.

4) *Lung\_cancer* (<https://archive.ics.uci.edu/ml/datasets/lung+cancer>): Integer characteristics make up this multivariate dataset. It primarily has 56 features and 32 occurrences.

5) *ALLAML* (<https://www.kaggle.com/datasets/nikhilsharma00/leukemia-dataset>): This dataset, which can be used for training, mainly consists of 7129 probes, 38 samples of bone marrow, and it is associated with Leukemia.

6) *snp2graph* ([https://www.kaggle.com/code/ilfiore/ncbi-check-reference-genome-version/data?select=snp2graph\\_full.csv](https://www.kaggle.com/code/ilfiore/ncbi-check-reference-genome-version/data?select=snp2graph_full.csv)): SNPs are identified and selected from gene variation associated with different types of human cancers.

##### B. Performance Metrics

Various performance metrics, including accuracy, F measure, sensitivity, specificity, and recall statistics, are taken into consideration while evaluating the effectiveness of the proposed gene expression data classification. The mathematical expressions used to describe various metrics are shown in the following representation.

1) *Accuracy*: The entire count of accurate predictions over the entire total amount of predictions is called accuracy. The accuracy can be mathematically expressed as,

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (23)$$

Where  $TP$  means true positive,  $FP$  describes false positive,  $TN$  represents true negative, and  $FN$  indicates false negative.

2) *Precision*: The percentage of reliable predictions from the predictor model that correctly anticipated positive cases from all positive predictions is called precision.

$$Precision = \frac{TP}{TP + FP} \quad (24)$$

3) *Recall*: The ratio of appropriate items chosen to the total number of appropriate objects is known as recall.

$$Recall = \frac{TP}{TP + FN} \quad (25)$$

4) *F1-score*: The harmonic means of the Positive predictive value (PPV) and the Recall or True positive rate (TPR) is determined as the F measure. It can be mathematically signified as,

$$F_{measure} = 2 \frac{PPV \times TPR}{PPV + TPR} \quad (26)$$

5) *Specificity*: The number of negative outcomes over the whole number of accurately negative samples. The specificity rate can be mathematically denoted as,

$$Specificity = \frac{TN}{TN + FP} \quad (27)$$

C. Performance Analysis

The analysis contains the main performance metrics, including accuracy, F-measure, recall, sensitivity and specificity, which are considered when comparing the performance of proposed and current techniques. The explanation of the performance includes a description and a graphical representation. The dataset such as Colon, Isolet, ALLAML, Lung CANCER, Prostate and Snp2 are used to classify gene expression into six categories. The performance comparison of accuracy is given in Table III.

TABLE III. PERFORMANCE COMPARISON OF THE PROPOSED METHOD

Performance Metrics	ALLML dataset	Colon dataset	Isolet dataset	Lung Cancer dataset	Prostate dataset	Snp2 dataset
Accuracy	0.9960	0.9995	0.9963	0.9951	0.9971	0.9979
Specificity	0.9927	0.9954	0.9949	0.9876	0.9889	0.9900
Precision	0.9896	0.9937	0.9911	0.9983	0.9930	0.9921
F1-Score	0.9748	0.9830	0.9830	0.9821	0.9938	0.9794
Recall	0.9817	0.9994	0.9988	0.9873	0.9876	0.9829

The comparison of Accuracy, Specificity Precision, F1-score and Recall with its values is represented in Table III. The accuracy of the proposed approach using the ALLML dataset is 99.60%, the Colon dataset is 99.95 %, the Isolet dataset is 99.63%, the Lung Cancer dataset is 99.51%, the Prostate dataset is 99.71%, and the Snp2 dataset is 99.79% obtained. The performance values of Specificity Precision, F1 score and Recall are also given in the table. The performance examination of the proposed Accuracy, Sensitivity, Precision, F1-score, Specificity and Recall is given in Fig. 3.

Accuracy, Specificity, Precision, Recall and F1-score performance is greater than the existing method. Table IV shows the accuracy performance comparison of existing and proposed approaches using the Colon dataset.

The accuracy of the proposed FDASVM-MIKL method is 99.95%. The existing method includes DNN, Improved DNN, CNN, and RNN with accuracy performance of 91.4%, 91.4%, 82.8% and 84%, respectively. Related to the existing methods proposed FDASVM-MIKL approaches has a better accuracy outcome. The performance comparison of the proposed and existing methods using the Colon dataset is represented graphically in Fig. 4.

Fig. 5 presents the comparative graphical representation of the proposed method using current approaches. Table V presents an accuracy comparison of proposed and current approaches using the Isolet dataset.

The proposed FDASVM-MIKL approach has an accuracy value of 99.63%. The accuracy performance of the existing methods, including SVM with multiplicative kernel combination (GKML), ElasticNet-SVM, Multiple indefinite kernel learning based FS (MIK-FS), and SVM with l1 norm regularizer (l1-SVM), is 96.01%, 81.589%, 88.03%, and

94.86%, respectively. The proposed FDASVM-MIKL approach has improved accuracy performance compared to the current methods. The performance study of the proposed and current approaches utilizing the Colon dataset is visually depicted in Fig. 5.

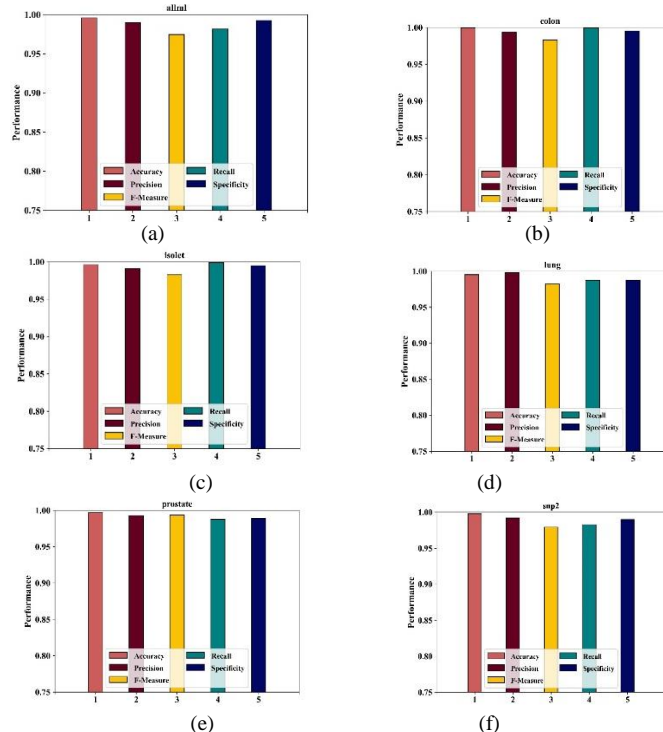


Fig. 3. Performance analysis of the proposed method using a different dataset.

TABLE IV. ACCURACY COMPARISON OF PROPOSED AND CURRENT METHODS USING THE COLON DATASET

Colon dataset	
Methods	Accuracy
DNN	0.914
Improved DNN	0.914
CNN	0.828
RNN	0.84
<b>Proposed FDASVM-MIKL method</b>	<b>0.9995</b>

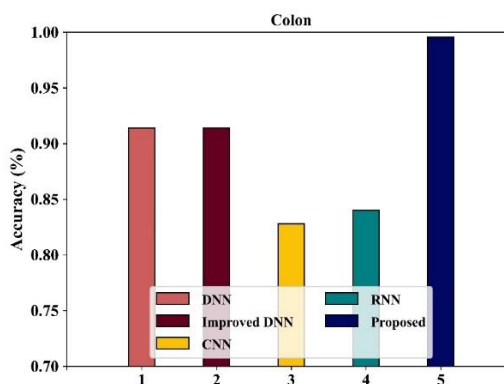


Fig. 4. Accuracy performance analysis of proposed and current methods using the Colon dataset.



TABLE V. ACCURACY COMPARISON OF PROPOSED AND CURRENT APPROACHES USING THE ISOLET DATASET

Isolet dataset	
Methods	Accuracy
GKML	0.9601
ElasticNet-SVM	0.81589
MIK-FS	0.8803
11-SVM	0.9486
<b>Proposed FDASVM-MIKL method</b>	<b>0.9963</b>

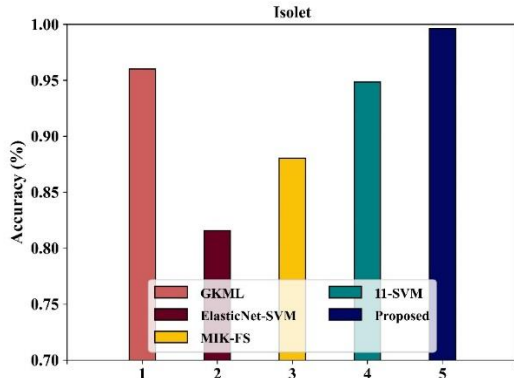


Fig. 5. Accuracy performance analysis of proposed and current approaches using the Isolet dataset.

The graphical comparison of the proposed method with the known methods is shown in Fig. 5. Table VI represents the accuracy comparison of the proposed and existing methods using the Prostate dataset.

TABLE VI. ACCURACY COMPARISON OF PROPOSED AND EXISTING METHODS USING THE PROSTATE DATASET

Prostate dataset	
Methods	Accuracy
DNN	0.892
Improved DNN	0.932
CNN	0.892
RNN	0.924
<b>Proposed FDASVM-MIKL method</b>	<b>0.9971</b>

The accuracy of the proposed FDASVM-MIKL approach is 99.71%. The accuracy performance of the existing methods, including DNN, Improved DNN, CNN, and RNN, is 89.2%, 93.2%, 89.2%, and 82.4%, respectively. The proposed FDASVM-MIKL approach has improved accuracy performance compared to the current methods. The performance study of the proposed and current approaches utilizing the Prostate dataset is visually depicted in Fig. 6.

The graphical comparison of the proposed method with the known approaches is shown in Fig. 6. Using the ALLAML dataset, Table VII compares the accuracy of the proposed and current approaches.

The accuracy of the proposed FDASVM-MIKL technique is 99.60%. The current methods include rMRMR-nMGWO, Random Forest, Least Absolute Shrinkage and Selection

Operator (LASSO), Elastic Nets, and Decision Tree accuracy performances are 98.3%, 48.6%, 87.5%, 98.7%, and 83.3%, respectively. The result shows that the accuracy performance of the proposed FDASVM-MIKL methodology is greater when compared with existing approaches. Fig. 7 illustrates the performance analysis of proposed and current approaches using the ALLAML dataset.

The graphical comparison of the proposed technique with the known methods is shown in Fig. 7. Using the Lung cancer dataset, Table VIII compares the accuracy of the proposed and current approaches.

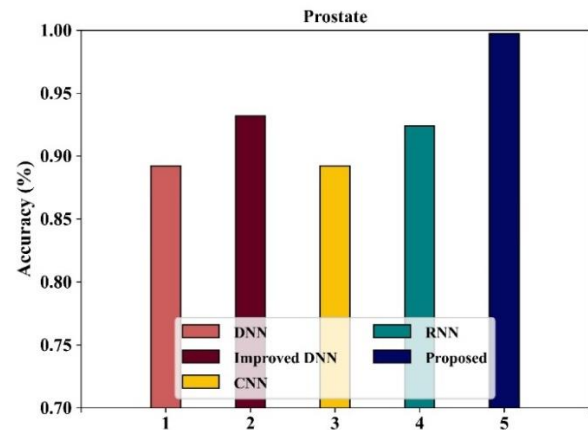


Fig. 6. Accuracy performance analysis of proposed and current approaches using the Prostate dataset.

TABLE VII. ACCURACY COMPARISON OF PROPOSED AND CURRENT APPROACHES USING THE ALLAML DATASET

ALLAML dataset	
Methods	Accuracy
rMRMR-nMGWO	0.983
LASSO	0.486
Random Forest	0.875
Elastic Nets	0.987
Decision Tree	0.833
<b>Proposed FDASVM-MIKL method</b>	<b>0.9960</b>

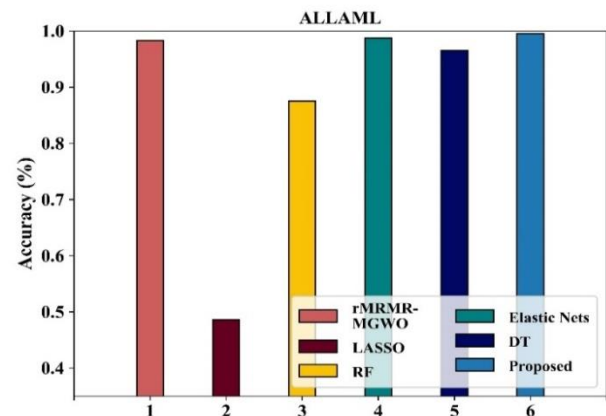


Fig. 7. Accuracy performance analysis of proposed and current approaches using the ALLAML dataset.

TABLE VIII. ACCURACY COMPARISON OF PROPOSED AND CURRENT APPROACHES USING THE LUNG CANCER DATASET

Lung_cancer dataset	
Methods	Accuracy
rMRMR-\nMGWO	0.975
LASSO	0.793
Random Forest	0.916
Elastic Nets	0.975
Decision Tree	0.876
<b>Proposed FDASVM-MIKL method</b>	<b>0.9951</b>

The accuracy of the proposed FDASVM-MIKL approach is 99.51%. The accuracy performance of the existing methods, including robust Minimum Redundancy Maximum Relevancy- Gray wolf optimizer algorithm (rMRMR-\nMGWO), Random Forest, Elastic Nets, Least Absolute Shrinkage and Selection Operator (LASSO) and Decision Tree, is 97.5%, 79.3%, 91.6%, 97.5% and 87.6%, respectively. The proposed FDASVM-MIKL approach has improved accuracy performance compared to the current methods. The performance study of proposed and current approaches utilizing the Lung cancer dataset is visually depicted in Fig. 8.

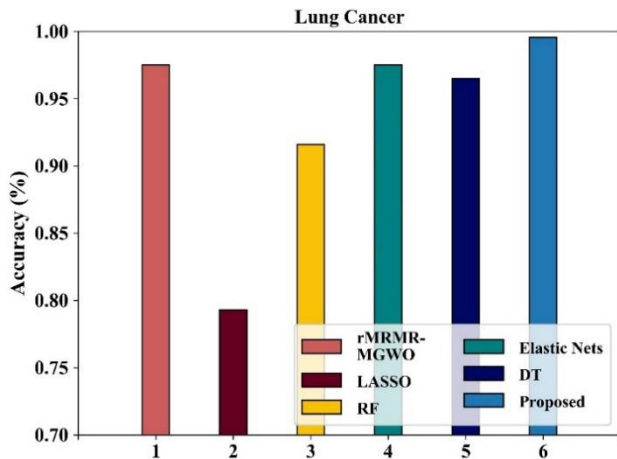


Fig. 8. Accuracy performance analysis of proposed and current approaches using the Lung cancer dataset.

The comparison employs several epoch counts. Fig. 9 compares the Loss epochs of Train, Test and Validation of the proposed system.

TABLE IX. ERROR RATE OF THE PROPOSED METHOD USING DATASETS

Dataset	Error rate
ALLML	0.0039
Colon	0.0004
Isolet	0.0036
Lung_Cancer	0.0048
Prostate	0.0028
Snp2_graph	0.0020

The training, testing and validation losses of the proposed approach on the provided dataset are plotted as a function of epoch number in Fig. 9. In the comparison, various epoch counts are employed. The Error rate of the proposed method for each dataset is illustrated in Table IX.

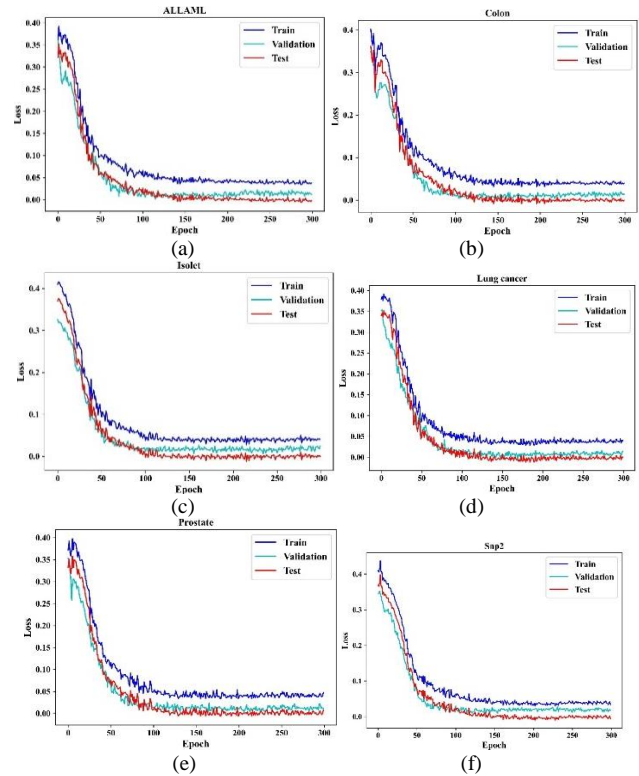


Fig. 9. Training, testing and validation epochs vs. loss.

### V. CONCLUSION AND FUTURE SCOPE

This paper proposes a unique method for the analysis of expression data based on multiple indefinite kernel learning, OKPCA and hybrid FDA-AOA is also employed. The PYTHON platform is used to carry out the proposed strategy. The evaluation results are also taken into account for various types of data sources. The accuracy of the classifications is used to determine the performance. The accuracy of the proposed technique using the colon dataset is 99.95%, the accuracy of the proposed technique using the Isolet dataset is 99.63 %, for ALLAML is 99.60%, using the Lung cancer dataset is 99.51%, for the prostate dataset is 99.71% and the proposed method accuracy using the Snp2 dataset is 99.79%. It is clear from the results that the Isolet database performs better. The comparative result of the proposed strategy demonstrated that it is more accurate than other existing methods. In the future, this study will be extended to include improved techniques and advanced classification approaches.

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# A 3D Processing Technique to Detect Lung Tumor

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**Abstract**—In this paper, the authors introduce a new segmentation technique based on U-NET algorithm from the deep learning used for lung cancer segmentation, which is the main challenge that medical Staff confront in their diagnosis process. The goal is to develop an ideal segmentation that enables medical personnel to distinguish the various tumor components using the completely U-NET convolution network architecture, which is the most effective. First, the regions of interest (ROI) in the 2D slides are established by an expert using the syngovia application of the Siemens. In this pre-processing step, the cancer area is isolated from its surroundings, and is used as a training model for U-NET algorithm. Second, the 2D U-NET model is used to segment the DICOM images (Digital Imaging and Communications in Medicine) into homogeneous regions. Finally, the post processing step has been used to obtain the 3D CT scan (computerized tomography) from the 2D slices. The segmentation results from the proposed method applied on biomedical images from nuclear medicine and radiotherapy that are extracted from the archiving system of the Institute of Salah Azaiez from Tunisia. The segmentation results are validated, and the prediction accuracy for the available test data is evaluated. Finally, a comparison study with other existing techniques is presented. The experimental results demonstrate the superiority of the used U-NET architecture applied either for 2D or for 3D image segmentation.

**Keywords**—Deep learning U-NET architecture; 3D CT scan (computerized tomography); DICOM images (Digital Imaging and Communications in Medicine); 2D slices; ROI (regions of interest)

## I. INTRODUCTION

Some of the main difficulties in image processing and computer vision could involve split imaging [1]. The divisions of the imaging in just this topic have the broadest use across several disciplines and technical advances [2 and 3]. The most known concept is to implement different software for the feature spaces of both the partitioned 3D melanoma illustration and the U-NET measurement, in either the permitted dimensional characterizing boundary. Which the distributions produced with peak contribution through one pixel to the following juxtaposition. As well as a wide range of intensity only within the visual performance of the segment. The main idea is to create an optimum cluster approach with medical scanning ground and to obtain the wanted findings through analysis.

For medical images, only several segmentation methods are available [4, 5, 6, and 7]. Mohamed et al. [8] established that

computed tomography (CT) imaging is one of the crucial development radiological aspects for illness diagnoses. In this study, the author provides an approach for CT image processing that integrates the spatial and transform domains. Low-contrast details that are often smoothed out by edge detection filters can be restored with the help of transform domain filters. The homogeneity Phase (PC) and the redesigned remove noise technique form the foundation of the prefilter. In the same context, Imen et al. [9] suggests a computer-aided diagnostic (CAD) method for diffusion-weighted magnetic resonance imaging (DWI)-based early identification of prostate cancer. That was defined as the region of interest for the proposed system across the several slices of the input DWI volume. The defined ROI appear the diffusion coefficient (ADC) which was determined, normalized and improved.

In order to identify local scale nodules less than 3 mm and non-nodules on tomography (CT scan) networks, Monkam et al. [10] has mentioned various CNN layouts also with many of convolution layers. The researchers were using a 5-fold parallel validation approach to assemble the designs on different shapes of  $(16 \times 16)$ ,  $(32 \times 32)$  and  $(64 \times 64)$  CT scan images captured from the LIDC repository at  $(512 \times 512)$ . The experiments have found that the CNN with two fully connected layers within the instance of  $(32 \times 32)$  patching, measure an incredible performance and prospective.

Similarly, Mundher Shabiet al. [11] researched a 3D convolutional neural network (CNN) established on the most important objectives. For the automatic recognition of the whole disease of lung cancer that is screened on computed tomography (CT) scans. If it can accurately classify malignant/cancerous lung nodules, many lives could be saved. In the meantime, SiyuanTangetal [12] explored the pulmonary tissue area and used a 3D U-NET convolution neural network.

Unfortunately, the outcomes of the preponderance extraction feature in practice when it is used on 3D medical data are erroneous. The fragmentation of lesions allows swift and exact disease identification by healthcare experts. Consequently, selecting the appropriate feature is an essential step in the analysis technique of a medical image.

The U-NET architecture is a particular sort of fully convolutional network (FCN) defined by an encoder-decoder structure. Those are developed for semantic segmentation, which is often referred to as pixel categorization. That was

developed for the direct extraction of high-level image from blocks during the expansion phase. These connections defined the block boundaries during the rectification.

Section 2 introduces the proposed method for detection of Lung Tumor. The experimental results are discussed in Section 3. The discussion is presented in Section 4 and the conclusion and future work is given in Section 5.

## II. PROPOSED APPROACH

Forty cases were involved in the investigation (thirty males and ten females), with a prognosis and reported age range of 55 years (45-65 years). The cancerous nodule that was identified reached approximately 3 cm. Data extracted from the local system of storage and transfer of data (PACS) is extracted according to Salah Azaiez Institute of Cancerology various nuclear medicine, radio-assistance and radiotherapy in order to develop the optimization techniques. That approach out 3D lung cancer tiny cellular (CPC) of the multiple levels which would be associated with smoking use and contributes for 25% of carcinoma [15]. The non-small cell lung cancer (NSCLC) subgroup provides for the remaining 75% of cases of pulmonary cancer. The outcome displays the inadequate CT SCAN performance of seventeen patients.

In an attempt to evaluate the provided framework's efficiency, accuracy and awareness for the split samples, the consequences are juxtaposed against approaches that have been established as effective. Those protocols have been implemented on Ubuntu by using the deep learning framework and NumPy dialect settings.

The underlying 3D data is saved in the RGB (red, green, and blue) layout. The primitive shade occupies 8 bits per pixel, and the luminance can vary from 0 to 255. The engagement in learning how to tag the DICOM data will later be used for edge detection. The full-size cut with a measurement of  $(256 \times 256)$  and an estimate of  $(96 \times 128)$  of the ROI is defined (see Fig. 11).

The Different diagnoses, which use a wide range of techniques to treat extended pathologies, are particularly employed on clinical imaging. With this field in healthcare, training is now immediately accessible. The medical techniques of imagery allowed a visual description focused on physical or chemical features instead of a straightforward snapshot of the tissue or organ being researched; especially those employed in nuclear medicine, which carry out reconstructive and volumetric acquisitions directly.

Consequently, the findings of the preponderance of the widely employed feature extraction, whenever extended to 3D medical data, are not consistent anymore. The major objectives are to make it simpler for clinicians to immediately and accurately diagnose malignancies. Therefore, among the most necessary phases in image processing is determining an optimal decision.

In this case, applying the U-NET approach to divide a three-dimensional image of a patient suffering from lung cancer seems like an intriguing technique. Therefore, the primary objective of this study is to develop the best algorithm.

The biomedical engineering produces the desired optimal result for healthcare experts.

Preprocessing, U-NET segmentation and post processing are the three main phases that make up the proposed method. In the first phase, the local region of interest (ROI) and 3D volume have been converted into an arrangement of 2D slices in the first phase. The local area of interest is partitioned by using 2D U-NET framework in the second phase. Finally, the 3D CT SCAN has been reduced again to 2D slices by using the post-processing phase. The flowchart depicted in Fig. 1 demonstrates the characteristics of the proposed segmentation technique the contribution applied by extracting the different parameters from the syngovia system (the archiving system) in the input to the pre-processing, U-NET architecture, post-processing and the output result to obtain the 3D U-NET segmentation.

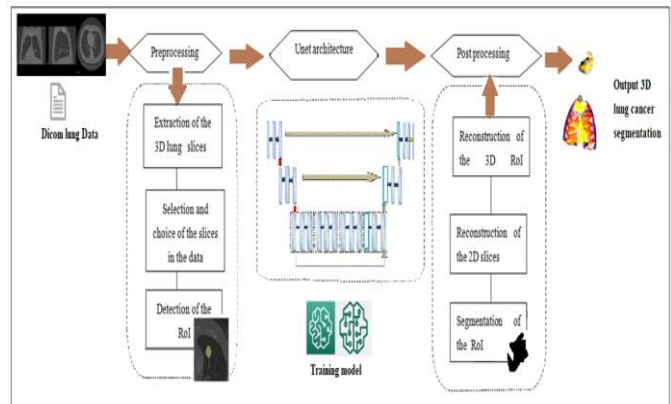


Fig. 1. Suggested approach defined by the preprocessing step the U-NET architecture and the post processing step.

The proposed algorithm of the U-NET can be summarized by the following steps:

**Step 1:** The 3D volume was changed into 2D slices, and the local Region of interest (ROI) was selected, which represents the ground truth an estimate of  $(96 \times 128)$ .

**Step 2:** Convolution layers, three - dimensional up-convolutions and 3D max partitioning -3D operations that substitute the professional 3D decompositions and thus are epitomized in 3D axes that are explored.

- The architecture involves screening out the highest-risk malignant nodule prospects among storage containers.
- The U-NET CNN architecture is a great tool for the segmentation of biomedical imagery. The recommended implementation of U-NET is the least straightforward way to reduce memory consumption; check Fig. 3.

For the training stage, the suggested U-NET adapted framework  $(256 \times 256)$  as provided 2D Tomography scans are slices up and provided with information and annotation, as  $(256 \times 256)$  overlays, and tumor regions are 1 while other regions are 0.

**Step 3:** The post-processing algorithm requires frames  $(256 \times 256)$ , in which each pixel's datatype ranges



from zero to 1, reflecting the likelihood that pixel is a participant. Fig. 2 to 4 illustrates identical entries and prognostications for all patients in the ultimate U-NET layer.

In this contribution, the U-NET strategy will be applied for the segmentation of the lung DICOM image. In this proposal, the authors begin with the preprocessing and the post processing. At the first stage, the 3D volume has been changed over into a course of actions into the 2D slices and the (ROI) has been made. At the second stage, the 2D U-NET demonstrates the utilized section nearby the ROI. Finally, the post processing step has been obtained to diminish the 3D CT SCAN from the 2D.

#### A. Pre-processing Procedure of 3D Lung Cancer Slices

The segmentation of the CT SCAN data is performed using the pre-processing approaches. To accomplish this frame, the 3D CT SCAN provided from the 2D slices must initially be stripped whereby each subject includes about 260 slices. Secondly, the 2D determined slices have been applied to establish the region of interest (ROI). The multi-view split of the crucial, coronal, and sagittal planes (see Fig. 6), has been performed by using deep learning techniques (the information of standardization and expansion).

The pre-processing steps convert the 3D CT SCAN into 2D slices in order to create the ROI, which could be used as an input by the 2D split. In an attempt to apply digital competence in a slice-wise strategy for greatest performance the 2D slices were produced from 3D slices. Those slices are obtained concurrently and applied at the orthogonal planar 3D in space, and the basic computing CDA was developed exclusively for DICOM imaging [13]. For the medical establishment, the authors opt for Siemens Healthcare that is specialized on PACS Syngovia software and is applied to the process of the 3D image segmentation expertise. This application is used to extract features of the DICOM images for the preservation and accomplishment support of a precise and efficient diagnostic.

In this location, the volumetric sampling adds a third dimension relative to two dimensions (2D) computerized in the following figures. The screening method is focused within the building blocks referred to as three-dimensional (3D) pixels. However, the volume rendering is made possible by the representation of (3D) datasets. Consequently, multidimensional components of numeric or data vectors are used to characterize the datasets. That is used to create the 3D CNN architecture that combines subsample and recorded values [14]. Fig. 2 illustrates the preprocessing steps in the beginning the choice of the appropriate 3D lung cancer that was extracted by the medical expert and selects the best slices to be used in the terminologies of the 2D slices and finally the different parameters was defined to obtain the appropriate ROI.

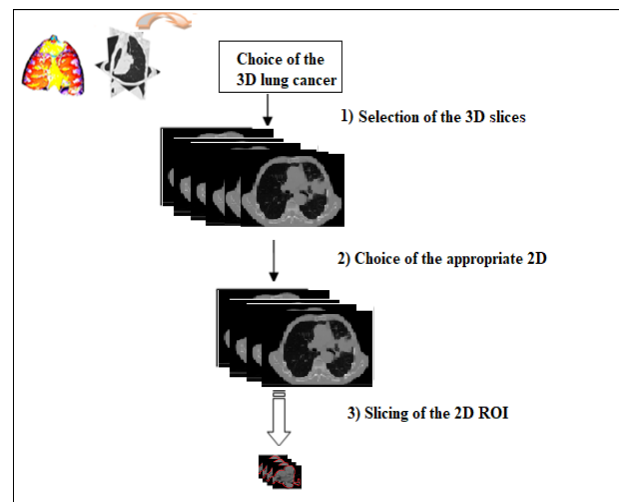


Fig. 2. Preprocessing step demonstrated by the choice of the 3D lung cancer. (1) selection of the 3D slices. (2) choice of the appropriate 2D. (3) slicing of the 2D ROI.

In order to be precise, the different parts of the slices have been resized to achieve the same (256 × 256) pixel approximation. This methodology decreased the number of 260 slices presented as abnormal for every CT scan. Each procedure decreased the median slice count to every Scan between 260 into 35 (see Fig. 3). Consequently, the screened slices were subsequently projected on the region of interest (ROI), which had been extracted from the full-size cut with a measurement of (256 × 256) and an estimate of (96 × 128) as demonstrated in Fig. 3.

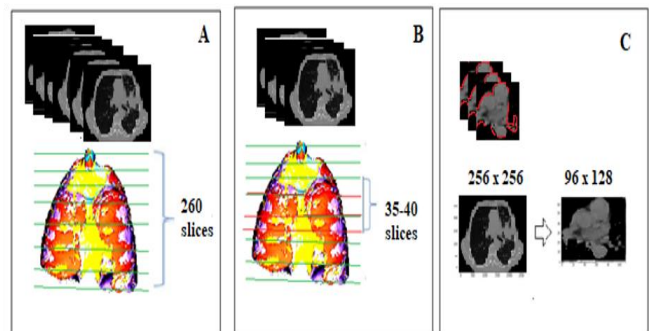


Fig. 3. Preprocessing steps, (A) the 3D slicing, (B) the selection of slices and (C) the region of interest (ROI).

#### B. 3D Extension based on 2D Segmentation using U-NET Architecture

The proposed method is employed from deep CNN and the data was implemented to stretch the 3D segmentation volume and have the latest new U-NET architectural decision. Fig. 4 contains the fundamental concepts of the segmentation applied to the U-NET configuration.



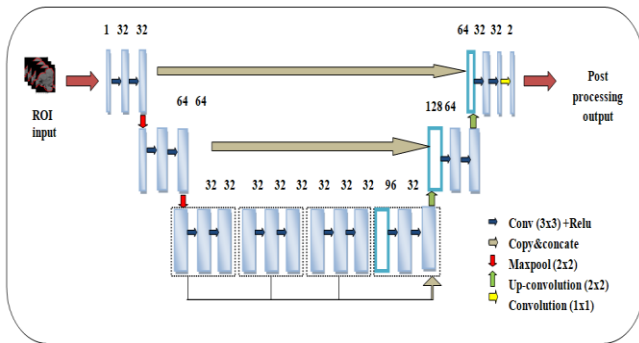


Fig. 4. The U-NET architecture approach presented by the input of the patched ROI into the defined layers and the output of the post processing step.

Regarding the difficulties of splitting in the medical field, it has been proposed that the U-NET approach presented as wide multilayer perception for this division process [15]. This expert system is one of the most well-suited and sufficient for partitioning clinical imagery. The approach made it possible to identify valuable details from DICOM. This technique includes an encoder and a decoder that accomplishes down, and up sampling using four components and are related via skip associations to produce high-resolution image.

Whilst also reducing the final two layers of the first explanation and boosting the bottleneck layer of the division result, the authors reduce the segmentation approximation under this project to 50%. By skipping connections, the characteristics acquired through the encoders' method at each level are transmitted to the decoding method. The encoder approach conducts two rounds of convolution, aggregate equalization, and dropout simultaneously for each layer. The image measurement will be split in half by the max-pooling and sent to the next layer. This handle is retained until the image reaches the bottleneck layer, the last layer in the encoder path. This layer now has three empty squares and two convolutional rounds that were normalized and discarded separately.

After the subsequent phase, the authors combined the yield from all previous blocks into the final bottleneck layer square. This experimentation with different amounts of blocks inside the hidden layer demonstrated of the three additional square configurations. The decoding path starts at the end of the pre-processing step on the upper right. The image identification is first expanded by the use of over fitting. Typically, a transposed convolution takes the place of the convolutions in oversampling. The image is then transmitted to the layer in the decoder method, which combines the highlight mapping from the contraction method (encoder), does two rounds of convolution group normalization, and independently performs dropout. The method continues sampling the images until each one approach the last stage of the decoder, at which point information is returned towards its original estimate of (96 × 128). The final layer of the decoding technique comprises a sigmoid stage that divides every pixel into two main categories with a probability ranging from 0 to 1.

According to Fig. 4, the image data is coupled to a rectangle size width (3 × 3) in order to generate a boundary inside the convolution implementation. For this reason, the

authors use the ReLU activation technique in each of these convolution patterns [16]. The positive weights of the attributes remained undamaged by this implementation process strategy, however all of the spotlights' deleterious evaluations have been assigned a value of zero.

Furthermore, Cluster standardization was employed to speed up the arrangement processing by decreasing the rate at which each gradient was received. The distribution changes during preparation since the characteristics of the previous time step change. Likewise, over fitting and Dropout are anticipated using the premature ceasing [17] as batch normalization tactics within the implementation. At every layer, the weight and inclination were improved using the Adam optimizer [18]. The ROI image of a slice from a cell lines CT SCAN serves as the input and the yield is the segmentation.

This solution performs well for connecting the intra-slice images, identifying the boundaries, and fragmenting the layers from the human lung CT SCAN dataset since the U-NET uses fewer training parameters and is quicker to focalize.

This provides the capability of an unsupervised layer in a multi-level structure that is automatically chosen for other illustrations. When the neural network is trained, Deep convolutional (CNN) model of decoders [19] mainly abstains the harshness of prejudice that canaries exhibit (without pre-initialization). In order to insert scientific information (such as the patient's age and weight) into the 3D U-NET formula, a total of 563 patients' data were collected and anonymized. The use of modern methods for DICOM and other medical imaging sources has showed an impressive performance in the area of morphology identification in radiography.

Additionally, the authors define the characteristic segment as  $x$  and the concatenated as  $x'$ , respectively. The stacked layer corresponds to another  $F(x')$  cartography. The underlying  $H(x')$  is defined as follows:

$$H(x') = F(x') + x \quad (1)$$

A linear projection  $Ws$  is carried out during skip connections where  $x$  and  $F$  dimensions must both be equal. The definition of the building block used is:

$$y = F(x', Wi) + Ws \quad (2)$$

The transmitter and receiver parameters of the construction block under consideration are  $x'$  and  $y$ , respectively. The function  $F(x', Wi)$  is used to express the residual mapping that needs to be learned.

The computational calculation for the 2D combination process as following:

$$C(I \times S)_{ij} = \sum_{m=0}^{p-1} \sum_{n=0}^{q-1} [S(m, n) \times I(i + m), (j + n)] + b \quad (3)$$

While  $C$  denotes the yield of the fully connected layer and  $(i, j)$  denote the input ROI of the CT SCAN measurement, which ranges from 0 to 255 escalated values and the  $(m, n)$  gives the matrix measurement, where  $I$  is the characteristic outline,  $S$  is the skip of the encoder-decoder and  $q$  have an impact on the spatial assessment of the filter. The word "predisposition" is represented by  $b$ . This data is subjected to the multilayer process and the max-pooling is then attached.

Equation is used to carry out comparable feature extraction in the remaining squares of the encoder.

During training, the model assessed its performance using the Weighted Binary Cross-Entropy, loss function  $J$ , and the stochastic gradient descent optimization procedure. A better model is indicated by a greater loss function value, whereas a better training result is shown by a lower loss function value, which improved the model's performance by reducing the classification error brought on by the class imbalance between the target and background pixels.

$$J = -\frac{1}{M} \sum_{m=1}^M [wxym \log(h(xm)) + (1 - ym)x \log(1 - h(xm))] \quad (4)$$

Where  $M$  is the total number of training examples,  $w$  denotes weight,  $y$  denotes the targeted term for training case  $M$ ,  $x$  denotes input image and  $h$  denotes the model's stacked neural network.

### C. Post Processing Procedure of 3D Lung Cancer Slices

The post processing organization of the U-NET 3D segmentation was outlined to guarantee a forecast of 3D slices. As presented in Fig. 5, the post processing step consists of three lower stages:

- The split yield is filtered to remove the genuine positives.
- Recreation of the 2D slices from the fragmented 2D ROIs (converting 2D complete images to 2D ROI images).
- Fig. 5 shows the reconstruction of the 3D proportions from the 2D replicated slices (from 2D proportioned cuts to 3D CT SCAN) to obtain in the output the 3D U-NET segmentation.

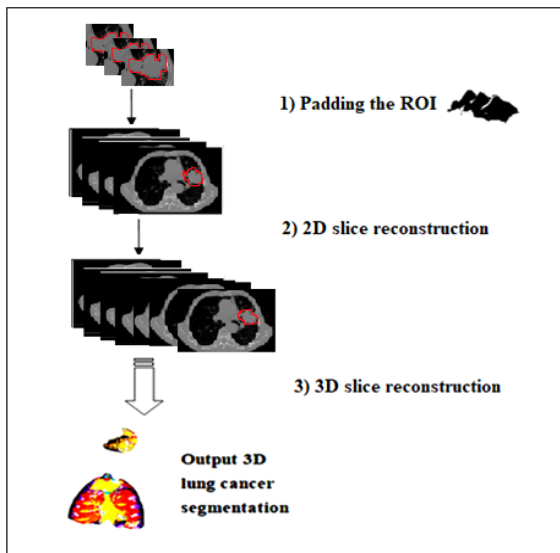


Fig. 5. The post processing step including the reconstruction of the 3D slices. (1) The padding ROI. (2) 2D slice reconstruction. (3) 3D slice reconstruction.

However, there was noise within the ROI causing the segmentation to dismount one identifier by few base pixels.

There were two methods used to present the outflow of falsely positive results:

- Instead, every neuron has the attribute "1" on it.
- The erroneous positive pixels inside the quasi being suggested to be identified and removed.

The non-locale was chosen by a rectangular framework of  $(96 \times 128)$  per each slice while considering the ROI. While pixels have been supposed to appear in the cleared-out and right areas, the authors implemented a filter to eliminate additional pixels outside of the boundaries. Then, using padding the 2D sectioned slices were restored to their distinct size of  $(256 \times 256)$  as seen in Fig. 5. Defining every ROI in this arrangement may therefore be sliced. Finally, the 3D CT SCAN lung for each participant was rebuilt using all the clarified division. There may be a difference in the number of divisions. As a consequence, the initial slices got swapped to reconstruct the 3D lung.

### III. SIMULATION RESULTS

In this part, several biomedical results obtained by the proposed method are provided. Fig. 6 presents the samples of the DICOM features extracted with various CT SCAN layers.

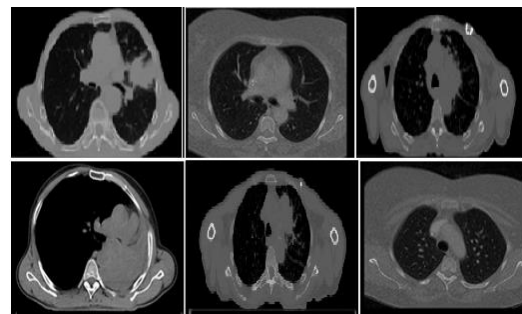


Fig. 6. Training set chosen for the scientific study.

### A. Evaluation of the Results

The mean squared error (MSE) is the best and most widely utilized difference degree for image quality investigation. The MSE is easy to compute and incorporates several alluring properties applications. Moreover, it endures from a few principal issues [20] presented by the following expression (5):

$$MSE = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N [p(i, j) - q(i, j)]^2 \quad (5)$$

The proportion between the greatest conceivable controls of 3D images through compression of the undermining that creates distortion. The small esteem of the Peak Signal to Noise Ratio (PSNR) implies that pictures are of destitute quality. The value of PSNR for superior picture quality can be calculated based on the following equation:

$$PSNR = 10 \log \frac{(2^n - 1)^2}{MSE} \quad (6)$$

It should be noted that the reduced PSNR values reflect inferior cloning. On the other hand, a lower regard for MSE seems to indicate improved regeneration.

B. The Contribution Results

The encoder-decoder and primarily several varieties of completely convolution neuronal networks are marked by the U-NET layout. The class of neural network models (FCN) by integrating the interactions comprises the layer works and blocking straight to factor in the overall in the heterogeneity stage. The feature extraction draws just on fully convolution framework and is integrated with the pixel identification.

The application of the 3D U-NET Automated system applied on 3D approaches is the empirical tests dedicated to the identification of biomedical cancerology images. Fig. 7 depicts the outcomes of the segmentation of the samples [21].

Besides, TP, TN, FN, and FP successively the proportion of cancerology patches are true positive, true negative, false negative and false positive, correspondingly.

- True Positive (TP) called sensitivity: The region of crossing point between Ground Truth (GT) and division mask(S), numerically, usually coherent AND operation of GT and S.

$$TP = GT \cdot S \tag{7}$$

- True Negative (TN) called specificity: Equivalent to a true positive, a true negative is an ending when the classifier is trained the negative subclass with accuracy.

$$TN = 1 - FP \tag{8}$$

- False Positive (FP): The anticipated zone exterior the ground truth. Usually, the coherent OR of GT and division short GT.

$$FP = (GT + S) - GT \tag{9}$$

- False negative (FN): number of pixels within the ROI zone that the model failed to anticipate. This is often the coherent OR of GT and division short S.

$$FN = (GT + S) - S \tag{10}$$

The IoU is the proportion to the combined ROI and scientific facts. Due to the parameters of TP, FP, and FN are nothing but ranges or number of pixels; ready to compose as takes after.

The anticipated ground-truth is drawn see Fig. 9 to 12, Computing Crossing point over Union can in this manner be decided through the equation below see (11):

$$IoU = \frac{TP}{TP+FP+FN} \tag{11}$$

The performance of the research of lung cancer segmentation scheme was evaluated referring to the evaluation in the literature, namely accuracy, sensitivity, precision and dice. Those were evaluated using equations (12) to (15):

$$Accuracy = \frac{TP + TN}{TP + TN + FN + FP} \tag{12}$$

$$Sensitivity = \frac{TP}{TP+FN} \tag{13}$$

$$Precision = \frac{TP}{TP+FP} \tag{14}$$

$$Dice = \frac{TP+TP}{TP+TP+FP+FN} \tag{15}$$

TABLE I. COMPARED THE PERFORMANCE OF THE INVESTIGATION EMPLOYING ELECTED AND CURRENTLY USED METHODOLOGIES

Methods	Name of dataset	Model	Accuracy %	Sensitivity %
The Proposed Method	Hospita 1	3 U-NE T	98.9	97.99
Mundher AL-Shabi [11]	LIDC-IDRI	3D U-NE T	95.28	94.33
Monkam and al[10]	LIDC-IDRI	3D CNN	88.28	83.82
SiyuanTang[12]	LUNA 16	3D U-NE T	94	92.4

Table I indicates the accurate feature extraction rate of the database obtained inside the various experiment methods with consideration to the sensitivity and the accuracy. The medical teams appointed to accomplish the finding model as depicted in the graphic (Fig. 7). Fig. 12 demonstrates the Dice findings and the best outcomes from the contributing experiment.

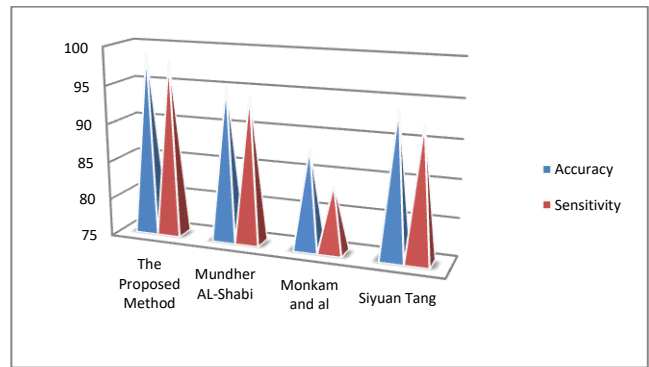


Fig. 7. Evaluation of the performance of the metrics of the sensitivity and accuracy of the proposed method comparing with other study.

As is apparent from the same, the accuracy corresponds to 88.28%, 94%, 95.28% and 98.9% of intensity values for the techniques of roughly Mundher AL-Shabi [11], Siyuan Tang [12], and the predicted model that was combined. In addition, the sensitivity corresponds to 83.82% for the methods of Monkam and al [10], 94.33% for the approaches of Mundher AL-Shabi [11], 92.4% for the algorithms of Siyuan Tang [12] and 97.99% for the processes.

Meanwhile, the malignant locations are successfully delineated in Fig. 9 and 12 utilizing the DICOM dataset; the accuracy and sensitivity were more well-liked and validated by doctors. This data will be shared in the subsequent steps.

The representative ROC curve seen in Fig. 8 was conspired to show how the algorithm can discern in mid the true positives and negatives rate. The authors will calculate the AUC "Area under the ROC Curve" which tells us how much of the plot is found beneath the curve. The closer AUC is to 1, the superior is the model. From the plot that can see the taking after AUC

measurements for each model: AUC of the calculated relapse present: The logistic regression model on the following representation of the ROC curve is demonstrated with the blue line at (0.4; 0.82) and the gradient model is presented with the orange line that held (0.1; 0.9897). The performance of the ROC curve that it grips the peak of the angle of the scheme best is the model chosen for the data segmentation.

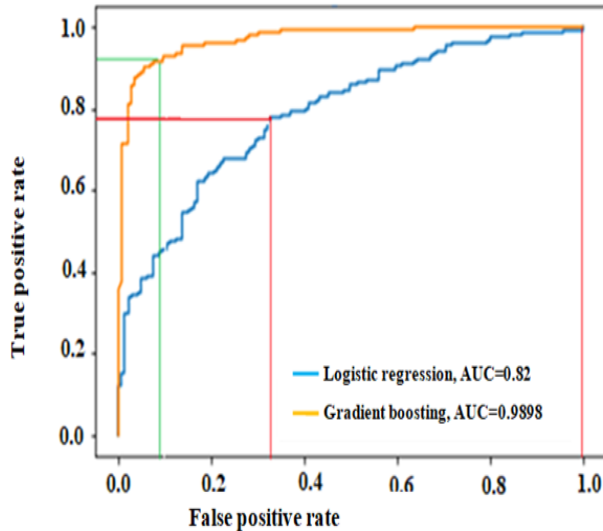


Fig. 8. The precision of the data's ROC curve presenting the false positive rate and the true positive rate presented with the logistic regression and the gradient model.

The database extracted exceeds more than 3000 slices (see Fig. 9 and 12), in 2D slices each of which are of a resolution (512 × 512) whose medical staff provided us their marking of each that the cases studied with the tumor dimension which is >3cm, shown by the Tables II and III below. Through a clinical study, it was noticed that the majority of the cases present a very short life expectancy of no more than 2 years, as well as the rapid evolution of the cancer disease that reaches in a few months without any treatment the case of metastasis spreading through the bone and reaching the brain.

Due to the patient's physical and mental tiredness after undergoing surgery, chemotherapy, and radiotherapy, the treatment can be very challenging, and the severity of mortality is significant. This proves that this disease affecting this organ is responsible for breathing and the circulation of oxygen (O<sub>2</sub>) in the blood increasing the risk of a stroke.

The figures below show the marking made by the medical staff on the DICOM images. Extracted from the archiving and recording system (PACS) and the comparison with the results achieved with the segmentation systems and the proposed U-NET architecture. Fig. 9 represents the PET scan DICOM and the segmentation of the U-NET architecture compared to the (ROI) an estimate (96 × 128) contoured by the medical staff.

Therefore, the Dice has been employed as a loss function in the investigation. While this issue is adjusted by using probability ratios instead of Boolean, it is also known as sophisticated dice disappointment. Comparing the sophisticated dice unfortunate approach to the cross-entropy, it is relatively straightforward to optimize. Analysts have frequently

used the DSC equation in more recent times [22]. The DSC scoring system is used to assess the effectiveness of lung tumor segmentation. The DSC is provided in order to evaluate the outcomes of the actual and planned feature extraction (16).

$$DSC(X, Y) = \frac{2(X \cap Y)}{X + Y} \quad (16)$$

Where Y provides precise or hypothetical segmented lung regions and X relates to the predicted value of the lung segmented areas. The authors use the dice-based loss function, which is defined by (17), for assistance:

$$D = 1 - DSC \quad (17)$$

Furthermore, Fig. 9 demonstrates the segmentation of the PET scan values calculated with 90% accuracy, 91% sensitivity, and 93% dice. Where D is the delicate dice mishap, X is the ground truth, and Y is the predicted output.

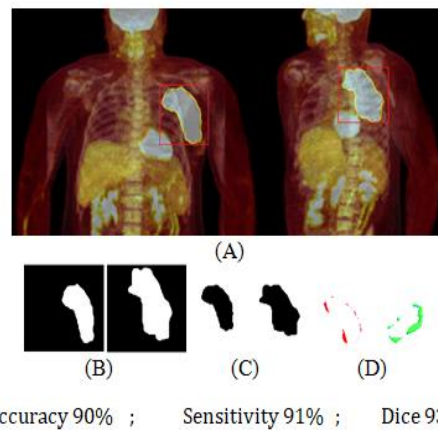


Fig. 9. Segmentation of tumors in 3D pet scan data viewed from several sides, (A) original images, (B) ROI, (C) segmentation with U-NET, (D) difference between ROI and U-NET.

The Crossing point over union is an assessment metric utilized to measure the degree of precision on a specific dataset [23]. The IoU is the essential metric to assess and demonstrate accuracy in the case of image Division. The zone of the ROI is not essentially rectangular. It can have any standard or unpredictable shape. Meaning the forecasts are division veils and not bounding boxes. In this manner, pixel-by-pixel examination is done here.

The representation of 3D medical with the ground truth of the medical staff is shown in figure (A) and (B) from Fig. 10.

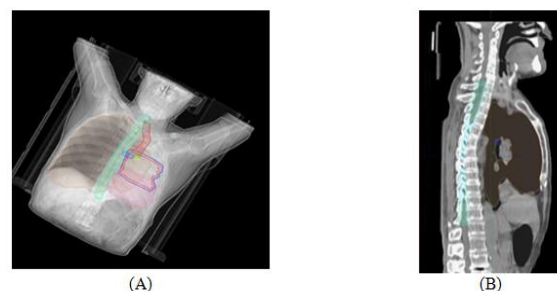


Fig. 10. 3D representation of the patient (A) and profile representation in (B).



After choosing the adequate representation from the DICOM, the second step is to upload the chosen DICOM Data of the three patients into the appropriate U-NET architecture the following 2D segmentation from the U-NET and the difference of the ROI showed in Fig. 11 that the three patients presented with 90%, 91% and 92% of accuracy, 90%, 93% and 94% of sensitivity and 91%, 92% and 95% of Dice.

The following Fig. 11 presents real cases attacked by lung cancer disease. The doctor then needs to apply margin of sub-chemical tissue to produce the clinical target volume (CTV). The margins are applied to the gross tumor volume (GTV), which is depicted in red, denotes the macroscopic, radiological measurable tumor that was selected from the appropriate software of the Eclipse contouring. Actually, it might be difficult to distinguish tumors from lung tissue in CT images. The algorithms that enable co-registration of diagnostic images with the principal simulation CT scan have been created in order to increase the accuracy of GTV identification. When comparing MRI to CT imaging for lung tumors, it reveals higher resolution and more soft tissue contrast. The clinical target volume (CTV) which is colored in orange is a second volume added to the GTV as a margin to cover nearby locations that must be targeted in order to cure disease that could be present at microscopic levels. Based on anatomical and ROI data obtained from cross-sectional imaging, the CTV is defined. Uncertainty in treating is accommodated by the geometrical software of the planned target volume (PTV) bounded with blue hue, it accounts for the daily random and systematic fluctuations in patient setup, additionally to the internal motion of the tumor during treatment (internal target volume (ITV) displayed in green). These variations may include shifts in the tumor's position and shape as a result of its regression or growth, bladder filling or rectal distension, as well as, unforeseen changes brought on by a change in the patient's position or the method used to set up the machine between each delivered fraction. As a result, the PTV is the suggested parameter to ensure that all areas of the CTV areas receive an acceptable dose of radiation.

When looking at the planning of the non-small cell lung carcinoma patient in the 3D, the software reconstructs the data in sagittal and coronal planes. That helps the doctors to plan the volumes in 3D by the contouring then the doctors use the lung window that is easier to visualize the extend of the volume tumor. Then the pitch that present the distance travelled in one 360° rotation in the CT Scan, remaining the breathing during treatment with the same parameters see (18) and (19).

After uploading the different parts of the slices from different representation the second step consists of choosing one of the best results that are the adequate representations, and to do the 3D image representation from the 2D and try to have the final 3D result of the best-case result with 92% of accuracy, 94% of sensitivity and 95% of dice, see Fig. 12.

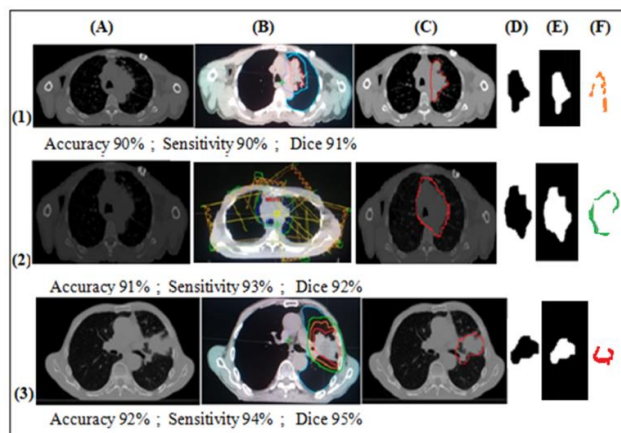


Fig. 11. Segmentation 3D of lungs seen from DICOM;(A) original image;(B) predicted 3D image by medical staff;(C) ground truth mask;(D) segmentation with U-net; (E)ROI;(F)difference between ROI and U-NET.

The results confirm the similarity between the extraction of the volume parameters and surface measured from the different slices (S1, S2, S3 and S4) with the ground truth (cm<sup>2</sup>) compared with medical staff estimation volume (cm<sup>3</sup>) see Table II:

TABLE II. VOLUME OF CANCER IN RELATION TO TOTAL LUNG VOLUME EXTRACTED WITH MEDICAL STAFF

N° Patient	Volume cancer (cm <sup>3</sup> )	Volume of the normal lung (cm <sup>3</sup> )	Volume two lungs (cm <sup>3</sup> )
1	541	2500	4459
2	540	1855	3170
3	112	927	1742

The result of the extracted ROI results from U-NET architecture with the choice of the third patient as best case result, see Table III and the following equation:

TABLE III. VOLUME OF THE LUNG CANCER EXTRACTED FROM THE U-NET ARCHITECTURE OF FIG. 11 BEST CASE OF THE THIRD PATIENT

	S1	S2	S3	S4
Surface (cm <sup>2</sup> )	31.737	54.088	15.945	9.40
Volume (cm <sup>3</sup> )		111.17		

$$CTV = GTV + the\ pitch \quad (18)$$

$$PTV = CTV + the\ pitch \quad (19)$$

After presenting the best case results of Tables II and III of the third patient the authors will choose the best slices from the parameters of accuracy, sensitivity and dice of the showed results in Table III and II and Fig. 11 and upload it into the U-NET architecture to finally obtain the 2D segmentation of the different slices and the 3D representation of the ROI segmentation of the best result communicated in Table I and compared with other authors that are demonstrated (see Fig. 12) and present the best accuracy 98.9%, sensitivity 97.99% and dice 97%, that explained the segmentation of 3D lungs seen from DICOM.

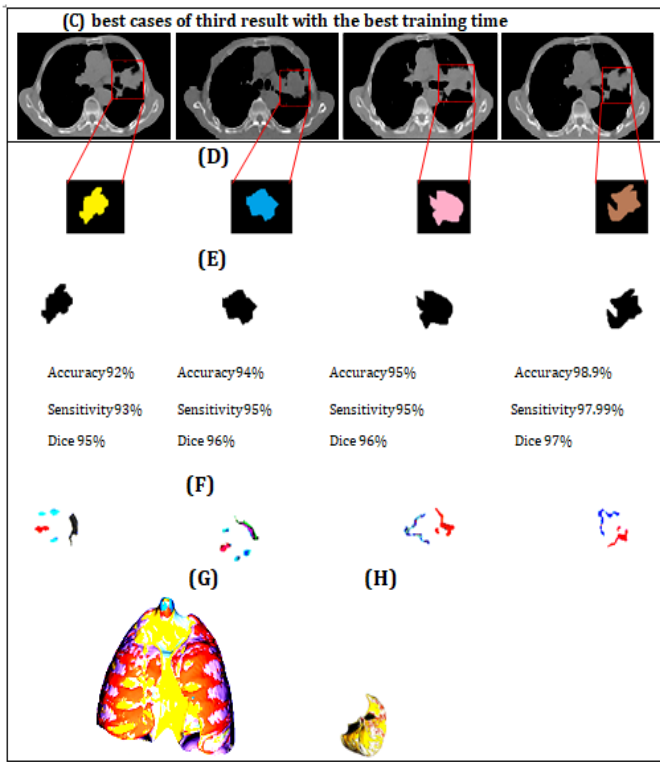


Fig. 12. Segmentation 3D of lungs seen from DICOM, (A) original image, (B) predicted 3D image by medical staff, (C) ROI with ground truth mask, (D) ROI, (E) segmentation with U-net, (F) concatenated 3D images between (E) and (D), (H) and (G) 3D lung segmentation.

Interestingly, in accordance with the 3D U-NET architecture's empirical offshoots seen in Fig. 12, the recommended procedure is more accurate than the conventional framework in terms of delineation performance, as evidenced by the segmentation's sensitivity [24] for further data, seen in Table I.

### C. Generating the Luminosity Picture of the Data

Images captured using specular microscopy typically has low contrast and non-uniform illumination throughout. Here, we want to determine whether picture improvement for CNN would be beneficial. Standardizing the fourth result of the output images in Fig. 12 is also a typical procedure in neural networks. We suggested using contrast constrained adaptive histogram equalization with a kernel of  $(96 \times 128)$  to improve local image contrast. Where  $In$  present the norm of the image  $I(X, X')$  and this kernel size roughly correspond to the size of an average cell see 20.

$$In(X, X') = \frac{I(X, X') - \min(I(X, X'))}{\max(I(X, X')) - \min(I(X, X'))} \quad (20)$$

The advantages of local contrast enhancement would be diminished by a kernel that is too large, while noise would be excessively amplified by a kernel that is smaller than half of a cell. We found that intensity normalization significantly improved performance see Fig. 13.

Interestingly, in accordance with the 3D U-NET architecture's empirical offshoots, the recommended procedure is more accurate than the conventional framework in terms of

delineation performance, as evidenced by the segmentation's sensitivity [24]. For further data, see Table I. Furthermore, the split sensitivity treatment in the database presented in Fig. 13 seems to be more important compared to any other recommended approach. This indicates that, in comparison to the various ways that have been exhibited, the addition of 3D U-NET can help networks achieve the highest execution of the concept of three - dimensional segment.

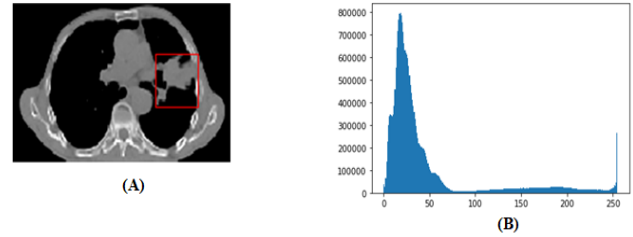


Fig. 13. Redistribution of the histogram of the result of (A) by intensities shifts (B) of the data.

Furthermore, the split sensitivity treatment in the database presented in Fig. 13 seems to be more important compared to any other recommended approach. This indicates that, in comparison to the various ways that have been exhibited, the addition of 3D U-NET can help networks achieve the highest execution of the concept of three - dimensional segment.

This paper relates the outputs of the consecutive frames depicted in Section 3 to evaluate the allocation grey level approaches in the histogram and its establishment. The first two items featured in the original imagery on which the juxtaposition was done may be clearly distinguished [25]. The other two photos display the intensity value adjustment's dispersion in relation to the original imagery. Variance is utilized as a criterion among the gray scale images' cohesiveness [26] that are formed via numerous 3D imagery of  $(512 \times 512)$  pixels, once data experimentation has been authenticated. To enable the clinician to fine-tune his diagnosis, the objective is to segment the specific area of interest the (ROI) an estimate  $(96 \times 128)$  contoured by the medical staff. Accordingly, the identification must be exact around the subject of interest and must not be hampered by imaging interference (such as patient movement or perspiration).

The consequence allows for a degree of robustness to variations in average luminance by treating the histogram as a compactness of likelihood (probability and impact of a grey scale similar level to all the pixels).

The progress of the diagram demonstrates that the selected assumption may be true since the concluding the artifact setting that nearly equal to Gaussian. These values were as opposed to those created since the epochs by trying to minimize the variance and by reducing the fluctuation threshold, where the disparity of the Gaussian function is predicted in every incarnation of the dataset.

The statistical likelihood  $p$  of the intensity of the histogram distribution, together with its mean  $\mu$  and the variance  $\sigma^2$  shown in (21):



$$p = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (21)$$

The predicted linear growth in the histograms results in a broader range of gray levels for the main image. As seen by the outcomes in Fig. 13, the performance of the histogram segmentation in PETSCAN and CT SCAN data presented in 3D medical imaging and proved with the results of the pixels intensity are determinate; that can prove that the implementation on the U-NET architecture is more sufficient compared to other literature which concentrates on one study. This contribution opens horizon to data scientists to develop their research with the cooperation of medical staff to obtain the best result in little time and reduce the exposition on x-ray that can have a bad effect especially on the patient.

#### IV. DISCUSSION

The new proposal incorporates a modern sequence segmented technique on the U-NET Algorithm, compared to the result of other data performs the contouring and the final vision of medical staff that the result of the research was achieved and applied with different data from different service unlike other literature applied to a single and unspecified one. This study is the first to discern the importance of deep science in the medical field, especially in 3D image detection. This way offers the chance to develop other perspectives in the near future.

First of all, the 3D segmentation predicting necessitates significantly more complicated computational resources, which in turn affects a model's capacity to execute the training with huge datasets [27]. According to certain research, 2D U-Net performed more accurately, consumed less memory, and required less training time than 3D U-Net. Instead of a 3D segmentation model, several 2D segmentation models targeting the 3D segmentation in U-NET were created. By combining the 2D segmentation model with modern pre- and post-processing image evaluation techniques, researchers were able to build the U-NET, a completely automated end-to-end 3D segmentation network. So, compared to other systems, U-NET provided us with a better performance using the real data extracted from Salah Azaiez Institute.

Secondly, considering its small morphology and constrained location decisions, CT scan is considerably harder for segmentation effectively than other work structures that are frequently segmented manually. The difficult task of segmenting is resolved in this study by the U-NET approach and enhanced image analysis techniques. The comparative examination demonstrates the ability to segment skills of the U-NET. The research's findings and its comparison with previous studies have highlighted the U-NET advantages. As far as the authors are aware, the automatic end-to-end 3D segmentation findings are state-of-the-art [28]. The current study showed that the U-NET technique has considerable potential for creating an automatic and precise segmentation tool for extremely difficult medical imaging segmentation challenges [29].

As 3D U-NET architecture can still be improved, but the authors need an innovative method to solve a difficult

segmentation issue like the subject matter and incompatibility problem.

#### V. CONCLUSION

The suggested approach entails developing a new scientific perspective for the biomedical industry through networking, which improves credible steps in radiation healthcare, notably for tumor segment diagnostics.

The acquired results show that these methodologies can accurately divide an image into homogenous parts and show the potential of the testing, which provides a foundation for the creation of biological data science images. The cooperative work between medical fields and scientists opens the horizon for many points, especially the hardness of the localization of the ROI and the validity of the purpose which demands such time and effort from each contributor. This work was established to perform the imaging system in the medical field of the institute of Salah Azaiez.

For further investigation the requirement for more effective ROI identification while working with various CT scan datasets. Using more sophisticated models, such attention modeling or sequential modeling using GAN for future work, the deep learning networks could be expanded to include contextual data, to overcome the paucity of human-annotated data, a semi-supervised technique involving human and machine collaboration is needed rather than supervised learning.

#### ACKNOWLEDGMENT

The technical staff provides us with the study realized in collaboration with the institute of Salah Azaiez which offers us the required materials and has a significant impact on the success of this work.

#### AUTHORS' CONTRIBUTIONS

ELLOUMI Nabila wrote the paper, slim ben CHAABANE and Hassen SEDDIK contributed to this research with technical and academic writing assistance. The final paper was read and endorsed by all writers.

#### AVAILABILITY OF DATA AND MATERIALS

The DICOM images utilized in the research described in this publication were received from the Institute of Salah Azaiez of Cancerology in Tunisia and are publicly accessible for use in the public's research. The District Referral Hospital will use the tool, which is still in the process of being tested.

#### FINANCIAL SUPPORT AND SPONSORSHIP

Not Applicable.

#### CONFLICTS OF INTEREST

Not Applicable.

#### ETHICAL APPROVAL AND CONSENT TO PARTICIPATE

Since this was a registration-only study, the ethics reviews board accepted it for release without requesting informed consent from research participants.

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# Prediction of Breast Cancer using Traditional and Ensemble Technique: A Machine Learning Approach

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**Abstract**—Breast cancer is a prevalent and potentially life-threatening disease that affects millions of individuals worldwide. Early detection plays a crucial role in improving patient outcomes and increasing the chances of survival. In recent years, machine learning (ML) techniques have gained significant attention in the field of breast cancer detection and diagnosis due to their ability to analyze large and complex datasets, extract meaningful patterns, and facilitate accurate classification. This research focuses on leveraging ML algorithms and models to enhance breast cancer detection and provide more reliable diagnostic results in the real world. Two datasets from Kaggle have been used in this study and Decision tree (DT), Random Forest (RF), Logistic Regression (LR), K-Nearest Classifier (KNN) etc. are applied to identify potential breast cancer cases. On the first dataset, A, the test's accuracy using Logistic Regression, SVM, and Grid SearchCV was 95.614%, however in dataset B, the accuracy of Logistic Regression and Decision Tree increased to 99.270%. The accuracy of Boosting Decision Tree was 99.270% when compared to other algorithms. To defend the performances, various ensemble models are used. To assign the optimal parameters to each classifier, a hyper-parameter tweaking method is used. The experimental study examined the findings of recent studies and discovered that LRBO performed best, with the highest level of accuracy for predicting breast cancer being 95.614%.

**Keywords**—Breast cancer; prediction; machine learning algorithms; ensemble models; voting; stacking

## I. INTRODUCTION

Multiple tissues are being harmed or developing out of control, which is known as cancer, since sickness is the worst aspect of our daily lives. Breast cancer is a type of cancer that develops when unregulated tissue or damaged tissue does so [1]. This patient's prevalence is significantly rising. However, finding or recognizing the injured region at the time of diagnosis is the key issue. Machine learning may be the most effective component of a crucial factor in predicting the presence of breast cancer from responsive health datasets by examining various variables and patient diagnosis records. We looked at the patient's diagnosis papers for our work and discovered certain key factors to pinpoint the condition. The dataset dealt with the size and structure of a woman's bodily tissues as well as determining whether or not she had breast cancer [7]. In order to employ machine learning algorithms to recognize the cancer tissue in the body, several different

researchers have worked together. However, their method and accuracy were not appropriate nor smooth for predicting breast cancer [12]. We suggest our method to increase the accuracy rate of breast cancer prediction in a woman's body. There are two different kinds of machine learning techniques. One of them is under supervision, while the other is not. Working with labeled data, supervised learning creates outputs from inputs based on examples of input-output pairings. The dataset's training data is used as the working data. Unsupervised learning works with the unlabeled data and creates the model to work with its patterns and information which was not detected previously. Unsupervised learning uses unlabeled data to build models that can make use of previously undetected patterns and information.

## II. BACKGROUND LITERATURE

Breast cancer is the most common and rapidly developing illness in the world. Breast cancer is more commonly detected in women. Breast cancer can be controlled if it is detected early. A hybrid approach-based methodology that uses machine learning has been presented. This method was put into practice utilizing MRMR feature selection using four classifiers to determine the optimal outcomes. The four classifiers SVM, Naive Bayes, Function tree, and End Meta were utilized by the author, and they were all compared. SVM was discovered to be an effective classifier. to ascertain better outcomes [1]. To achieve the most accurate result machine learning is the most reliable technique. We have used a few machine learning classifiers to categorize breast cancer, and they are appropriate for the job we are proposing. To execute decision models, machine learning algorithms that are based on decision tree models are known as "tree structures" [2]. similarly proposed a comparison between Random Forest, Naïve Bayes, Support Vector Machines (SVM), and K-Nearest Neighbors (K-NN) and they found the SVM is the best classifier with an accuracy of 97.9% compared with K-NN, RF, and NB, they are based on Multilayer perceptron with 5 layers and 10 times cross-validation using MLP. The author F. M. Javed Mehedi Shamrat et al. [3] focused on the enhancement of the accuracy value using the Wisconsin Breast Cancer Diagnostic Dataset (WBCD) by applying an ML-based system for the early prediction of breast cancer disease. Six supervised classification techniques are used which are: SVM, NB, KNN, RF, DT, and LR. According to the analysis of breast cancer prediction performance, SVM

had the highest performance and the highest classification accuracy (97.07%). While NB and RF have attained the second-highest prediction accuracy. Mumine Kaya Keles [4] predicted and detected breast cancer early where Random Forest outperformed all the other algorithms giving an average accuracy of 92.2 percent. K.Anastraj et al. [5] depicts that the support vector machine had given better results (94%). In the experimental results [6], BayesNet was the best classification method with an accuracy rate of 97.13%. Ch. Shravya et al. [7] provided relative study on the implementation of models using Logistic Regression, Support Vector Machine (SVM) and K Nearest Neighbor (KNN) on the dataset taken from the UCI Repository. With respect to the results of accuracy, precision, sensitivity, specificity and False Positive Rate the efficiency of each algorithm is measured and compared and focused in the advancement of predictive models to achieve good accuracy in predicting valid disease outcomes using supervised machine learning methods. The results analysis shows that the combination of multidimensional data with various feature selection, classification, and dimensionality reduction techniques can offer advantageous tools for inference in this field. This study has shown that SVM is the best accuracy of 92.7%. The authors Ertel Merouane et al. in [8] provide a cloud-based Extreme Learning Machine (ELM) architecture for the classification of breast cancer. Cloud computing increases categorization accuracy and provides access around the clock. When compared to standalone systems, the ELM model executed faster and with higher accuracy when it was put on the Amazon EC2 cloud platform. Future additions may improve the framework's functionality in image-processing applications like medical imaging and character recognition [9]. Probability is constantly between 0 (never happens) and 1 (occurs). In the case of binary classification, using our COVID-19 example, the likelihood of testing positive and not testing positive will total up to the logistic function or sigmoid function to compute probability in logistic regression. The logistic function is a straightforward S-shaped curve that converts input into a value between 0 and 1 [17].

### III. RESEARCH METHODOLOGY

The Dataset sourced from Kaggle [9] [10].The size of the dataset A is 32x569 and B is 10x683. The frequency of breast cancer is categorized in the diagnostic and Class column. Malignant (M) and Beginning (B) conditions are used to categorize patients. There, 0 represents "B" and 1 represents "M." 212 individuals were at the malignant stage, leaving 357 patients in the initial stage in dataset A. Another dataset B had 239 patients in the malignant stage and 444 individuals in the initial stage. Fig. 1 for dataset A and Fig. 2 for dataset B below display the ratio. The dataset was split into a testing and training set. We've chosen 20% for the exam portion and another 80% for the learning portion. The dataset contains nominal values and there were no missing or incorrect values. A comprehensive explanation of the dataset with its range is displayed in Tables I and II.

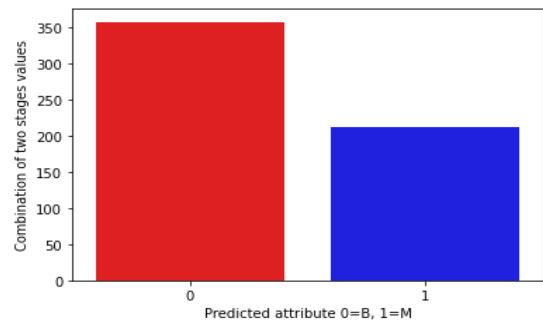


Fig. 1. Number of target values dataset A.

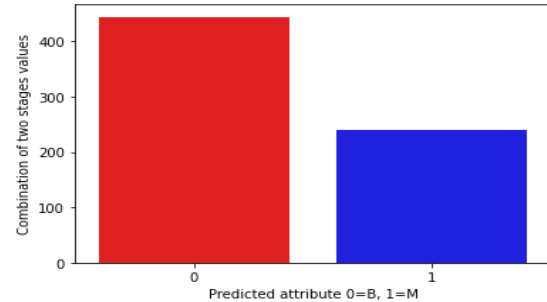


Fig. 2. Number of target values dataset B.

TABLE I. DETAILS OF THE DATASET A

Attributes	Description	Value Range	Types of values
Diagnosis	Malignant or Begin	0 and 1	Integer
Radius_mean	Radius of Lobes	6.98 to 28.1	Float
Texture_mean	Mean of Surface Texture	9.71 to 39.28	Float
Perimeter_mean	Outer Perimeter of Lobes	43.8 to 188.5	Float
Area_mean	Mean Area of Lobes	143.5 to 2501	Float
Smoothness_mean	Mean of Smoothness Levels	0.05 to 0.163	Float
Compactness_mean	Mean of Compactness	0.02 to 0.345	Float
Concavity_mean	Mean of Concavity	0 to 0.426	Float
Concave points_mean	Mean of Concave Points	0 to 0.201	Float
Symmetry_mean	Mean of Symmetry	0.11 to 0.304	Float
Fractal_dimension_mean	Mean of Fractal Dimension	0.05 to 0.1	Float
Radius_se	SE of Radius	0.11 to 2.87	Float
Texture_mean	SE of Texture	0.36 to 4.88	Float
Perimeter_se	Perimeter of SE	0.76 to 22	Float
Area_se	Area of SE	6.8 to 542	Float
Smoothness_se	SE of Smoothness	0 to 0.03	Float
Compactness_se	SE of Compactness	0 to 0.14	Float
Concavity_se	SE of Concavity	0 to 0.4	Float

TABLE II. DETAILS OF THE DATASET B

Attributes	Description	Value Range	Types of values
Clump Thickness	Thickness of Clump	1 to 10	Integer
Uniformity of Cell Size	Cell size	1 to 10	Integer
Uniformity of Cell Shape	Cell shape	1 to 10	Integer
Marginal Adhesion	Adhesion Marginal value	1 to 10	Integer
Single Epithelial Cell Size	Cell size	1 to 10	Integer
Bare Nuclei	Number of Nuclei	1 to 10	Integer
Bland Chromatin	Number of Bland Chromatin	1 to 10	Integer
Normal Nucleoli	Number of Normal Nucleoli	1 to 10	Integer
Mitoses	Number of Mitoses	1 to 10	Integer
Class	Malignant or Begin	0 and 1	Integer

### A. Statistical Analysis

Statistical analysis is one of the most crucial segments of any research. In this work, we employed four distinct kinds of algorithms in this work, including Random Forest (RF), Logistic Regression (LR), Gradient Boosting (GB), K-Nearest Classifier (KNN), Adaboost Classifier (ABC), Decision Tree (DT), GridSearch CV (GS), XGBoost Classifier (XGB), Gaussian Naïve Bayes (GNB), and Support Vector Classifier (SVC). Logistic Regression, Support Vector Classifier and Grid SearchCV was 95.614% accuracy for dataset A. Logistic Regression and Decision Tree was 99.270% accuracy for dataset B. Following the use of bagging, boosting, stacking and voting algorithms. Hyperparameter tweaking and 10-fold cross-validation have both been employed.

### B. Proposed Methodology

The dataset for the system's training and testing was initially introduced. Next, we used data preparation techniques such as the Standard Scaler Transform. Categorical data conversion to numeric data. We utilized 80% for the training portion and 20% for the testing portion. After that we implemented algorithms and assessed the outcomes. Then, to get the highest forecast accuracy, we employed ensemble methods. Bagging, Boosting, Stacking and Voting are ensemble algorithms. The outcomes of the ensemble algorithms that were used were then assessed. Then we used Hyper Parameter Tuning to verify the outcome. Then, using outcome analysis, we assessed the models that had been put into practice. Fig. 3 displays the recommended model technique.

### C. Implementation Requirements

A number of filtering techniques is used to clean the dataset. Then, data preprocessing techniques like Standard Scaler Transform were used. We utilized 80% for the training portion and 20% for the testing portion. After that, we implemented algorithms and assessed the outcomes. Then, in order to get the highest forecast accuracy, we employed ensemble methods. Bagging, Boosting, Stacking and Voting are the ensemble algorithms. The outcomes of the ensemble algorithms that were used were then assessed. Then we used

Hyper Parameter Tuning to verify the outcome. Then, using outcome analysis, we assessed the models that had been put into practice. After that we need to execute the data analysis part to start the learning process. Later, to execute model learning and fit the method of predictions. Finally, we need to bagging, boosting, stacking and voting the models to get the best accuracy. Then we can decide the best model to implement considering the best accuracy, precision, recall, and F-1 score. The learning process must then be initiated by carrying out the data analysis step. Next, we must put model learning into practice and fit the predictions approach. To acquire the best accuracy, we must then vote, boost, and bag the models. The best model may then be chosen for implementation based on accuracy, precision, recall, and F-1 score.

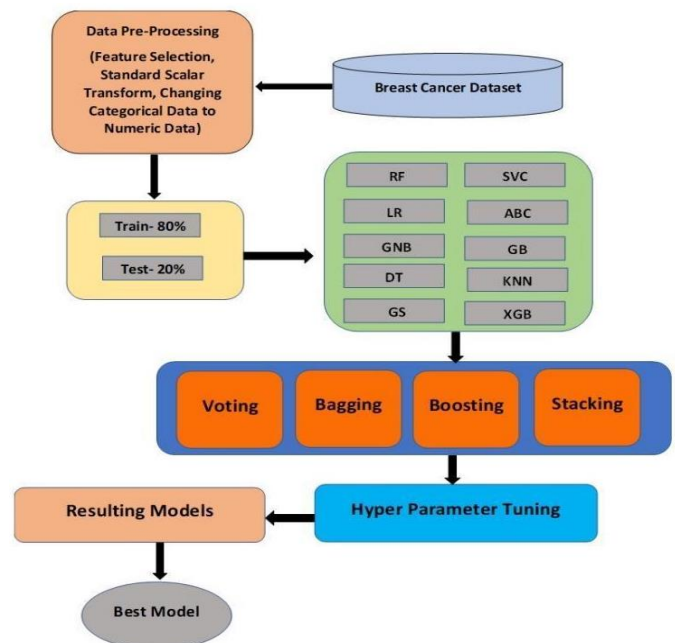


Fig. 3. Methodology of breast cancer prediction.

A correlation subplot has been used to underlying the relationships between two variables or how one variable changes as a result of a change in another. The greater the dependency between variables, the more likely it is that one variable may be successfully predicted from another. It suggests a greater understanding of the dataset and facilitates our capacity to pinpoint the important variables [11].

## IV. EXPERIMENTAL RESULTS AND ANALYSIS

### A. Classifier Algorithms

We have implemented some different classifiers named Random Forest (RF), Logistic Regression (LR), Gradient Boosting (GB), K-Nearest Classifier (KNN), Adaboost Classifier (ABC), Decision Tree (DT), GridSearch CV (GS), XGBoost Classifier (XGB), Gaussian Naïve Bayes (GNB), Support Vector Classifier (SVC) algorithms [13].

1) *Adaboost classifier*: AdaBoost is a boosting classifier that joins a number of ineffective classifiers to create a powerful classifier. 1000 samples are used by ABC to forecast



TA. Weights that differ for classifiers and samples are fixed by ABC [22]. This makes it challenging for classifiers to concentrate on the end outcome. The final formula to achieve TA is,

$$H_k(P) = l - (\sum_{k=1}^k a_k h_k(P)) \dots \dots \dots (1)$$

Here, N=frequency of training data, k = total number of weak classifiers combined to use, hk = output of weak classifier (lower limit 1 to upper limit k), ak = weight of classifier. The notion is depicted in Fig. 4.

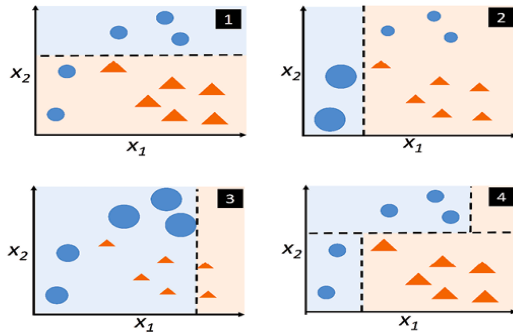


Fig. 4. Adaboost classifier.

2) *Gaussian NB Classifier (GNB)*: Gaussian NB Classifier calculates the likelihood of an event occurring given the chance of another event occurring as expressed. Here, every pair of features being categorized is independent of each other (equation 3). The concept is shown below Fig. 5.

$$P(B) = \frac{P(A)P(A)}{P(B)} \dots \dots \dots (2)$$

For each feature in Gaussian NB, the continuous value is assumed to have a Gaussian distribution. The resulting histogram looks like bell curve, with all points being equal distance from the curve's center. The conditional probability is provided by equation (4) if the feature likelihood is Gaussian.

$$P(y) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x_i - \mu_y)^2}{2\pi\sigma^2}\right) \dots \dots \dots (3)$$

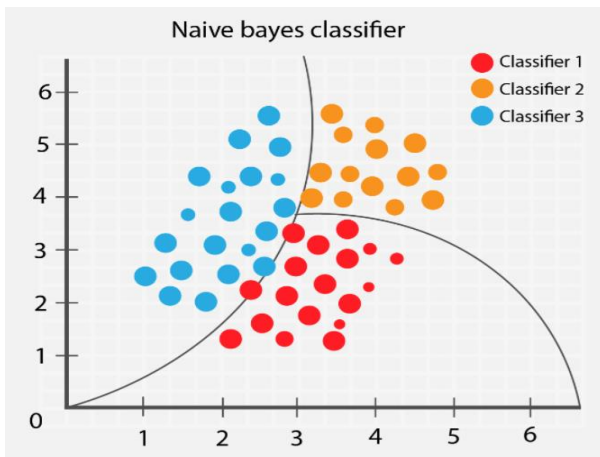


Fig. 5. Gaussian NB classifier.

3) *K-Nearest Classifier (KNN)*: K-Nearest Neighbors (KNN) calculates the Euclidean distance between new (x1, x2) and existing (y1, y2) data.

$$\text{Euclidean Distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (4)$$

The concept is shown in below Fig. 6.

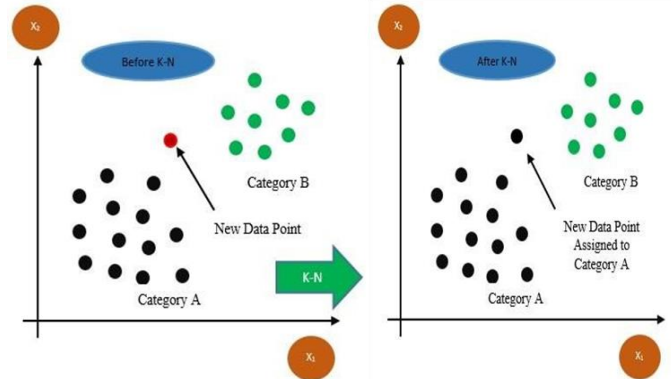


Fig. 6. K-Nearest classifier.

4) *Grid Search CV (GS)*: Grid Search CV is the process of performing hyperparameter tuning in order to determine the optimal values for a given model. The performance of a model significantly depends on the value of hyperparameters. The concept is shown below in Fig. 7.

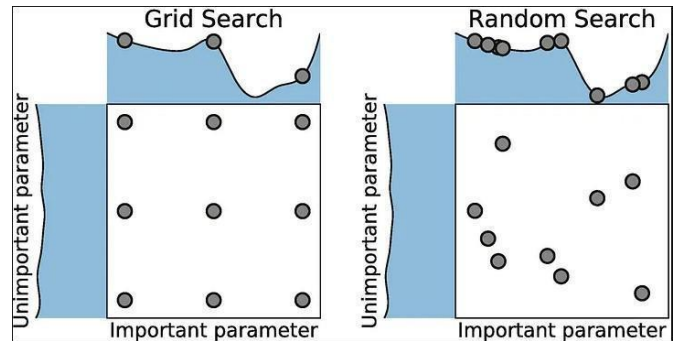


Fig. 7. Grid search CV classifier.

5) *Decision Tree (DT)*: Decision trees categorize occurrences by branching them out from a central node to a collection of "leaf" nodes that offer the categorization. To assign a category to an instance, we look at the attribute pointed out by the root node of the tree and then follow the branch of the tree that corresponds to the attribute's value. It is usual practice to calculate two additional metrics to identify the "Best Attribute," "Entropy," as shown in (2), and "Information Gain," as shown in (3) [14]. The "best characteristic" is the trait that provides the most valuable data. Entropy measures dataset homogeneity, whereas information gain measures the rate of change in entropy of attributes. The concept is shown below Fig. 8.

$$E(D) = -P(\text{positive}) \log_2 P(\text{positive}) - P(\text{negative}) \log_2 P(\text{negative}) \quad (5)$$



$$Gain (Attribute X) = Entropy (decision Attribute Y) - Entropy (X, Y) \quad (6)$$

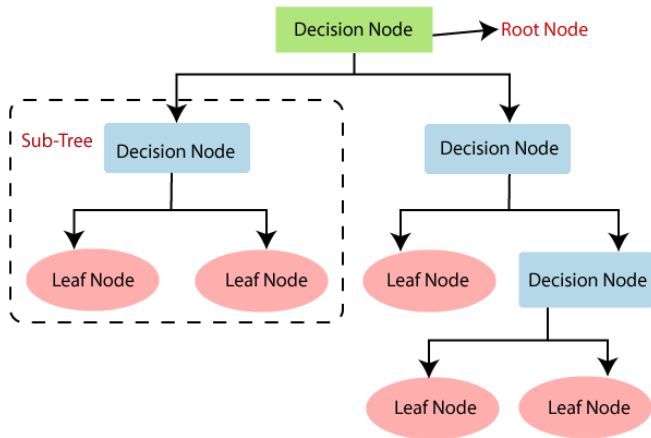


Fig. 8. Decision tree.

6) *Logistic Regression (LR)*: A classifier approach based on machine learning called logistic regression (LR) contains two categories for the class label: yes or no, like a binary (0/1) scale. Although it permits the combined value of continuous variables and discrete predictors, logistic regression is appropriate for discrete variables [16]. The idea is depicted in Fig. 9 below. Logistic regression adopts the supervised machine learning approach. The fundamental equation is shown below [17].

$$h(x) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X)}} \quad (7)$$

' $h\Theta(x)$ ' is the output of the logistic function, where  $0 \leq h\Theta(x) \leq 1$ .

' $\beta_1$ ' is the slope.

' $\beta_0$ ' is the y-intercept.

' $X$ ' is the independent variable.

$(\beta_0 + \beta_1 X)$  - derived from the equation of a line  $Y$  (predicted) =  $(\beta_0 + \beta_1 X)$  + Error.

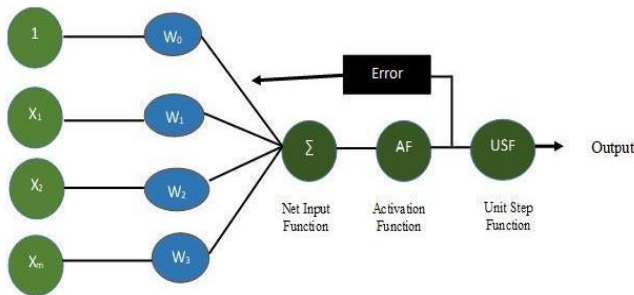


Fig. 9. Logistic regression classifier.

7) *Random Forest (RF)*: Different Decision Tree algorithms make up the Machine Learning (ML) based classifier ensemble approach known as Random Forest (RF) [18]. In order to provide an ideal decision model with more accuracy than the single decision tree model, RF builds several decision trees while the algorithm is being trained. The

notion is depicted in Fig. 10 below. All decision tree methods are calculated using the Random Forest algorithm [20].

$$j = \frac{1}{B} + \sum_{b=1}^B fb(X') \quad (8)$$

Concerning  $X = \{x_1, x_2, x_3, \dots, x_n\}$  with respect to  $Y = \{y_1, y_2, y_3, \dots, y_n\}$  with the lower to upper limit is 1 to B.

Sample  $x'$  = mean of the sum of the prediction  $\sum_{b=1}^B (X')$  for every summation.

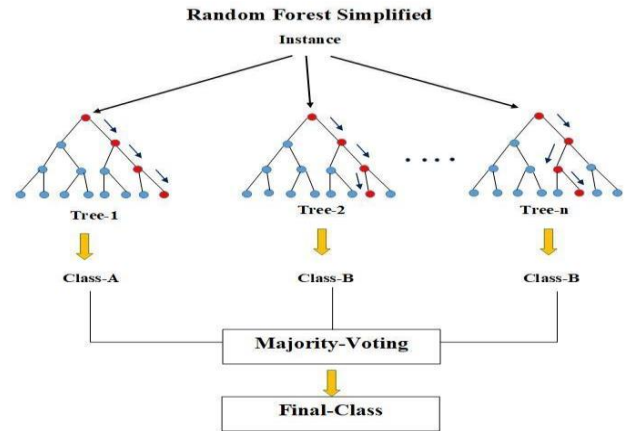


Fig. 10. Random forest classifier.

8) *Gradient Boosting (GB)*: The loss function is the main component of the boosting method known as Gradient Boosting (GB). The notion is depicted in Fig. 11 below. It works by combining and optimizing weak learners to reduce a model's loss function. To improve an algorithm's performance, over fitting is eliminated [7]. Here  $f_i(x)$  = loss function with correlated negative gradients ( $-\rho_i \times gm(X)$ ),  $m$  = number of iterations.

Feature increment ( $i$ ) = 1, 2,3, ... . . . ,  $m$ . Therefore, the optimal function  $F(X)$  after  $m$ -th iteration is shown below.

$$F(X) = \sum_{i=0}^m f_i(x) \quad (9)$$

Here,  $gm$  = the path of loss function's fast decreasing  $F(X) = F_{n-1}(X)$  the decision tree's target is to solve the mistakes by previous learners [21].

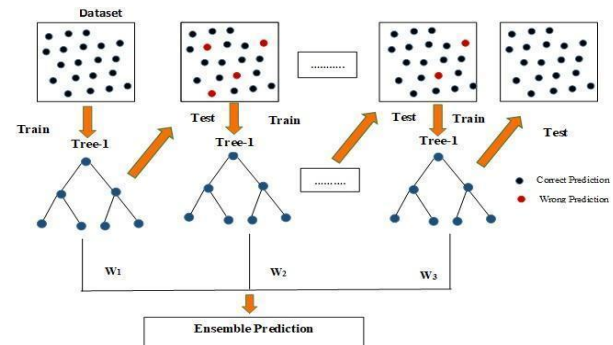


Fig. 11. Gradient boosting classifier.

9) *Support Vector Classifier(SVC)*: The Support Vector Classifier (SVC) approach aims to discover a line, or decision boundary, that divides the space into classes in the most optimum way possible across all n dimensions in order to efficiently categorize new data points [15]. Fig. 12 is showing the working process of Support Vector Classifier (SVC).

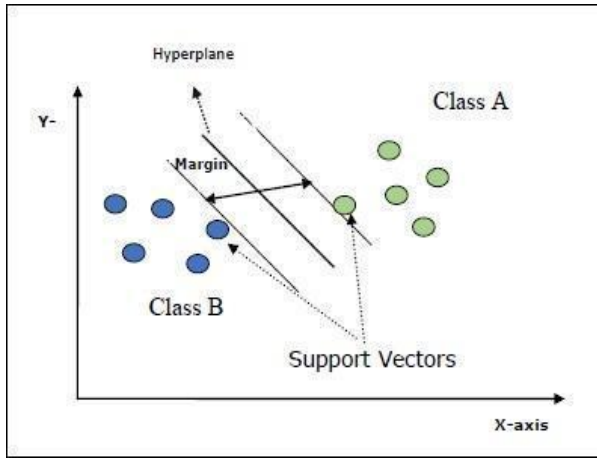


Fig. 12. SVC classifier.

### B. Ensemble Methods of Machine Learning

The term "ensemble approach" refers to the use of several classifiers to turn weak classifiers into strong classifiers by producing the greatest accuracy and effectiveness. It was used in our investigation due to variable handling, bias, and uncertainty since it lowers variances, merges predictions from several models, and narrows the prediction spread [23]. In our investigation, four ensemble approaches were employed. Bagging, Boosting, Stacking and voting ensemble modeling was employed.

1) *Bagging*: Bagging describes the decrease of variance, diminishing handling, and missing variables. The Bagging model's classification formula is displayed below [24].

Here  $f'(x)$  is the average of  $f_i(x)$  for  $i = 1, 2, 3, \dots, T$ .

$$f'(x) = \text{sign}(\sum_{i=1}^T f_i(x)) \quad (10)$$

2) *Boosting*: The term "boosting" indicates a method that uses an weighted average to operate with several algorithms and create the loss functions [25]. In our study, the training and testing phase of the hybrid model construction uses the boosting method. The formula is displayed below.

Here,  $Y_t = 1/2 - \epsilon_t$  (how much  $f_t$  is on the weighted sample).

$$\frac{1}{n} \sum_{i=1}^n I(y_j g(x_i) < 0) \leq \prod_{t=1}^T \sqrt{1 - 4Y_t^2} \quad (11)$$

3) *Stacking*: Stacking is used to explore many models for the same problem. The idea is that we may approach a learning issue with many models that can learn a piece of the problem but not altogether. Each learnt model can have its own intermediate prediction, allowing for the creation of several distinct learners. As a result, the intermediate prediction may be used to train a second model that will

eventually learn the same goal [19]. Stacking outperforms any single model in terms of efficiency. It can offer a representation that uses Logistic regression as a joiner method to blend all conventional classifiers into a final prediction using a joiner technique.

4) *Voting*: Voting classifiers are a group of classifiers that are used to forecast the class with the best majority of votes. It implies that the model trains using many models to anticipate outcomes by aggregating the results of voting. The notion is depicted in Fig 16 below. The formula we employed is shown below [26] [27].

Here,  $w_j$  = weight that can be assigned to the  $j^{th}$  classifier.

$$y' = \text{argmax} \sum_{j=1}^m w_j p_{ij} \quad (12)$$

### C. Experimental Results and Analysis

First of all, we will clarify the judicial system of our proposed model. We have considered the accuracy, precision, recall and F-1 score shown in Fig. 13.

1) *Accuracy*: It speaks about the proportion of testing data predictions that were correct. Whereas accessibility of the measures with actual measurements is performed by accuracy. It is founded on a solitary variable. Accuracy only addresses deliberate mistakes. It is one of the most straightforward measurement methods for any model. We must strive to make our models as accurate as possible.

$$\text{Accuracy} = \frac{\text{TruePositive} + \text{TrueNegative}}{\text{TruePositive} + \text{FalsePositive} + \text{TrueNegative} + \text{FalseNegative}}$$

2) *Precision*: It speaks about the percentage of positively expected observations that really occurred. The genuine true portion of all the cases where they correctly predicted true are identified by precision. For any type of model, a high recall might also be highly deceptive.

$$\text{Precision} = \frac{\text{TruePositive}}{\text{TruePositive} + \text{FalsePositive}}$$

3) *Recall*: It speaks about the percentage of positively anticipated observations from a model. High accuracy, though, might occasionally be deceptive. Normally Recall determines the proportion of expected positives to all positive labels.

$$\text{Recall} = \frac{\text{TruePositive}}{\text{TruePositive} + \text{FalseNegative}}$$

4) *F-1 Score*: It speaks of precision and recall harmonic means. Both the recall and precision ratios are relevant. If the harmonic mean is smaller, the model is probably not very good.

$$F - 1 \text{ Score} = 2 * \frac{\text{Recall} * \text{Precision}}{\text{Recall} + \text{Precision}}$$

At first, we calculated the missing or incorrect values and filtered these from our dataset A and B[28]. The Random Forest (RF), Logistic Regression (LR), Gradient Boosting (GB), K-Nearest Classifier (KNN), Adaboost Classifier

(ABC), Decision Tree (DT), GridSearch CV (GS), XGBoost Classifier (XGB), Gaussian Naïve Bayes (GNB), Support Vector Classifier (SVC) algorithms applied and their performance are measured. We have measured Confusion matrices Accuracy, Precision, Recall and F-1 Score for our proposed algorithms. We have evaluated Bagging, Boosting, Stacking and voting ensemble techniques for dataset A and B.

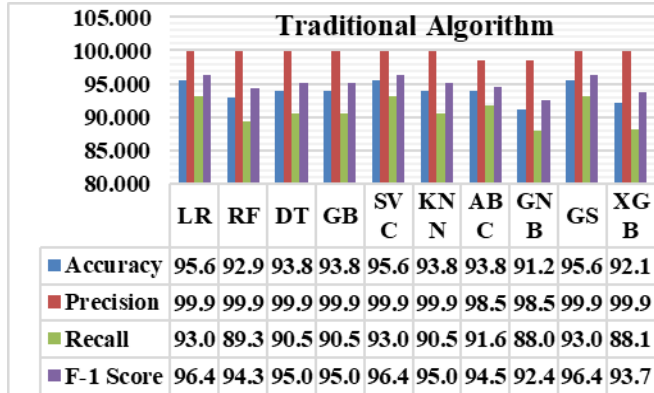


Fig. 13. Experimental results of classifiers for dataset A.

Firstly, we considered the performances of algorithmic classifiers, the best accuracy obtained at 95.614% using Logistic Regression (LR), Support Vector Classifier (SVC), and Grid SearchCV (GS). The best precision score was obtained from Random Forest (RF), Logistic Regression (LR), Gradient Boosting (GB), K-Nearest Classifier (KNN), Decision Tree (DT), GridSearch CV (GS) and XGBoost Classifier (XGB) about 99.99%. The best recall score was obtained from Logistic Regression (LR) and Support Vector Classifier (SVC) with 93.055%. The best F-1 score was obtained at 96.402% from GridSearch CV (GS), Logistic Regression (LR) and Support Vector Classifier (SVC). The visualization is shown in Fig. 14.

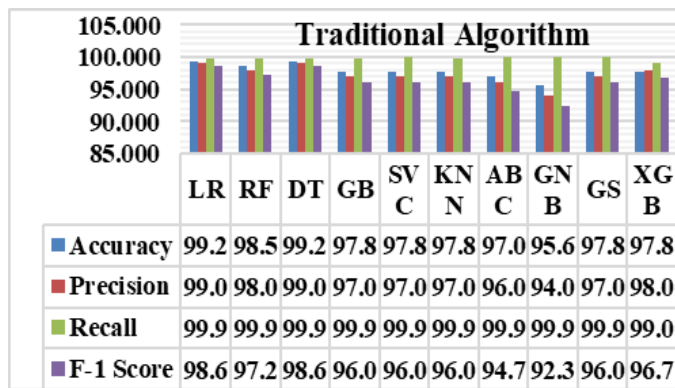


Fig. 14. Experimental results of classifiers for dataset B.

We considered the performances of algorithmic classifiers, the best accuracy obtained at 99.270% using Logistic Regression (LR) and Decision Tree (DT). The best precision score was obtained from Logistic Regression (LR) and Decision Tree (DT) about 99.00%. The best recall score was obtained from Adaboost Classifier (ABC), GridSearch CV (GS), Gaussian Naïve Bayes (GNB) and Support Vector Classifier (SVC) with 99.99%. The best F-1 score was

obtained at 96.402% from Logistic Regression (LR) and Decision Tree (DT).

Fig. 15 showed that Decision Tree (DT) had acquired the best score of 99.99%. But GridSearch CV (GS), XGBoost Classifier (XGB) and Support Vector Classifier (SVC) had acquired 99.89%. Hence according to the above analysis as well as the detailed results with graphical representation, Decision Tree (DT) can be stamped as the best algorithmic classifier.

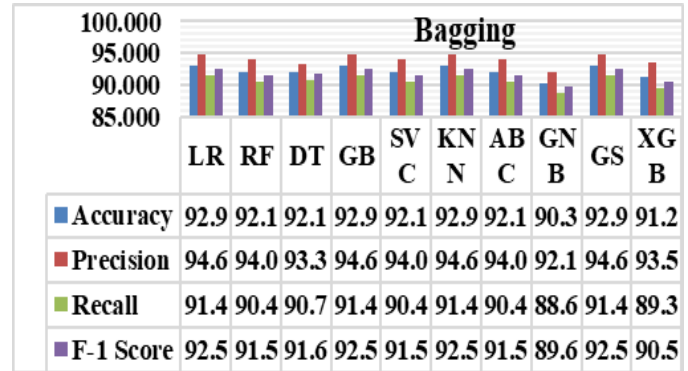


Fig. 15. Experimental results of bagging for dataset A.

Secondly, we considered the performances of Ensemble Classifier Bagging, the best accuracy had obtained at 92.982% using Logistic Regression (LR) and Gradient Boosting Classifier (GB), KNeareast Classifier (KNN) and Grid Search CV (GS). The best precision score was obtained from Logistic Regression (LR) and Gradient Boosting Classifier (GB), KNeareast Classifier (KNN) and Grid Search CV (GS) about 94.666%. The best recall score was obtained from Logistic Regression (LR) and Gradient Boosting Classifier (GB), KNeareast Classifier (KNN) and Grid Search CV (GS) with 91.489%. The best F-1 score was obtained at 92.531% from Logistic Regression (LR) and Gradient Boosting Classifier (GB), KNeareast Classifier (KNN) and Grid Search CV (GS). The visualization is shown in Fig. 16.

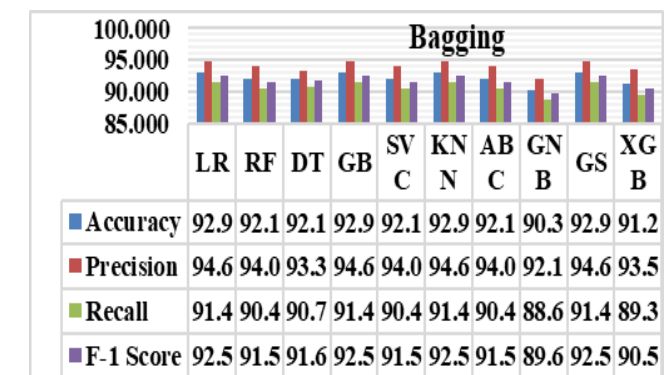


Fig. 16. Experimental results of bagging for dataset B.

We considered the performances of Ensemble Classifier Bagging, the best accuracy obtained at 99.270% using Logistic Regression (LR) and Gradient Boosting Classifier (GB), XGBoost Classifier (XGB) and Grid Search CV (GS). The best precision score was obtained from Logistic Regression (LR) and Gradient Boosting Classifier (GB),



XGBoost Classifier (XGB) and Grid Search CV (GS) about 98.648%. The best recall score was obtained from Logistic Regression (LR) and Gradient Boosting Classifier (GB), XGBoost Classifier (XGB) and Grid Search CV (GS) with 99.504%. The best F-1 score was obtained at 99.066% from Logistic Regression (LR) and Gradient Boosting Classifier (GB), XGBoost Classifier (XGB) and Grid Search CV (GS).

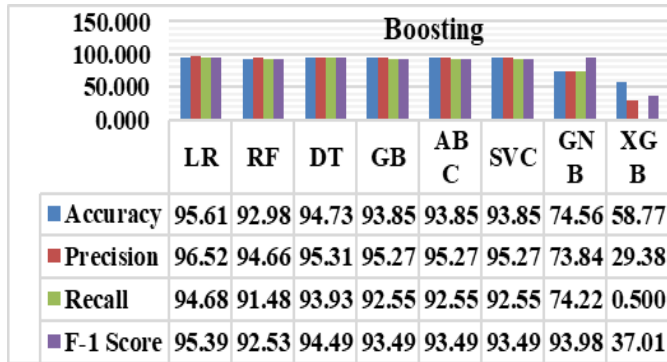


Fig. 17. Experimental results of boosting for dataset A.

The final consideration should be the performance obtained using boosting algorithms. After applying boosting algorithms, the best accuracy was obtained at 95.614% using Logistic Regression (LR). The best precision score was obtained from Logistic Regression (LR) about 92.527%. The best recall score was obtained from Logistic Regression (LR) with 94.680%. The best F-1 score was obtained at 95.392% from Logistic Regression (LR). The visualization is shown in Fig. 17.

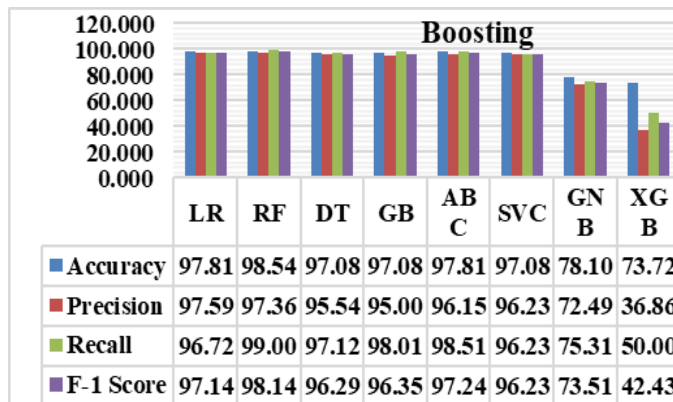


Fig. 18. Experimental results of boosting for dataset B.

The final consideration should be the performance obtained using boosting algorithms. After applying boosting algorithms, the best accuracy had obtained at 98.540% using Random Forest Classifier (RF). The best precision score was obtained from Logistic Regression (LR) about 97.591%. The best recall score was obtained from Random Forest Classifier (RF) with 99.009%. The best F-1 score was obtained at 98.148% from Random Forest Classifier (RF). The visualization is shown in Fig. 18.

## V. CONCLUSION

In this article, the researchers assess the influence rate of individuals employing algorithms. The prediction system may

benefit from the diagnosing technology. People can gain from understanding if they will have an impact or not. They should presumably be aware about breast cancer. If individuals use this approach, they can quickly identify the various stages of breast cancer. Assuming the suggested model can also be beneficial to diagnosis authority. The time and difficulty involved in diagnosing breast cancer sickness have decreased because to new technology. The study have made an effort to provide the folks something fresh. A variety of widely used algorithms have been employed that are quick to construct, simple to use, and accurate. Two sets of data has been used and the size of the first dataset, A is 32x569 and the second dataset, B is 10x683. The frequency of breast cancer is categorized in the diagnostic and Class column. That provides the accuracy of 99.270%. Which made this study very relatable to the real life environment and the model can learn by itself which will make this a platform oriented and advance method to predict breast cancer. And early prediction is a cure of this kind of disease. This study has tried to simplify the process of predicting breast cancer in humans. Innovative models can assist people. It's important to make sure the concept is workable and try to add a lot more features and work on more well-liked topics in the future.

## VI. LIMITATIONS OF A STUDY

The most crucial limitation of this study is the insufficiency of sample data sets and test dataset. Cell anatomy is evolving day by day and this limitation is a curse of disease prediction methods. Every human body is a box of mystery and it's tough to fight against anything with a limited amount of data. To achieve this awareness needs to be raised. In this research, the methodology is used to forecast breast cancer in humans. But it is also observed that there is a shortage of knowledge and diagnostic tools. Cancer detection and symptom analysis are expensive in developing nations. This research work is attempting to use machine learning to address the issue.

## VII. RECOMMENDATION FOR FUTURE RESEARCH

Expanding the datasets used for breast cancer prediction can provide a more comprehensive understanding of the disease. Including data from different demographics, geographic regions, and medical institutions can help capture a broader spectrum of breast cancer cases and improve the generalizability of the models. Future work can focus on developing real-time prediction models that can assist healthcare professionals in making timely and informed decisions. Integration with electronic health records (EHRs) and clinical decision support systems can enable seamless integration of the prediction models into the clinical workflow. Applying emerging technologies, such as deep learning, reinforcement learning, and federated learning, can further enhance the performance and scalability of breast cancer prediction models.

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# Research on Settlement Prediction of Building Foundation in Smart City Based on BP Network

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**Abstract**—In the construction process of high-rise buildings, it is necessary to predict the settlement and deformation of the foundation, and the current prediction methods are mainly based on empirical theoretical calculations and methods and more accurate numerical analysis methods. In the face of the interference of complex and ever-changing terrain and parameter values on prediction methods, in order to accurately determine the settlement of building foundations, this study designed a smart city building foundation settlement prediction method based on BP neural network. Firstly, a real-time dynamic monitoring unit for building foundation settlement was constructed using Wireless Sensor Network (WSN) technology. Then, the monitoring data was used to calculate the relevant parameters of building foundation settlement through layer sum method. Finally, input the monitoring data into the BP network results, adjust the weights of the output layer and hidden layer using settlement related parameters, and output the settlement prediction results of the smart city building foundation through training. The study selected average error and prediction time as evaluation criteria to test the feasibility of the method proposed in this article. This method can effectively predict foundation settlement, with an average prediction error always less than 4% and a prediction process time always less than 49ms.

**Keyword**—Smart city; intelligent architecture; foundation settlement; settlement prediction; BP neural network; parameter

## I. INTRODUCTION

Urban high-rise buildings are increasing recently. From the beginning of construction to the completion acceptance of high-rise buildings, regular monitoring of foundation settlement and prediction of deformation trend are of great significance to ensure the construction safety and normal use of the building [1]. Therefore, many models and methods are put forward to solve the prediction problem of foundation settlement and deformation. These methods can be roughly categorized as two kinds: theoretical calculation and measured data analysis method based on measured data. Among them, the theoretical calculation method can be subdivided into empirical method and numerical analysis method. The former is simple and practical, and is generally determined based on laboratory test results combined with relevant experience, and the calculated results generally have a large deviation from the measured values [2-3]. The latter is the product of modern mechanics research and develops gradually with the progress of computer technology. With the continuous development of computer technology, the methods for analyzing foundation settlement and deformation have gradually evolved from experience to empirical theory. However, due to the

complexity and variability of factors that affect foundation settlement and deformation in practical engineering, it is difficult to determine the values of various geological parameters, which makes it difficult for analysts to establish numerical models that match the actual engineering situation, thus greatly limiting the application of this method in engineering practice [4].

Therefore, a prediction method of building foundation settlement based on the “S-index” mathematical model is designed in research [5]. This method firstly analyzes the settlement law of building foundation, then optimizes the Logistic curve (S curve) model and exponential curve model, and puts forward “S-exponential” mathematical model, and theoretically analyzes the model from the mathematical point of view. In study [6], a soft soil foundation settlement prediction method is designed based on the modified and optimized comprehensive prediction model. For predicting soft soil foundation settlement, a modified and optimized comprehensive prediction model is proposed to solve the problem that the choice of single prediction method is difficult to adapt to the actual engineering situation. The monitoring data of soft soil foundation settlement are independently mined from different angles to analyze the change law of soft soil foundation settlement, and the comprehensive prediction of soft soil foundation settlement is realized. Firstly, the hyperbolic method and GM (1,1) model are considered comprehensively, and a preliminary comprehensive prediction model is established based on the arithmetic weighted average combination idea. Then, the real-time correction weight coefficient is constructed, the real-time correction amount is calculated to modify the preliminary comprehensive prediction model, and the comprehensive prediction model of modification optimization is established. Finally, the modified and optimized comprehensive prediction model can be used to predict soft soil foundation settlement. In reference [7], the grey model with fractional order is studied and applied to the prediction of foundation settlement. This method takes the grey model as the research object and improves the prediction effect of the grey model by changing the integer order differentiation into fractional order differentiation. The biggest difference between this model and the traditional model lies in the addition of fractional order recognition. Firstly, the ordinary differential equation without input is obtained by combining grey theory. Then the input term is introduced and the ordinary differential equation is transformed to obtain the fractional differential equation. However, it is found in practical application that the method has the disadvantages of large average error and long time consuming. In [8], it was



found that current clustering algorithms lack effective representation learning, and deep learning techniques can be utilized in document clustering to enhance the learning process. Firstly, by retaining important information in the initial data, the original samples and their extensions are pushed together to solve the problem of learning representation. In addition, the problem of cluster position preservation is also addressed by pushing adjacent data points together. To this end, a deep embedding clustering framework based on compressed autoencoders (DECCA) was proposed to learn document representation. In addition, in order to grasp relevant document or word features, the Frobenius norm was added as a penalty term to the traditional autoencoder framework, which helps the autoencoder perform better. The authors in [9] proposed a new grey wolf optimized Extreme learning machine model, namely GWO-ELM model. This model trains and predicts land subsidence by combining Extreme learning machine and grey wolf optimization algorithm, and establishes three GWO-ELM models considering the influence of time series, settlement factors and optimization to predict land subsidence near the foundation pit. The prediction results show that the average relative error and Mean absolute error values from large to small are: GWO-ELM model based on time series, GWO-ELM model based on sedimentation factor, and three GWO-E optimized GWO-ELM models. In reference [10], healthcare is also widely integrated with the Internet of Things to develop an upcoming industrial system. Utilizing this type of system can promote optimal patient monitoring, effective diagnosis, intensive care, and include appropriate surgery for existing critical illnesses. Due to massive data theft or privacy breaches, security, and privacy based on patient information data, it has become necessary to protect personal patient information data in digital communities. The article emphasizes excellent monitoring and perceptual extraction of keyframes, as well as lightweight cosine functions for further processing using hybrid chaotic mapping keyframe image encryption. This encryption combines keyframes, is very secure, and is not affected by external factors or any opponents. The proposed method verifies the effectiveness of the entire IIoT ecosystem.

Smart City is a term that originated in the field of media and has become popular in recent years. The concept refers to using a variety of information technologies to integrate urban systems and services to achieve greater efficiency in resource utilization, improved urban management and services, and ultimately a higher quality of life for citizens. This innovative approach to city building can help alleviate many of the problems cities face, such as overcrowding and poor resource management. Wisdom City, on the other hand, is a new generation of technology-based city management strategies that integrate knowledge and innovation from all walks of life. It combines the latest advances in information technology, industrialization, and urbanization to effectively meet the challenges posed by modern urban development. Through refinement and dynamic management, it aims to enhance the quality of urbanization and promote better urban management performance, ultimately improving the quality of life for urban residents [11-12].

Smart city is an innovative approach to city building that

leverages next-generation information technologies to integrate urban systems and services. These technologies include the Internet of Things, cloud computing infrastructure, and geospatial infrastructure, as well as various tools and methods such as social networks, Wikis, and all-media integrated communication terminals. This approach to city building is characterized by comprehensive and thorough perception, broadband interconnection, intelligent integration, and sustainable innovation. It is driven by user innovation, open innovation, mass innovation, and collaborative innovation, and involves a range of integrated methods such as Living Lab and Fab Lab. The goal of smart city development is to improve resource utilization, optimize urban management and services, and enhance the overall quality of life for city dwellers through innovation and collaboration [13]. The idea of smart city has emerged as a response to the changing landscape of the networked world. In the knowledge society, this advanced form of information development is seen as the successor to the digital city. The construction of a smart city is a complex process that involves the integration of multiple technologies and the democratization of innovation. Key to this is the application of new generation technologies like cloud computing and the Internet of Things, which drive the development of comprehensive perception and ubiquitous interconnection. Using mobile technology, the concept of smart city also involves the democratization of innovation, aimed at enhancing the quality of life for citizens. The approach is characterized by converged application and ubiquitous computing and has the potential to revolutionize the way cities are managed and function.

Based on the above background, smart architecture came into being. Intelligent building first rise in foreign countries, through intelligent device for intelligent management for the whole building space and its internal facilities, according to the architectural space feature matching corresponding intelligent system, in order to achieve energy conservation and emissions reduction, comfortable living, convenient management, safety and environmental protection effect, such as the main service groups, using, and managing personnel to live [14-15]. Therefore, we can understand that, in construction of digital intelligent wisdom city is the city development direction, intelligent building is in the process of building construction, unit for construction personnel and management personnel to provide digital intelligent management, the operation of the service system, the main service groups are construction workers, construction management and construction enterprises; Smart building is to provide intelligent services for residents, users and managers after the building is completed.

Therefore, when maintaining the stability and safety of intelligent buildings, it is very important to accurately predict the foundation settlement. Therefore, in view of the shortcomings of traditional methods, this study designed a prediction method for foundation settlement of smart city buildings based on BP neural network. Based on WSN, this study aims to establish a real-time dynamic monitoring system for building foundation settlement. Based on measured data, a hierarchical summation method is used to determine the parameters related to building foundation settlement. Finally,

the monitoring data is input into the BP neural network, and the weights of the output layer and hidden layer are modified based on the parameters related to settlement, ultimately achieving the prediction of basic settlement in smart cities. The feasibility of the proposed algorithm was tested using average error rate and prediction time as evaluation indicators.

The prediction method of smart city building foundation settlement based on BP network is to analyze the structure of the BP network, input monitoring data into the BP network model results, adjust the weights of the hidden layer and output layer using settlement related parameters, and output the prediction results of smart city building foundation settlement through training. It can be well applied in more intelligent building construction in the future, and can accurately predict foundation settlement, Make timely response. Compared with other methods, the building foundation settlement prediction system based on WSN technology proposed in the study is innovative, and the experimental verification in the following text shows that the prediction has smaller errors and faster response speed.

## II. FOUNDATION SETTLEMENT PREDICTION OF SMART CITY BUILDINGS

### A. Real-time Dynamic Monitoring of Building Foundation Settlement

In this study, WSN technology is firstly used to construct a real-time dynamic monitoring unit for building foundation settlement. The overall architecture of the monitoring unit is shown in Fig. 1.

The monitoring unit mainly includes the following four parts: building sensor node distribution module, sensor network module, communication module and upper computer monitoring module. Among them, the sensor network mainly collects the foundation settlement displacement data, and sends the data to the serial port of the coordinator, and then to the upper computer module. The middleware of serial communication can identify whether the information is valid or not, and analyze the valid and available information, and then transfer and store it in the database. The monitoring module of upper computer can realize remote node information management and control, historical information retrieval, data curve visualization and dynamic warning, etc.

As for real-time dynamic monitoring of building foundation settlement, it is defined that settlement measurement is effective when the monitoring error is controlled within 50mm [16]. Therefore, the unit adopts a displacement sensor with a precision of 0.1mm. Its operating principle is: when the sensor is compressed due to displacement, the resistance of the winding resistance wire changes a series of times, so that the voltage also changes, and the displacement can be estimated by the voltage change value. The measurement environment is shown in Fig. 2.

Use reinforced concrete design to make the base point of the column pillar, and dig down 3m at the base point. The triangular bracket is installed and fixed at the settlement monitoring position of the wall. One end of the displacement sensor is fixed on the base point, and the other end is in contact with the triangular baffle. Once the foundation

settlement, the wall will also downward displacement, triangular baffle and sensor will produce extrusion, at this time the sensor is compressed, the voltage between point B and C will produce a certain change, so as to obtain the foundation settlement data.

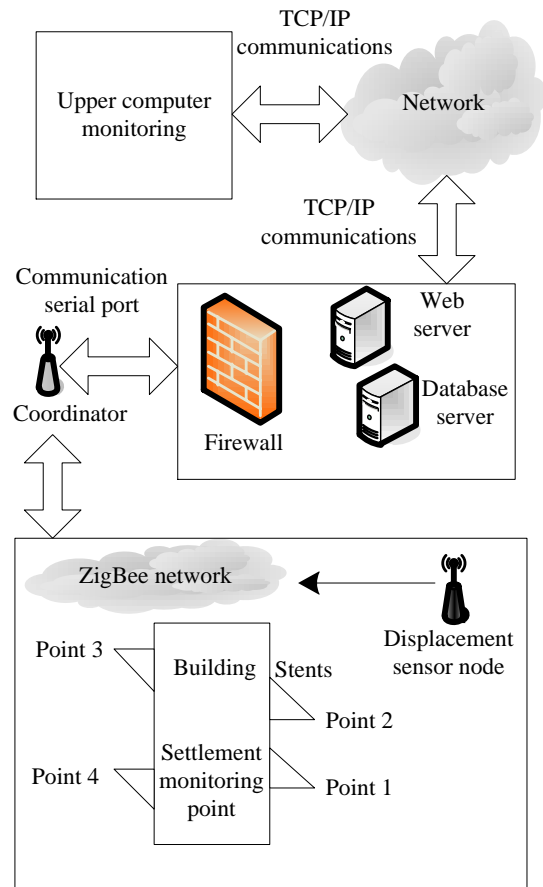


Fig. 1. The whole structure of real-time dynamic monitoring unit for foundation settlement.

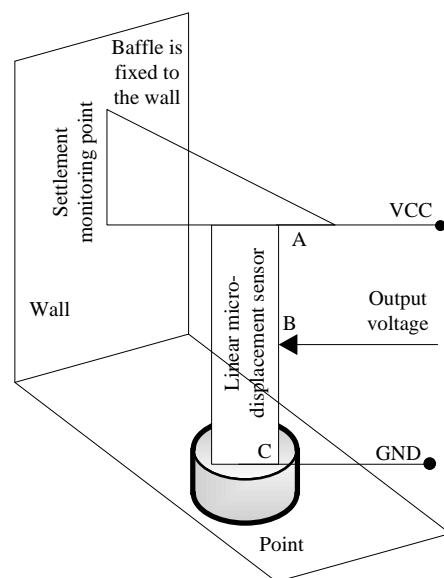


Fig. 2. Schematic diagram of measurement environment.

When displacement sensors are set at the corresponding positions of settlement monitoring points, multiple displacement sensor monitoring points are set around the building [17-18]. The plane distribution of monitoring points is shown in Fig. 3.

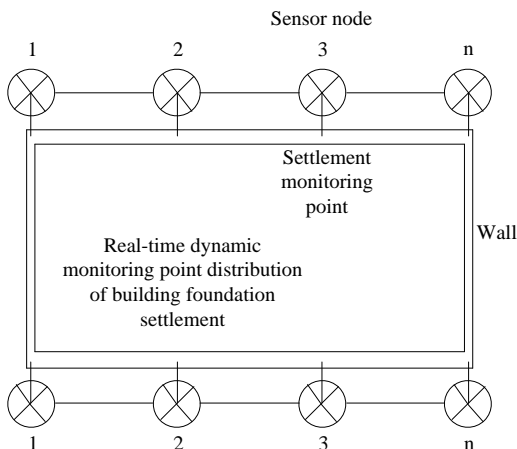


Fig. 3. Plane distribution of monitoring points

The building foundation settlement information data acquisition module is composed of highly accurate displacement sensor and ZigBee network equipment. Among them, the main function of each displacement sensor in ZigBee network is to communicate with superior nodes, and collect real-time displacement data of building foundation settlement and complete package transmission [19]. The routing node is mainly responsible for relaying the information data of monitoring points, so as to ensure that all monitoring points can efficiently send data to the coordinator position in the whole communication range. The coordinator is responsible for bringing together all the ZigBee network data and enabling the network to be turned on or off.

TABLE I. EXPLANATION OF FORMULA SYMBOLS

Formula symbols	Meaning
$\psi$	Axial stress
$\psi'$	Axial strain
$E$	Initial combined deformation modulus of soil mass
$B$	Poisson's ratio of soil mass
$\delta$	The failure ratio of soil mass
$c$	Soil cohesion
$f$	The maximum principal in the vertical direction
$f'$	Minimum principal stress in the horizontal direction
$\hat{\sigma}$	Pressure coefficient of static soil

The upper computer software adopts B/S mode, which has the biggest advantage of realizing data storage and real-time dynamic monitoring in the gateway of the coordinator, and at the same time, it can use the network to inquire the displacement information data and early warning situation remotely. The communication between the coordinator and the upper computer of the system is realized by gateway. The

communication gateway detects the data flow, receives the data flow packet from the serial port in real time, parses the data, and saves it to the corresponding database. Once the sensor displacement exceeds the limit, the exceeding information data will be saved in the warning information Table I. The client can browse through the Internet to check the system measured data and graph as well as the construction warning situation.

### B. Calculation of Related Parameters

The above monitoring data of building foundation settlement are introduced into the Duncan-Chang constitutive model and combined with the layer-summation method to calculate the relevant settlement parameters.

Duncan-chang model is a constitutive model constructed based on the correlation curve between Kondner's triaxial stress and strain [20-21], and its expression is as follows:

$$D = \frac{\psi \times v}{(m+n)\psi'} \quad (1)$$

Where,  $\psi$  and  $\psi'$  respectively represent axial stress and strain,  $v$  represents soil confining pressure, and  $m$  and  $n$  represent fitting parameters of the curve between stress and strain. The calculation process is as follows:

$$\begin{cases} m = \frac{1}{E} \\ n = \frac{1}{B\psi} \end{cases} \quad (2)$$

Where,  $E$  represents the initial joint deformation modulus of soil mass, and  $B$  represents poisson's ratio of soil mass.

Assume that  $\delta$  represents the failure ratio of soil and the ratio between the failure partial stress  $\psi$  and the ultimate partial stress  $B\psi$ , which is generally 0.75-1. Thus, equation (3) can be obtained:

$$n = \frac{\delta}{\psi} = \frac{\delta(1-\sin\phi)}{2c\cos\phi + 2v\sin\phi} \quad (3)$$

Where,  $c$  represents the cohesion of soil and  $\phi$  represents the Angle of internal friction. Since the Duncan-Chang model only considers the settlement under the influence of deviational stress, the foundation deformation caused by hydrostatic pressure should also be taken into account.

$$s = s_i + s_i' \quad (4)$$

In the formula,  $s$  represents the vertical deformation of the  $i$ -th layer,  $s_i$  and  $s_i'$  represent the vertical deformation under the influence of water purification pressure and deviational stress, and these two parameters are calculated by Hooke's Law and Duncan-Chang respectively.

Because different compressible layers in the foundation will have different deformations under the influence of additional stress, it is necessary to obtain the initial deformation modulus value. Under the influence of dead weight stress, the maximum principal stress  $f$  in the vertical direction and the minimum principal stress  $f'$  in the horizontal direction are obtained, then the initial ground stress calculation process of the  $i$ -th compression layer is as follows:

$$F = \left( \gamma_k h_k + \frac{g}{2} \times p \right) \times \partial \quad (5)$$

Where,  $\gamma_k$  and  $h_k$  respectively describe the weight value and thickness value of soil at layer  $k$ ,  $g$  represents the mean value of vertical dead weight stress,  $p$  represents the mean value of horizontal lateral pressure, and  $\partial$  represents the pressure coefficient of static soil, which can be expressed as:

$$\partial = \frac{B}{1-B} \quad (6)$$

### C. Settlement Prediction Based on BP Network

BP(Back Propagation) network is a multi-layer feed-forward neural network trained according to error reverse Propagation algorithm, and it is one of the most applied neural network models. BP network is a multi-layer feedforward network trained by error back propagation. Its algorithm is called BP algorithm. Its basic idea is gradient descent method, and gradient search technology is used to minimize the mean square error of the actual output value and the expected output value of the network.

The BP neural network is particularly effective when it comes to solving problems that a simpler perceptron cannot, such as the Exclusive OR (XOR). Structurally, the BP network consists of three layers: input, hidden, and output. In practice, the BP algorithm uses the square of the network error as the objective function and employs a gradient descent method to calculate the minimum value of this function. This allows it to effectively map complex, high-dimensional data sets onto a lower-dimensional space, providing a powerful and flexible tool for a range of applications. Ultimately, the BP neural network is a powerful tool that can help unlock the potential of big data [22].

The BP algorithm is a multi-step process that involves both forward and backward propagation. During forward propagation, the input signal is transformed through the hidden layer and generates an output signal through nonlinear transformation. If the actual output is different to the expected output, then the error backpropagation process begins. Backpropagation involves adjusting the weight and threshold in the direction from output to input, allowing the system to learn and adjust based on the errors identified. This process is iterative, with the network continually re-evaluating and refining its judgments based on new data [23]. Error backpropagation is the process of transmitting output error

back through the hidden layer to the input layer. This involves apportioning the error to all of the elements in each layer and using these error signals to adjust the weights of the connections between nodes. Through the repeated adjustment of these connection strengths and threshold values, the error can be minimized along the gradient direction, allowing the network to learn and adapt to new data. Eventually, this process leads to the identification of network parameters, such as weights and thresholds that correspond to minimal error. Once these parameters are identified, the training process is complete, and the neural network is ready to process new inputs. By applying nonlinear transformations to these inputs, the network can effectively map them onto a lower-dimensional space and process them with minimal error.

With the BP neural network analysis, for the influence of mechanical parameters change due to the nonlinear soil, combined with BP network to achieve accurate prediction of building foundation settlement. Fig. 4 shows a three-layer BP model.

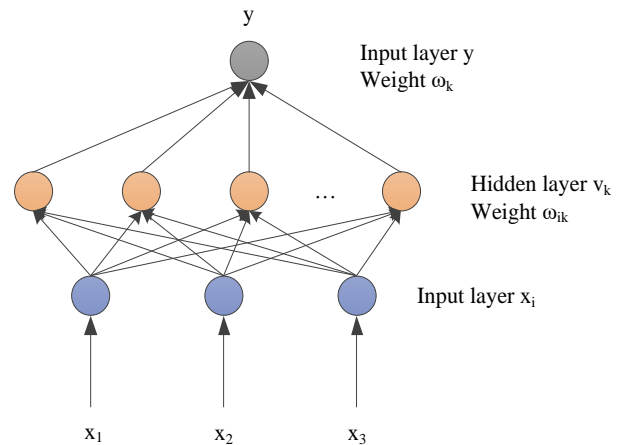


Fig. 4. BP model.

In general, the number of hidden layers in BP neural network  $\cong 1$ . All mappings from  $m$  dimension to  $q$  dimension can be realized by using 3-layer BP neural network. Therefore, the number of hidden layers can be set as 1, and the number of existing neurons is  $k$ . The connection strength between this layer and other two layers needs to be described by using weights. The input vector is described by  $X = \{x_1, x_2, x_3\}$ ; The output vector is described by  $y$ . The weights of hidden layer and output layer are  $\omega_{ik}$  and  $\omega_k$  respectively. In the hidden layer, vectors matching neurons are described by  $v_k$ .

The core idea of BP neural network is that signal and error are propagated forward and backward respectively. The neuron excitation function is described by  $f(*)$ . According to the forward propagation of the signal, expressions related to the hidden layer described in Formula (7) and (8) can be obtained:

$$y_k = f(\text{net}_k), k = 1, 2, \dots, n \quad (7)$$

$$\text{net}_k = \sum_{i=1}^n \omega_{ik} x_i, k = 1, 2, \dots, i, \dots, n \quad (8)$$

Expressions about the output layer obtained are described by formulas (9) and (10) :

$$z_k = f(\text{net}_k) \quad (9)$$

$$\text{net}_k = \sum_{i=1}^n \omega_{ik} y \quad (10)$$

On this basis, the expected and actual output is subtracted. Suppose  $e$  represents the error function, and its calculation process is as follows:

$$e = \sum_{k=1}^n (t_k - z_k)^2 \quad (11)$$

The application process of error function to input layer is as follows:

$$E = \sum_{k=1}^n \{t_k - f[\sum_{j=1}^n \omega_{jk} f(\sum_{i=1}^m \omega_{ij} y)]\}^2 \quad (12)$$

With the above formula, the weight can be adjusted to make the error change. The error is continuously reduced to ensure that the weight adjustment amount and its negative gradient change trend are the same, namely, the basic criterion of weight adjustment, which is described by the following formula:

$$\Delta \omega_{ik} = -\eta \frac{\partial e}{\partial \omega_{ik}} \quad (13)$$

Where,  $\eta$  represents the learning rate, and its value range is (0,1). Gradient descent is described by a negative sign.

The weight of each layer is updated in a circular way. The learning process of BP neural network, namely the process of repeatedly updating the weight, and the increase of new data can gradually reduce the error.

Based on the above analysis, the concrete prediction steps of foundation settlement of smart city building based on BP network are designed. Before the prediction, it is difficult to establish the specific relationship between the influencing factors and the settlement because the mechanism of foundation settlement deformation is relatively vague and the influencing factors are highly complex, which is also the fundamental reason why the application of conventional analysis methods is limited and the effect is not ideal.

Considering that the measured settlement data already contains the information of influencing factors, the settlement data in a certain time period is taken as the input of the neural network, and the predicted data in an unknown time period is taken as the output data. Therefore, in this study, the first three monitoring data are used to predict the next data, and the BP network structure is determined as follows: the number of

nodes in the input layer is 3, the number of nodes in the hidden layer is 5, and the number of nodes in the output layer is 1.

According to the measured foundation settlement value of the project, 27 samples were established. The first 17 samples were used as training samples for BP neural network training and learning, and the last 10 samples were used as prediction samples to test the prediction and generalization ability of the established BP neural network model. The steps are as follows:

Step 1: Assume that the input information of BP neural network is  $x$ , the target input is  $d$ , and the actual output is  $y$ , and randomly generate the initial value and threshold value as the connection weight between nodes.

Step 2: According to the real-time dynamic monitoring of settlement of building foundation obtained in Part 2.1, calculate the actual output  $y$  of BP neural network, and the process is as follows:

1) For input layer node, its output  $a_i$  is equal to the input data, that is,  $a_i = x_i$ ;

$$\text{net}_k^H = \sum_{i=1}^3 \omega_{ik}^H$$

2) For the hidden layer node, its input is  $a_k = f(\text{net}_k^H - \phi_k)$ ,  $\phi_k$  is the threshold of the hidden layer node,  $f$  is generally Sigmoid function;

$$\text{net}^0 = \sum_{k=1}^n \omega_k^{aH} a_k$$

3) For the output layer node, its input is  $a_k = f(\text{net}^0 - \phi^0)$ ,  $\phi^0$  is the threshold of nodes in the output layer;

Step 3: Calculate the energy function  $E = (d - y)^2$ . If the energy function is less than the specified value, go to Step 5; otherwise, go to Step 4;

Step 4: Adjust the weights of hidden layer and output layer in combination with relevant parameters of settlement of building foundation calculated in Part 2.2.

Step 5: Train the next sample until each training sample in the training sample set meets the target output, then BP network learning is completed. The actual output result is the prediction result of foundation settlement of smart city buildings.

### III. SIMULATION AND ANALYSIS

#### A. Preparing

For verifying the actual use of the prediction of foundation settlement of smart city buildings based on the designed BP network, the following simulation experiment is designed to verify it.

Windows 10 (64-bit, Anaconda3+TensorFlow 1.4.0) is the operation system, and the simulation platform is MATLAB.

Select a high-rise building in a smart city as the

experimental object. The building covers an area of 45m×23m. The overall structure is scissor wall. Bored piles are used in the foundation treatment process. The east and south sides of the building are adjacent to the street, the north side is more multi-storey buildings, and the west side is adjacent to a high-rise building to be built.

The site was rebuilt after the original low building was demolished, so the site is relatively flat. The relative height difference of the ground is roughly 1.4m. The overlying strata of the building construction mainly include loess and paleosol, while the underlying strata are mainly silty clay and sandy soil.

Fig. 5 shows the contour line of settlement of the experimental building. Among them, K1-K6 are the 6 detection points respectively. In the form of settlement isoline distribution, the middle part of the experimental building gradually expands to both sides, forming a curve in the form of equal settlement closure. This isoline reflects that the settlement amount generated by iteration of the stress of the building foundation is the largest, while the two sides are relatively small.

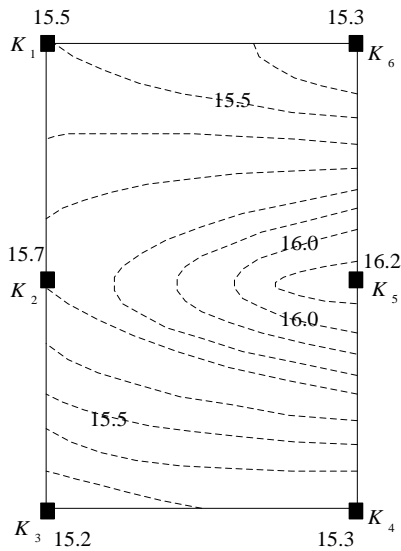


Fig. 5. Contour diagram of settlement of experimental building.

Fig. 6 shows the change of foundation settlement rate of the building over time. The settlement rate reaches the maximum value in the process of capping the main structure of the building, and becomes more and more stable after the completion of load loading. If the settlement rate of different monitoring positions is roughly the same, it indicates that the building has entered the stable period of foundation settlement.

**B. Based on Inspection**

The method in this paper was loaded on the Matlab platform to monitor the K1-K6 monitoring points and obtain the relevant data of building foundation settlement. The accuracy of the measurement results in this paper was judged by comparing with the actual values.

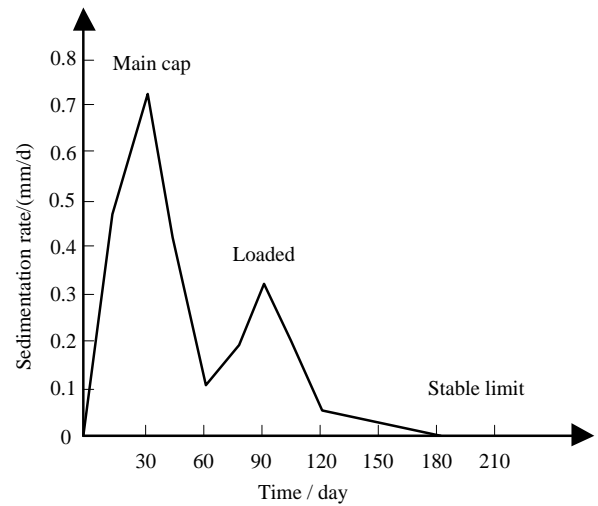


Fig. 6. Schematic diagram of sedimentation rate over time.

By comparing the difference between the predicted settlement value and the actual settlement value, the fitting degree between the two values is calculated. The fitting degree is calculated by the sum of the remaining squares. The closer the value is to 1, the smaller the gap between the predicted value and the true value is. The calculation process of fitting degree is as follows:

$$R = 1 - \frac{|q - x|}{x} \tag{14}$$

Where,  $R$  represents the fit degree,  $q$  is the predicted settlement value.  $x$  is the actual value. The fitting curve is shown in Fig. 7.

From Fig. 7, in different time periods, the fitting degree between the predicted results and the actual settlement value is always close to 1, which proves that the fitting degree between the two is high. Therefore, this method can effectively predict foundation settlement.

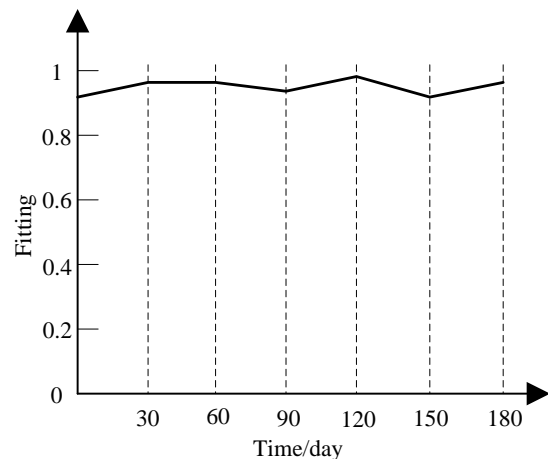


Fig. 7. Accuracy curve of calculated results.



### C. Contrast Test

In order to avoid unconvincing results, method of researches [5] and [6] were compared to for performance verification together with the proposed method. The comparison indicators are as follows:

1) *Average error (AE)*. The reliability of a foundation settlement prediction method can be evaluated based on the AE of its prediction results. A lower AE indicates higher prediction performance, greater reliability, and a stronger application advantage. By minimizing the AE, practitioners can ensure that their predictions are as accurate and reliable as possible. This can be achieved through careful selection of prediction models, validation of prediction results, and ongoing refinement of prediction methods based on new data. The calculating is followed:

$$A = \frac{\sum \frac{|y' - y|}{y}}{N} \times 100\% \quad (15)$$

A represents the foundation settlement prediction AE. N is sample size. y and y' represents real and predicted settlement value.

2) *Time consuming*. The time consumed in the forecasting reflects the timeliness. Higher timeliness needs shorter time consuming. The shorter the forecasting process, the higher the timeliness of the forecasting method, that is, the higher the forecasting efficiency.

First, the AE was tested, as shown in Fig. 8.

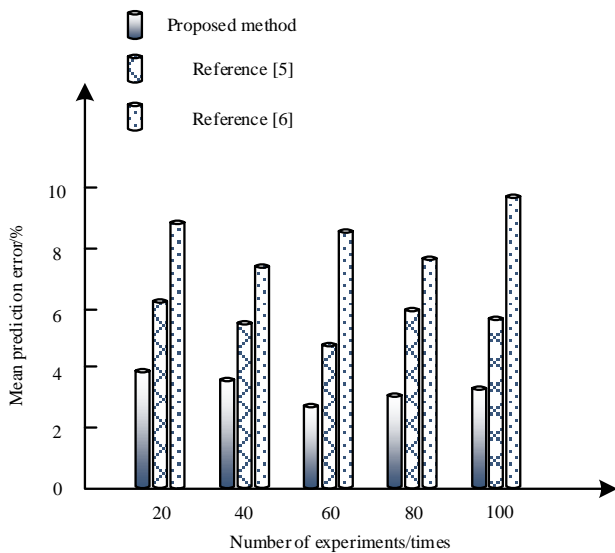


Fig. 8. Comparison of mean error of different prediction methods

The results shown in Fig. 8 indicate the prediction methods AE changes. However, in comparison, the AE of method of study [5] take the highest, and the highest AE is near 10%. The AE of this paper's method is the lowest, always below 4%, indicating it has higher reliability in predicting foundation settlement of smart city buildings.

Then we test the time-consuming process of foundation settlement prediction with different methods as shown in Table II.

The results in Table II show that the prediction time of different foundation settlement prediction methods also changes constantly with the experiments number. The prediction process of the method of reference [5] takes 50.13-68.03ms, and that of the method of reference [6] takes 61.02ms-71.81ms. However, the prediction time of method of this paper is always lower than 49ms. In contrast, the prediction process of method of this paper takes less time, which indicates that method of this paper has higher timeliness.

TABLE II. COMPARISON OF THE PREDICTION PROCESS TIME OF DIFFERENT METHODS

Number of experiments/times	Predict the duration of the process/ms		
	Method of this paper	Method of reference [5]	Method of reference [6]
1	38.41	50.13	61.02
2	41.26	52.59	62.32
3	42.37	54.62	64.14
4	42.54	56.42	64.74
5	43.54	57.26	66.25
6	44.86	61.53	67.11
7	43.60	62.45	67.82
8	47.02	64.86	68.74
9	48.22	67.64	70.85
10	48.53	68.03	71.81

### IV. CONCLUSION

In order to maintain the stability and safety of smart city buildings, this study designed a prediction method for foundation settlement of smart city buildings based on BP network.

Firstly, WSN technology is used to construct the real-time dynamic monitoring unit of building foundation settlement, which mainly includes four parts: building sensor node distribution module, sensor network module, communication module and upper computer monitoring module. Then, the above monitoring data are introduced into the Duncan-Chang constitutive model and combined with the layer-summation method to calculate the relevant parameters of building foundation settlement. Finally, on the basis of analyzing the structure of BP network, the monitoring data is input into the BP network model results, and the weights of hidden layer and output layer are adjusted by using subsidence related parameters, and the settlement prediction results of smart city building foundation are output through training.

In the experiment part, two parts of basic test and contrast test are designed. The results of basic test show that: in different time periods, the fitting degree between the predicted results of Method of this paper and the actual settlement value is always close to 1, which indicates that proposed method can effectively predict foundation settlement. The comparative test

results tell that the average prediction error of Method of this paper is always below 4%, and the prediction process takes less than 49ms, indicating that method of this paper has high reliability and timeliness of prediction. However, there are still some shortcomings in this study. For example, when selecting experimental sites and buildings, due to limited conditions and fewer buildings that meet the requirements, the type of building selected for the experiment is relatively single, and the universality of the proposed method in various experimental buildings has not been further tested.

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# A Classified Warning Method for Heavy Overload in Distribution Networks Considering the Characteristics of Unbalanced Datasets

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**Abstract**—In order to achieve heavy overload warning and capacity planning for the distribution network, it is necessary to classify the heavy overload warning of the distribution network. A distribution network with heavy overload classification warning method based on imbalanced dataset feature extraction is proposed. Screening the feature indicator set related to distribution network overload, constructing a hierarchical prediction framework for distribution network load situation, combining information such as power distribution points, road construction, municipal planning, and power load distribution to form distribution network capacity planning and line renovation plans. Based on K-means clustering, the undersampling method is used to extract features from the unbalanced dataset of distribution network overload classification, using decision trees as the basic learning unit. It includes multiple decision trees trained by Bagging integrated learning theory and random subspace method. The random forest algorithm is used to realize the feature detection and distribution network capacity planning of distribution network weight overload grading, and the grading early warning of distribution network weight overload is realized according to the capacity planning results. Tests have shown that this method has good accuracy in predicting electrical loads and can effectively solve the problem of excess capacity caused by light or no load, improving the ability of heavy overload warning and capacity planning in the distribution network.

**Keywords**—Imbalanced data; feature extraction; distribution network; overload classification warning

## I. INTRODUCTION

With the development of energy [1-3], research on the security and load stability of power distribution network networking has always received attention. In distribution network networking, it is necessary to build a graded warning model for heavy overload in the distribution network, screen the set of characteristic indicators related to heavy overload in the distribution network, and construct a graded prediction framework for the load situation of the distribution network. This can not only achieve short-term warning of heavy overload risk in the distribution network, but also predict and distinguish no-load and light load lines. Studying the classification and early warning method for heavy overload in the distribution network is of great significance in improving the power supply capacity and economic benefits of the distribution network. By establishing a distribution network load prediction model, scientific capacity planning and line transformation are carried out to address the problem of heavy overload in the distribution network, providing technical

support and support for improving the reliability of power supply, emergency response ability, and customer service level of the distribution network. The study of a graded warning model for heavy overload in the distribution network has important practical significance in promoting capacity planning and line optimization and renovation design.

In conducting relevant research on the phenomenon of heavy overload in distribution transformers, the method of feature analysis using imbalanced datasets is used to collect historical operation data of distribution networks, power outage repair work orders, transformer load data, and meteorological data. The above data are mostly imbalanced datasets, and data mining is conducted based on the aforementioned multi-source heterogeneous data to screen the feature indicator set related to heavy overload in distribution networks, Building a hierarchical prediction framework for the load situation of the distribution network can not only achieve short-term warning of the risk of heavy overload in the distribution network, improve the summer warning ability during peak hours, but also identify no-load and light load lines, providing a solution for later capacity planning. Starting from the actual situation of the distribution network, integrating multi-source heterogeneous data of the distribution network, proposing a distribution network overload warning and capacity planning technology based on historical data of the distribution network, completing the establishment of a hierarchical prediction model for the distribution network load situation, and forming a distribution network capacity planning and line transformation plan.

However, due to the low probability of distribution transformer overload, it is often difficult to obtain sufficient effective data for early data analysis and later model establishment, which also increases the difficulty for classification models to accurately predict power outages. In addition, many factors that affect power outages are difficult to present and obtain in the form of data values, which to some extent limits the establishment of feature index systems, making it difficult for prediction models to fully consider all influencing factors, thus increasing the difficulty of feature engineering and data preprocessing work. In the classification and warning of heavy overload in the distribution network, it is necessary to establish a distribution network load level prediction model based on imbalanced datasets to achieve early warning of heavy overload in the distribution network. It is expected to reduce the line outage rate index by more than 5%. In the analysis of imbalanced feature sets, how to combine

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information such as power distribution, road construction, municipal planning, and power load distribution after establishing a load prediction model. The formation of targeted distribution network capacity planning and line renovation plans is still an urgent problem to be solved. For example, Huang Yuanfang [4] et al. proposed a distribution transformer heavy overload risk warning method that takes load uncertainty into account. This method uses quantile regression algorithm of gated cycle unit to predict the load level of distribution transformer at different subpoints. In addition, utility function is used to describe the severity of heavy overload accidents suffered by distribution transformers. Combined with the power system risk theory, the potential heavy overload risk level of distribution transformers is assessed, and the risk warning is realized according to the evaluation results. Shi Changkai [5] et al. studied a method for predicting the load load of the Spring Festival distribution based on BP network and grey model. According to the particularity and regularity of the Spring Festival power load, this method uses fuzzy clustering method to divide the Spring Festival holiday period. Based on BP neural network and grey prediction system, the prediction model of the daily maximum load of the Spring Festival distribution is established, and the rated parameters of the distribution are combined. Judging whether the configuration is overloaded or not by analysing the prediction result. However, the warning accuracy of the above method is low, resulting in poor application effect.

In response to the current problems, combined with big data analysis and processing technology, a distribution network overload classification warning method based on imbalanced dataset feature extraction is proposed. Firstly, a hierarchical data acquisition model of distribution network heavy overload is established, and the feature index set related to distribution network heavy overload is screened. Combined with the unbalanced learning algorithm of inter class correlation, the random forest algorithm is used to realize the feature detection of distribution network heavy overload classification and the distribution network capacity planning. According to the capacity planning results, the distribution network heavy overload classification warning is realized. Then extract the inter class feature quantities of heavy overload in the distribution network, and based on the feature extraction results, achieve graded warning of heavy overload in the distribution network. Finally, simulation testing was conducted to demonstrate the superior performance of the method proposed in this paper in improving the ability of distribution network overload classification warning and planning. This method improves the early warning performance, and it has certain feasibility and effectiveness.

## II. OVERALL ARCHITECTURE AND DATA SAMPLING OF DISTRIBUTION NETWORK OVERLOAD WARNING AND CAPACITY PLANNING

### A. Overall Architecture of Distribution Network Capacity Planning

In order to realize the hierarchical early warning design of distribution network heavy overload, the capacity planning model of the hierarchical early warning of distribution network heavy overload is constructed. Through the parameter analysis

of the distribution network heavy overload early warning model, the KNN algorithm is used to process the missing values and outlier of the distribution network multi-source heterogeneous data. For the missing value processing of distribution network heavy overload early warning and capacity planning, based on the characteristics of distribution network data periodicity and continuity, KNN algorithm is used to realize the study of distribution network heavy overload early warning and capacity planning, find out the corresponding position of missing data in other cycles, so as to fill the missing data [6-7]. For the outlier processing of distribution network heavy overload early warning and capacity planning. Firstly, the STL-ESD technology, which combines the time series decomposition algorithm and the single sample multiple outlier detection algorithm, is used to detect the outlier in the distribution network load data, and the KNN algorithm is used to replace the distribution network heavy overload early warning and capacity planning outlier to ensure the completeness of the distribution network heavy overload early warning and capacity planning data.

On the basis of analyzing the data of heavy overload warning and capacity planning in the distribution network [8-9], a penalty based feature selection algorithm is used to analyze the power outage characteristics of the distribution network. Based on the fuzzy feature selection method, a feature subset of heavy overload warning and capacity planning in the distribution network is established. During the training process of the target model, the feature selection of heavy overload warning and capacity planning in the distribution network is carried out simultaneously, that is, feature selection is taken as a part of the model.

Using the K-means clustering [10-12] based undersampling method, the non-outage class dataset in the distribution network heavy overload warning and capacity planning dataset is undersampled. This method divides the imbalanced dataset into a majority class (non-outage dataset) and a minority class (outage dataset). Then, the clustering algorithm is used to cluster the multi class dataset of the distribution network heavy overload warning and capacity planning, and the random undersampling model parameters are obtained. Finally, the undersampling model parameters for distribution network heavy overload warning and capacity planning are obtained. Based on the above analysis, the overall structure of the distribution network overload warning and capacity planning is shown in Fig. 1.

Finally, a hierarchical prediction model for distribution network load is established using the Adaboost ensemble algorithm, which combines several weak classifiers into a strong classifier to improve the performance of hierarchical prediction based on distribution network load [13-14].

The undersampling method for power outage datasets based on K-means clustering mainly has two processes. The first process is to cluster the majority class dataset (non-power outage dataset) using K-means clustering method, dividing the dataset into K clusters; The second process is to conduct random undersampling in each cluster according to the density distribution. Specifically, it is ordered according to the size of the data variance in each cluster. First, the cluster with small

difference is subject to random undersampling at a certain sampling rate. After sampling, the multi class dataset and the few class dataset are combined to obtain a new balanced dataset.

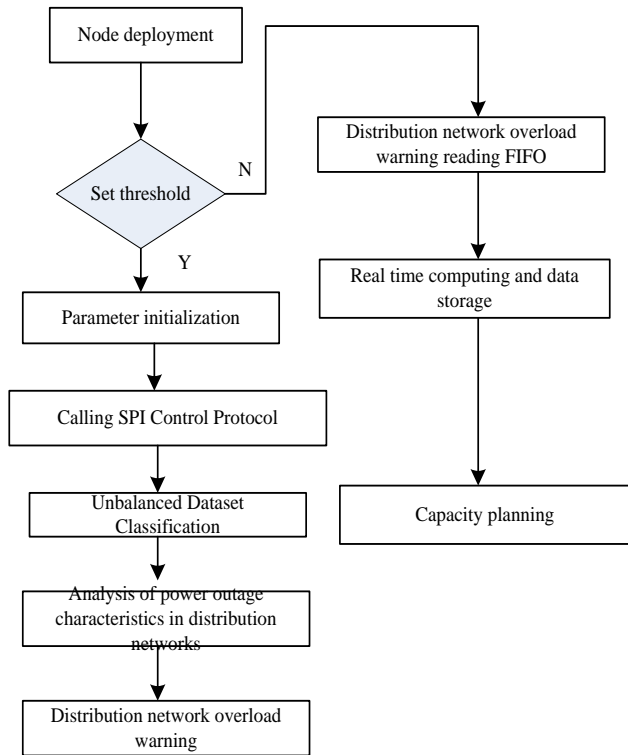


Fig. 1. Distribution network overload warning and capacity planning.

### B. Data Feature Sampling

Given the training sample set  $\{(x_i, t_i)\}$ , for distribution network capacity planning and line renovation, where  $x_i = \{x_{i1}, x_{i2}, \dots, x_{in}\} \in \mathbb{R}^n, t_i = \{t_{i1}, t_{i2}, \dots, t_{im}\} \in \mathbb{R}^m$ , including L hidden layer nodes for distribution network capacity planning and line transformation data feature detection, the distribution network weight overload activation function is  $f(x)$ , in the case of a single output node, the output function of the distribution network weight overload early warning ELM is:

$$f_L(x) = \sum_{i=1}^L \beta_i h_i(x) = h(x)\beta \quad (1)$$

Where,  $\beta = [\beta_1, \dots, \beta_L]^T$ , T represents the output weight vector between the distribution network overload warning hidden layer and the output node for L hidden layer nodes,  $h(x) = [h_1(x), \dots, h_L(x)]$  represents the hidden layer output vector of the distribution network overload warning input x, that is,  $h(x)$  maps the input distribution network overload warning data from the d-dimensional input space to the L-dimensional fuzzy dynamic feature space. Combined with the distribution of power supply points, road construction, and municipal planning, a heterogeneous algorithm is used to establish a clustering model. The minimum training decision function for the internal temporal features of the sample is obtained as follows:

$$\text{Minimize: } \|H\beta - T\|^2 \text{ and } \|\beta\| \quad (2)$$

Where, H is the dynamic allocation matrix of hidden layer output of cluster, which is expressed as:

$$H = \begin{bmatrix} h(x_1) \\ h(x_2) \\ \vdots \\ h(x_n) \end{bmatrix} = \begin{bmatrix} h_1(x_1) & \dots & h_L(x_1) \\ h_1(x_2) & \dots & h_L(x_2) \\ \vdots & \vdots & \vdots \\ h_1(x_n) & \dots & h_L(x_n) \end{bmatrix} \quad (3)$$

The process clustering learning of distribution network heavy overload warning is an unsupervised learning process. Select the K-mean standard SVM [15-16] classification model that meets the integration conditions, and get the maximum classification interval between the two classes of  $2/\|\beta\|$ . This norm actually controls the complexity of the function in the ELM feature space. Using a visual clustering point graph overlay analysis method, the disputed samples are temporarily classified into multiple clustering clusters, and two types of ELM models with single output are defined as follows:

$$\text{Minimize: } L_{ELM} = \frac{1}{2} \|\beta\|^2 + \frac{C}{2} \sum_{i=1}^N \varepsilon_i^2$$

$$\text{Subject to: } h(x_i)\beta = t_i - \varepsilon_i, i = 1, \dots, N. \quad (4)$$

Where,  $\frac{1}{2} \|\beta\|^2$  represents the structural risk of power outage data,  $\frac{C}{2} \sum_{i=1}^N \varepsilon_i^2$  represents the empirical risk of distribution network load.

Based on the KKT principle, the k-fold cross validation method is used to partition the data and transform the heavy overload classification warning problem of the distribution network into a dual optimization problem:

$$L_{ELM} = \frac{1}{2} \|\beta\|^2 + \frac{C}{2} \sum_{i=1}^N \varepsilon_i^2 - \sum_{i=1}^N \alpha_i (h(x_i)\beta - t_i + \varepsilon_i) \quad (5)$$

According to equation (5), the sliding time window method is used to obtain the KKT constraint conditions:

$$\frac{\partial L_{ELM}}{\partial \beta} = 0 \rightarrow \beta = \sum_{i=1}^N \alpha_i h(x_i)^T = H^T \alpha \quad (6)$$

$$\frac{\partial L_{ELM}}{\partial \varepsilon_i} = 0 \rightarrow \alpha_i = C \varepsilon_i, i = 1, \dots, N \quad (7)$$

$$\frac{\partial L_{ELM}}{\partial \alpha_i} = 0 \rightarrow h(x_i)\beta - t_i + \varepsilon_i = 0, i = 1, \dots, N. \quad (8)$$

Where,  $\alpha = [\alpha_1, \dots, \alpha_N]^T$ , where the standard deviation of response data fluctuation is used for data compression to obtain each Lagrange multiplier  $\alpha_i$ . For the i-th training sample.

Randomly divide K into k sets with similar numbers. When the number of training samples is small (i.e.  $N < L$ ), (6) and (7) are introduced into equation (8). From the above formula, it can be inferred that:

$$\beta = H^T \left( HH^T + \frac{1}{C} \right)^{-1} T \quad (9)$$

Similarly, when the training sample is large (i.e.  $N > L$ ), it can be inferred that the secondary learner contains the feature values extracted by the primary learner:

$$\beta = \left( H^T H + \frac{1}{C} \right)^{-1} H^T T \quad (10)$$

Similarly, when the training sample is large (i.e.  $N > L$ ), it can be inferred that the secondary learner contains the feature values extracted by the primary learner:

$$f(x) = h(x)\beta = h(x)H^T \left( HH^T + \frac{I}{C} \right) T \text{ or}$$

$$f(x) = h(x)\beta = h(x) \left( H^T H + \frac{1}{C} \right) H^T T \quad (11)$$

Based on the above analysis, a data collection and feature analysis model for heavy overload classification warning in the distribution network is constructed, combined with feature clustering and feature detection of imbalanced datasets, to achieve fuzzy sampling of overload data.

### III. CLASSIFICATION WARNING AND PLANNING ALGORITHM FOR HEAVY OVERLOAD IN DISTRIBUTION NETWORK

#### A. K-means Clustering based Feature Clustering Algorithm for Unbalanced Data in Distribution Networks

Using heterogeneous ensemble learning methods and K-means clustering based sampling methods can avoid deleting too much information on a certain data distribution and prevent data distortion caused by undersampling unevenness. The algorithm flow of the undersampling method for power outage datasets based on K-means clustering is as follows:

Step 1: preprocess the data set of unbalanced heavy overload hierarchical early warning of the original distribution network, including missing value processing based on KNN algorithm and outlier processing based on STL-ESD algorithm, and then select the characteristics to obtain the characteristic data set D with the labels of power failure ( $y=1$ ) and non-power failure ( $y=0$ ).

$$D = \{(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)\}, x_i \in R, y_i \in \{0,1\} \quad (12)$$

Step 2: Split the unbalanced dataset D of the distribution network overload classification warning, and select 80% of it as the training dataset  $D_1$ , 20% for test dataset  $D_2$ .

Step 3: Training dataset D for the imbalanced dataset of the distribution network overload classification warning\_ Unstop dataset T in  $D_1$ \_ Cluster 0 and randomly select k cluster centroids as:  $\mu_1, \mu_1, \dots, \mu_k \in R^n$ .

Step 4: For  $(x_i, y_i) \in T_0$ . Calculate the cluster to which the distribution network overload classification warning imbalanced dataset belongs,

$$c^{(x_i)} = \arg \min_j \|x_i - \mu_j\|^2, j = 1, 2, \dots, k \quad (13)$$

Where,  $c^{(x_i)}$  is the cluster to which photovoltaic characteristic data such as device parameters  $(x_i, y_i)$  belongs.

Step 5: For each cluster j, recalculate the centroid of the unbalanced dataset cluster for the distribution network overload classification warning.

$$\mu'_j = \frac{\sum_{(x_i, y_i) \in T_0} I(c^{(x_i)}=j)x_i}{\sum_{(x_i, y_i) \in T_0} I(c^{(x_i)}=j)} \quad (14)$$

Step 6: Calculate the maximum movement distance of the cluster center in the imbalanced dataset of the distribution network overload classification warning  $d = \max(\|\mu'_j - \mu_j\|_2)$ .

If  $d > \epsilon$ , update  $\mu_j = \mu'_j$ , skip to step 7 for execution.

Step 7: Scale each cluster of the above clustering results  $\alpha$  Perform random undersampling to obtain the distribution network overload classification warning imbalanced dataset, balanced training dataset  $D'_0$ .

#### B. Distribution Network Overload Classification Warning Imbalanced Dataset Diversity Scheduling Warning

The specific algorithm principle of using AdaBoost algorithm to build a distribution network overload classification warning imbalanced dataset scheduling is as follows:

Step 1: Input the training dataset of the distribution network overload classification warning imbalance dataset  $D = \{(x_1, y_1), (x_2, y_2), \dots, (x_N, y_N)\}, x_i \in X, y_i \in Y = (-1, +1)$  , ( $i = 1, 2, \dots, N$ ).

Step 2: Assuming that the weights of each sample in the dataset are initially uniform, the initial weights of the common modeling parameters for the imbalanced distribution network overload classification warning dataset in each sample are:

$$\omega_{1i} = \frac{1}{N} \quad (15)$$

Step 3: Set the maximum number of iterations [17] (i.e. the maximum number of linear combination weak classifiers)  $T: t = 1, 2, 3, \dots, T$ , to obtain the initial clustering objective function of the distribution network overload classification warning imbalanced dataset.

Step 4: When training the t-th weak classifier, the weighted weight [18-19] of the i-th sample's distribution network overload classification warning imbalanced dataset is  $\omega_{ti}$  with  $\sum_{i=1}^N \omega_{ti} = 1$  , the classifier of the distribution network overload classification warning imbalanced dataset trained is represented as  $G_t(x)$ .

Step 5: Calculate the imbalanced dataset D of the distribution network overload classification warning in  $G_t(x)$  Classification error rate on i (x)  $\epsilon_t$ :

$$\epsilon_t = P[G_t(x_i) \neq y_i] = \sum_{i=1}^N \omega_{ti} I[G_t(x_i) \neq y_i] \quad (16)$$

Where,  $I(\cdot)$  is the indicator function, and the mutual information  $I(\cdot)$  of the unbalanced data set of the distribution network heavy overload hierarchical early warning is equal to 1. Classifier  $G_t(x)$  The classification error rate of t (x) on the weighted training dataset D is equal to that of  $G_t(x)$ ; the sum of the weights of the misclassified samples in t (x).

Based on classification error rate  $\epsilon_t$  Computational basis classifier  $G_t(x)$  Weight of t (x):

$$\alpha_t = \frac{1}{2} \ln \frac{1-\epsilon_t}{\epsilon_t} \quad (17)$$

Training data distribution weights for the imbalanced dataset of distribution network overload classification warning after the t+1 iteration  $\omega_{t+1,i}$  Update:



$$\omega_{t+1,i} = \begin{cases} \frac{\omega_{ti}}{Z_t} e^{-\alpha t}, G_t(x) = y_i \\ \frac{\omega_{ti}}{Z_t} e^{\alpha t}, G_t(x) \neq y_i \end{cases} \quad (18)$$

If the imbalanced dataset samples of the distribution network overload grading warning are correctly classified [20], its weight will decrease; on the contrary, if misclassified, the weight will increase.

$$Z_t = \begin{cases} \sum_{i=1}^N \omega_{t,i} e^{-\alpha t}, G_t(x_i) = y_i \\ \sum_{i=1}^N \omega_{t,i} e^{\alpha t}, G_t(x_i) \neq y_i \end{cases} \quad (19)$$

Then output the final distribution network overload classification warning imbalanced data classification output:

$$G(x) = \text{sign}[\sum_{t=1}^T \alpha_t G_t(x)] \quad (20)$$

By processing the missing values and outlier in the data set, combined with the analysis results of the characteristics of the unbalanced data set, the system realizes the early warning of the distribution network heavy overload hierarchical early warning unbalanced data set diversity dispatching, focuses the main theories of distribution network capacity planning on the early load forecasting, and improves the early warning stability and dynamic analysis capability.

#### IV. EXPERIMENTAL TESTING AND RESULT ANALYSIS

##### A. Evaluation Index System

Establish a distribution network load level prediction model based on imbalanced datasets to achieve early warning of heavy overload in the distribution network. It is expected to reduce the line outage rate index by more than 20%. In the experiment, an evaluation index system is set up, and Gini index is given. Gini index can measure the impurity of nodes, and its formula is:

$$\text{GINI}(t) = 1 - \sum_j p^2(j/t) \quad (21)$$

In the formula:  $t$  is the branch attribute of the distribution network load level evaluation node;  $p(j/t)$  represents the proportion of the target category of the distribution network load level in node  $t$ . The Gini standard definition for the distribution node  $t$  of the distribution network overload classification warning imbalanced dataset is as follows:

$$\text{GINI}(s, t) = p_L \text{GINI}(t_L) + p_R \text{GINI}(t_R) \quad (22)$$

The division standard for the imbalanced dataset of distribution network overload classification warning is to minimize  $\text{GINI}(s, t)$ .

The least squares deviation is commonly used to measure the heavy overload classification warning ability of the regression tree allocation network, and the fitting error formula of node  $t$  is:

$$\text{Err}(t) = \frac{1}{n_t} \sum_{D_t} (y_i - k_t)^2 \quad (23)$$

In the formula:  $n$  is the number of instances in node  $t$ ;  $k_t$  is the average of the target values of instances in each node:

$$k_i = \frac{1}{n_i} \sum_{n_i} y_i \quad (24)$$

The least squares deviation standard for dynamic nodes in the distribution network overload classification warning imbalanced dataset divided by attribute values  $s$  is defined as:

$$\text{Err}(s, t) = \frac{n_{tL}}{n_t} \text{Err}(t_L) + \frac{n_{tR}}{n_t} \text{Err}(t_R) \quad (25)$$

In order to simplify the calculation process in the computer and avoid multiple traversals of attribute values, the above equation is simplified, and the hierarchical scheduling error of unbalanced data for distribution network overload classification warning can be obtained as:

$$\text{Err}(s, t) = \frac{S_L^2}{n_{tL}} + \frac{S_R^2}{n_{tR}} \quad (26)$$

Wherein,

$$S_L = \sum_{D_{iL}} y_i, S_R = \sum_{D_{iR}} y_i \quad (27)$$

By conducting hierarchical detection of the distribution network weight process, capacity planning and line transformation, analyzing the irrelevant or redundant information in the distribution network dataset, and designing partition standards to maximize  $\text{Err}(s, t)$ .

##### B. Result Analysis

Matlab is used for simulation test, and 270 normal distribution sample points are given in the unbalanced data set of the distribution network data set. These sample points are divided into two categories. The normal distribution  $N(u, \Sigma)$  respectively:

Class 1:  $N([1; 2], [0.23 \ 0; 0 \ 0.57])$ , a total of 70 points;  
Class 2:  $N([2.21; 0], [0.65 \ 0; 0 \ 0.88])$ , a total of 200 points;

Randomly generate 100 noise data using SVM, ELM, and ELM\_ The CIL algorithm performs this and provides an imbalanced dataset sample sequence as shown in Fig. 2.

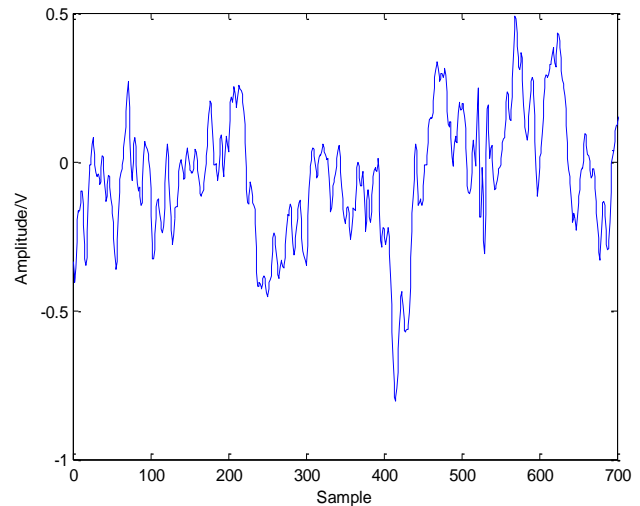


Fig. 2. Sample sequence of imbalanced dataset.

Using the data in Fig. 2 as the test object, different methods were used to obtain a noise free dataset and reference [4] method, reference [5] method, and ELM after adding the noise set\_ The CIL classification warning results are shown in Table I.

TABLE I. CLASSIFICATION WARNING RESULTS FOR NOISE DATASETS

	Reference [4] Method	Reference [5] Method	Proposed method
Accuracy	93.324	93.686	95.412
SE	88.235	84.029	95.235
SP	95.098	97.059	99.118
GM	91.598	90.314	94.676

According to the analysis of the hierarchical warning results in Table I, the classification and early warning results of the noise data sets of the three methods are all good, but the classification and early warning results of the proposed method are more accurate, the lowest value is 94.676, while the lowest value of the literature method is 88.235 and 84.029, which is more than 6 points higher than that of the proposed method. The clustering results of imbalanced dataset features are shown in Fig. 3.

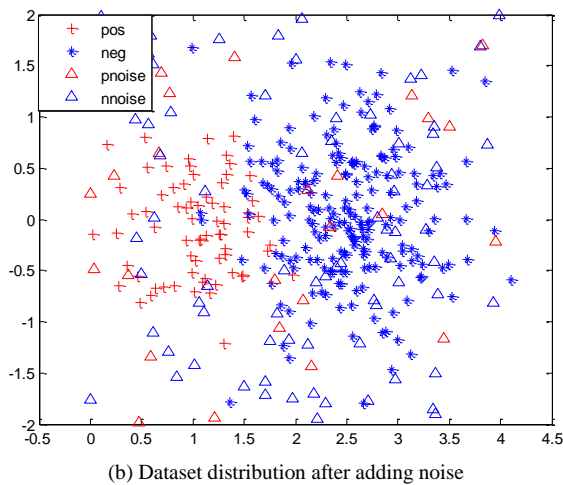
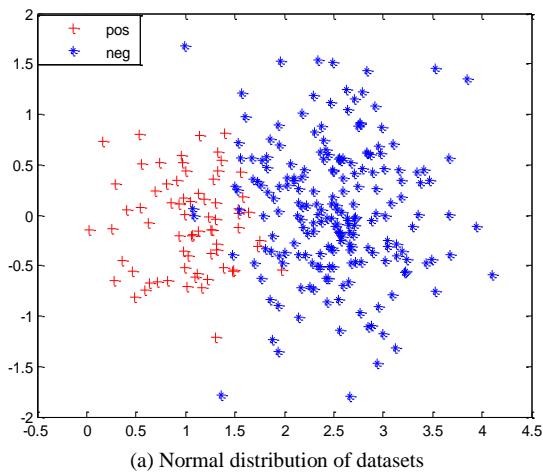


Fig. 3. Clustering results of unbalanced dataset features.

By analyzing Fig. 3, it can be seen that the method proposed in this paper has a good ability to plan for hierarchical warning of heavy overloads in the distribution network by clustering the features of the imbalanced dataset. According to the historical operation data of the distribution network (active load rate, three-phase imbalance, defect

records, fault records, etc.), distribution transformer account information, meteorological environment data, geographical environment data, user scale, and other multi-source heterogeneous data, first process the missing values and outlier in the data set, and carry out the distribution network heavy overload classification warning for each data set. The comparison results are shown in Fig. 4 to 6, the overall testing accuracy of the reference method is slightly lower than that of this method, the early warning accuracy of different data sets of the proposed method is higher than that of the literature method. The maximum value of the proposed method is 94.80, while that of the literature method is 87.48, which is more than 7 points higher than that of the proposed method. However, due to its significantly faster learning speed than support vector machines, the algorithm proposed in this paper has significant advantages in large-scale imbalanced data classification of sample sets.

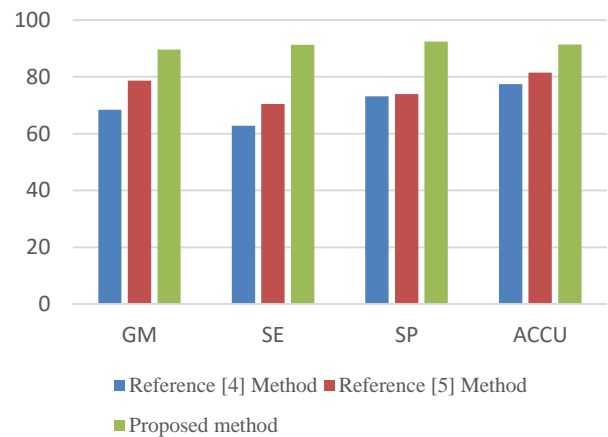


Fig. 4. Comparison of the results of various grading warning methods in Pima India.

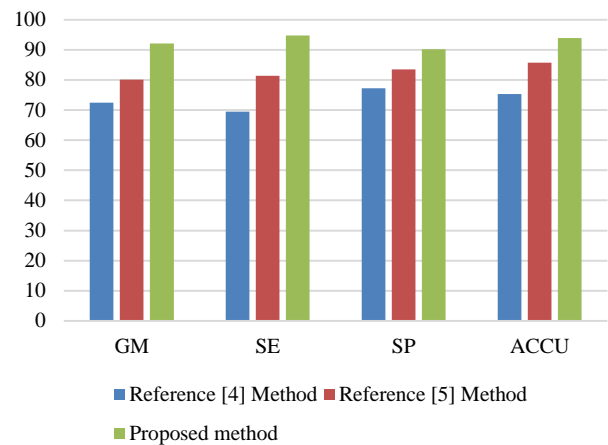


Fig. 5. Comparison of the results of various grading warning methods in transfusion.

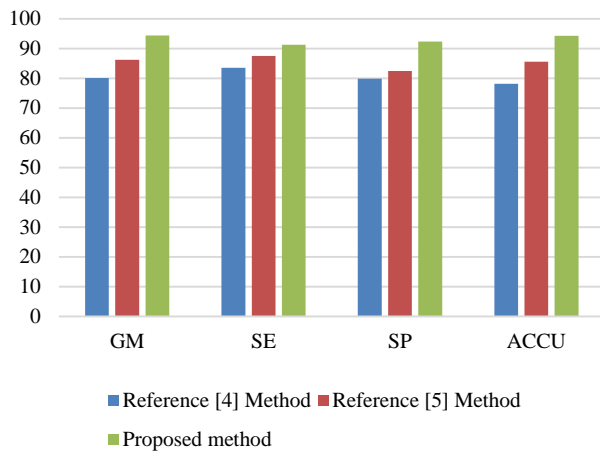


Fig. 6. Comparison of the results of various grading warning methods in Transfusion Haberman.

### C. Results and Discussion

By setting up the load forecasting model of distribution network, scientific capacity planning and line reconstruction are carried out to improve the power supply reliability, emergency response ability and customer service level of distribution network. By processing the missing values and outliers in the data set, the problems of missing and abnormal data caused by various factors in the load data of distribution network are solved, the quality of the data set is improved, and the subsequent model training is supported. By constructing new features and selecting the optimal feature subset, the problem of poor performance of prediction model caused by information irrelevance or redundancy in distribution network data set is solved. The problem of poor prediction accuracy of a few classes due to unbalance of data is solved by undersampling. The AdaBoost classification algorithm is used to solve the problem of building a hierarchical forecasting model for the load condition of distribution network. By collecting distribution network historical operation data, power outage repair work order, transformer load data and meteorological data, data mining is carried out based on the above multi-source heterogeneous data. The characteristic index set related to distribution network overload is selected, and the hierarchical forecasting framework of distribution network load is constructed. To realize short-term early warning of heavy load risk of distribution network in order to improve summer peak warning, emergency response ability and customer service level. Extract effective information from heterogeneous data from multiple sources, construct new features, and form a feature database. The feature selection method is used to filter out the optimal feature subset and undersample the unbalanced data set to reduce the unbalance degree of the data set. Finally, AdaBoost and other classification methods are selected to establish a hierarchical forecasting model of distribution network load condition to realize heavy overload warning. The load forecasting model is established to predict the total load and maximum load in the future, and the capacity planning and line reconstruction plan of the distribution network are formed by combining the information of distribution, road construction, municipal planning and load distribution, etc., so as to improve the power

supply capacity and economic benefits of the distribution network. The load forecasting model is established by using regression analysis and other load forecasting methods to predict the total load and maximum load in the future. At the same time, considering the distribution point, road construction, municipal planning, power load distribution and other factors, the capacity planning and line transformation of the distribution network. The analysis shows that the heavy overload classification early warning method adopted in this paper has good accuracy for power load prediction, effectively solves the problem of excess capacity caused by light load or no load, and improves the capacity of heavy overload early warning and capacity planning of distribution network. Compared with the literature method, the accuracy of this method is much higher than the literature method.

### V. CONCLUSIONS

Distribution network occasionally faces heavy overload phenomenon, and if the phenomenon is not warned in time, it is easy to affect the normal operation of distribution network. Therefore, in order to achieve accurate warning of heavy overload of distribution network, it is necessary to classify the heavy overload warning of distribution network. Therefore, a new classification and early warning method of heavy overload of distribution network based on feature extraction of unbalanced data set is studied. In this method, the characteristics of distribution network are defined, and K-means clustering and undersampling methods are introduced to extract features from unbalanced data sets of distribution network overload classification. At the same time, decision tree algorithm and random forest algorithm are adopted to build a heavy overload early warning method to achieve early warning. After the design of the method is completed, the performance of the proposed method is analyzed through experiments. It can be seen from the experimental results that the proposed method has high accuracy in early warning and effectively improves the early warning ability of heavy overload in the distribution network.

### ACKNOWLEDGMENT

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# A Novel Method for Myocardial Image Classification using Data Augmentation

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**Abstract**—Myocarditis is an important public health concern since it can cause heart failure and abrupt death. It can be diagnosed with magnetic resonance imaging (MRI) of the heart, a non-invasive imaging technology with the potential for operator bias. The study provides a deep learning-based model for myocarditis detection using CMR images to support medical professionals. The proposed architecture comprises a convolutional neural network (CNN), a fully-connected decision layer, a generative adversarial network (GAN)-based algorithm for data augmentation, an enhanced DE for pre-training weights, and a reinforcement learning-based method for training. We present a new method of employing produced images for data augmentation based on GAN to improve the classification performance of the provided CNN. Unbalanced data is one of the most significant classification issues, as negative samples are more than positive, decimating system performance. To solve this issue, we offer an RL-based training method that learns minority class examples with attention. In addition, we tackle the challenges associated with the training step, which typically relies on gradient-based techniques for the learning process; however, these methods often face issues like sensitivity to initialization. To start the BP process, we present an improved differential evolution (DE) technique that leverages a clustering-based mutation operator. It recognizes a successful cluster for DE and applies an original updating strategy to produce potential solutions. We assess our suggested model on the Z-Alizadeh Sani myocarditis dataset and show that it outperforms other methods.

**Keywords**—Myocarditis; generative adversarial network; data augmentation; differential evolution

## I. INTRODUCTION

Myocarditis is a type of cardiovascular disease in which the heart muscle cells inflame and is pathologically specified as inflammatory infiltrates of the myocardium with mononuclear cells. The clinical expressions of myocarditis range from asymptomatic states to cardiac arrest, arrhythmias, and cardiogenic shock [1], [2]. Viral infections are the most critical causes of myocarditis, with recent meta-analyses indicating its pervasiveness among COVID-19 infected patients [3]. Epidemiological studies inform 10.2 to 105.6 cases per 100,000 worldwide and an estimate of 1.8 million annually. In 2017, the global number of myocarditis-related deaths was gauged to be approximately 46,486 cases [4]. Despite passing several centuries since the recognition of the myocardial disease, helpful treatment approaches are yet to be conducted due to several causes, including insensitivity to diagnostic tests and complicated relations between maladaptive and adaptive immune reactions [5], [6]. Current development in the genetic

basis of immune-mediated heart disease and animal analyses supplied vital information in curing this disease [7].

In medical imaging, CNNs are vital in conducting analysis and predicting various health outcomes. Nevertheless, it is a fact that these models struggle with performance issues when they are not sufficiently balanced. So, a compelling need for more robust methods to enhance their performance is required [8]. Existing methods to improve the performance of CNN models in the medical domain include domain adaptation and transfer learning [9]. However, a significant limitation in these methods is the lack of pre-trained models available on extensively annotated medical datasets, which is a critical requirement to train these models effectively. In the absence of such pre-trained models, researchers often resort to traditional transformations, such as rotation, translation, flipping, shearing, and scaling. While these transformations have been successfully applied to many medical datasets, they are not universally applicable. Some datasets are resistant to these transformations, as applying them may alter or compromise the properties of the annotated data. Certain transformations may cause image duplicity. This means that an image and its transformed counterpart are seen by the model as two distinct images. This misjudgment by the model can cause overfitting, where the model is overly calibrated to the training dataset and performs poorly on unseen data. Considering these challenges, there is an urgent need for innovative and effective solutions to enhance the performance of CNN models in the medical domain. Current research should focus on developing new methods that can be universally applied to diverse medical datasets without compromising the integrity of the data and without leading to model overfitting. Such methods will significantly improve the applicability and accuracy of CNN models in medical imaging analysis, leading to better healthcare outcomes.

So far, GANs [10] have achieved much attention in academics and industry for their usefulness in neutralizing domain changes and developing new image instances [11]. GAN models have attained modern efficiency in numerous image generation studies, such as text-to-image synthesis [12], [13], super-resolution [14], and image-to-image translation [15]. Recently it is also being utilized in the medical area [16]. Recent research has been on utilizing GAN in medical augmentation [17] and image segmentation [18]. However, a notable drawback with some of these applications is that they involve offline augmentation, which increases the size of the dataset to enhance model performance. This process can be resource-intensive and time-consuming, making it less suitable

for applications where speed and efficiency are crucial. In contrast, online augmentation methods keep the dataset size constant. During each mini-batch iteration, a fraction of the original images is kept, and the rest is replaced with GAN-generated images. This approach helps maintain a balance between performance improvement and computational efficiency, without the need for expanding the dataset significantly [19].

Deep learning models have played a transformative role in various applications [20], [21], [22]. They leverage complex algorithms that adjust their internal parameters, typically referred to as weights, to minimize the difference between their predictions and actual outputs. To achieve this, a learning process based on the backpropagation of errors is often employed, which adjusts the model's weights based on the calculated gradients of the loss function. However, these gradient-based optimization techniques are not without their limitations. One major vulnerability is their sensitivity to the initialization of the weights. If the initial weights are not set appropriately, these algorithms can converge to local minima, resulting in sub-optimal solutions. This is a standard issue encountered in classification works, where the objective is to categorize inputs into distinct classes. In light of these challenges, researchers have turned their attention to meta-heuristic algorithms [23], which offer alternative methods for optimization. These algorithms provide a more global approach to searching the solution space and are less susceptible to the problem of local minima [24]. One such powerful meta-heuristic algorithm is DE. It has been successfully utilized for a plethora of optimization issues [25]. The DE process involves three essential steps: mutation, crossover, and selection. A new solution is created during the mutation stage. Next, in the crossover phase, the newly created mutation vector is combined with the current vector, introducing diversity into the solution set. Finally, the selection phase evaluates all solutions and selects the best ones to pass into the next iteration. The use of DE in deep learning models could provide a robust alternative to traditional gradient-based optimization methods, mitigating the issues of weight initialization and local minima. Integrating DE into the training of deep models, it could potentially improve their performance, especially in challenging applications like medical image analysis. Consequently, the practical implications of this approach could be enormous, making it an exciting area for future research and development [26].

Imbalance in the categories can have an adverse effect on performance, which is the result of one category having more data than the other [27]. Because of its rarity and volatility, the minority example may be more difficult to identify than the majority example. The data level and algorithmic level are two methods for addressing the imbalance problem. At the data level [28], over-sampling minority or under-sampling majority classes may equilibrate the dispersion of classes, yet carry the hazards of over-fitting and information loss. These techniques provide promising ways to address the class imbalance problem. However, each method has its strengths and limitations, and their effectiveness can vary depending on the specific dataset and application. Consequently, it is crucial to carefully consider the nature of the imbalance problem and the

requirements of the specific application when selecting an appropriate method. A well-chosen strategy for handling class imbalance can significantly improve model performance, particularly in identifying the important but often overlooked minority classes. Using Deep Reinforcement Learning (DRL) has been confirmed to have success in a variety of spheres, enhancing the performance of classification systems through eliminating noisy data and heightening features. However, the computational time increases due to the intricate simulations between agents and environments. Some researchers have used DRL to improve classifiers, and an ensemble pruning approach has also been developed. Despite these advancements, the use of DRL in imbalanced classifications, especially in medical imaging, remains minimally investigated.

As far as we know, three deep network-based articles have been presented to diagnose myocarditis. Sharifrazi et al. [29] presented a three-step method using CNN and the k-means algorithm for myocardial image classification. In this research, images embedded in a vector were clustered using the k-means algorithm in four clusters, followed by a CNN to classify four clusters separately. Eventually, a voting system was employed to assign every image to its corresponding class. The method's fundamental flaw was that it embedded the images in a vector for the k-means algorithm, resulting in missing pixels surrounding a special pixel. Moravvej et al. [30] considered a CNN-based model that used the ABC algorithm as weight initialization of the model and reinforcement learning to solve the imbalanced classification problem. Danaei et al. [31] imitated the method presented by [30] except that they used an improved ABC algorithm for weight initialization. The ABC algorithm often requires many iterations to converge to an optimal solution, making it less efficient than some other optimization algorithms, especially when dealing with high dimensional problems. As the dimensionality of the problem increases, the performance of the ABC algorithm tends to deteriorate, making it less suitable for high-dimensional problems or very complex datasets.

In this article, we offer an automatic method for myocarditis diagnosis. Our proposed model contains a CNN and a feed-forward network to predict their similarity. The main contribution of this article is as: 1) We consider a deep convolutional GAN model effective for online augmenting, generating images allowed in regularization that reduces the over-fitting and enhances the accuracy of the model, 2) We come up with a better DE algorithm based on clustering for initializing weights. This supports us in identifying a likely region for the commencement of the BP algorithm on CNN and feed-forward networks. The mutation operator chooses the most suitable or almost suitable solution from the superior cluster to accomplish this as the primary solution. An updated strategy is then implemented to create potential solutions, and 3) We provide a reinforcement learning algorithm for the classification problem inspired by [30] in order to address imbalanced classification.

The remainder of this article is set as follows. Section II presents our proposed myocarditis diagnosis method, while Section III illustrates experimental results. Eventually, Section IV presents a conclusion of the paper.



## II. PROPOSED MODEL

As illustrated in Fig. 1, we employ a deep model for the binary classification of myocardial images. Our model gains a CMR image as input and passes it to a CNN, followed by a Softmax layer at the end serving as the final decision-maker. We use a GAN-based method for online data augmentation, rising the model performance for classification. The proposed model incorporates a clustering-based differential evolution algorithm to find the initial seeds of the network weights while using an RL-based algorithm to handle class imbalance.

### A. Online Data Augmentation

Data augmentation is an indispensable tool for training deep models. More recent advances have been made to discover an optimal augmentation policy in image classification. Nevertheless, the current methods uncovered two critical points related to data augmentation. One is that most current augmentation approaches are offline, which separates learning procedures from their use. The techniques that are taught during training remain consistent and are not changed based on the current state of the training model. These techniques depend on image processing functions that maintain class details. Applying offline techniques to new projects may need domain knowledge [32], [33].

To handle the problems above, we present an online data augmentation using a GAN-based model, trying to minimize the overfitting and enhance the performance of the proposed CNN architecture. The input to the second layer of the generator comprises the characteristics determined by the penultimate layer of the discriminator to recreate the original data. Specifically, the generator uses two inputs: random noise, which is utilized to generate real-like examples as standard GAN, and the actual data features used for reconstruction. Fig. 2 shows the proposed GAN, which shows how the process works. The generator input is manifested by the output of the

flatten layer of the discriminator, as shown by the faint black dotted line, when utilizing real data for reconstruction. The linear layer is not considered when the generator reconstructs real data [34].

### B. Pre-training Phase

Deep network weight initialization is a critical component of deep models. Inaccurate initial values can sometimes cause the model to fail to converge. In this article, we initialize the weights of the CNN, and feed-forward neural network. For this, we introduce an enhanced DE method that is boosted by a clustering scheme and a novel fitness function. In our enhance DE algorithm, we employ a clustering-based mutation and updating scheme to improve the optimisation performance.

The mutation operator, inspired by the work in [35], identifies a promising region within the search space. The population P at the current point is divided into k clusters using the k-means clustering method, with each cluster representing a different segment of the search space. The number of clusters is determined by selecting a random integer from the range [2, N]. After the clustering process, the most optimal cluster is deemed to be the one with the lowest average fitness among its samples.

The suggested mutation based on clustering is described as follows:

$$\vec{v}^{clu}_i = \overline{win}_g + F(\vec{x}_{r_1} - \vec{x}_{r_2}), \quad (1)$$

where  $\overline{win}_g$  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  $\overline{win}_g$  is not always the population's most acceptable solution. The clustering-based mutation procedure is implemented M times.

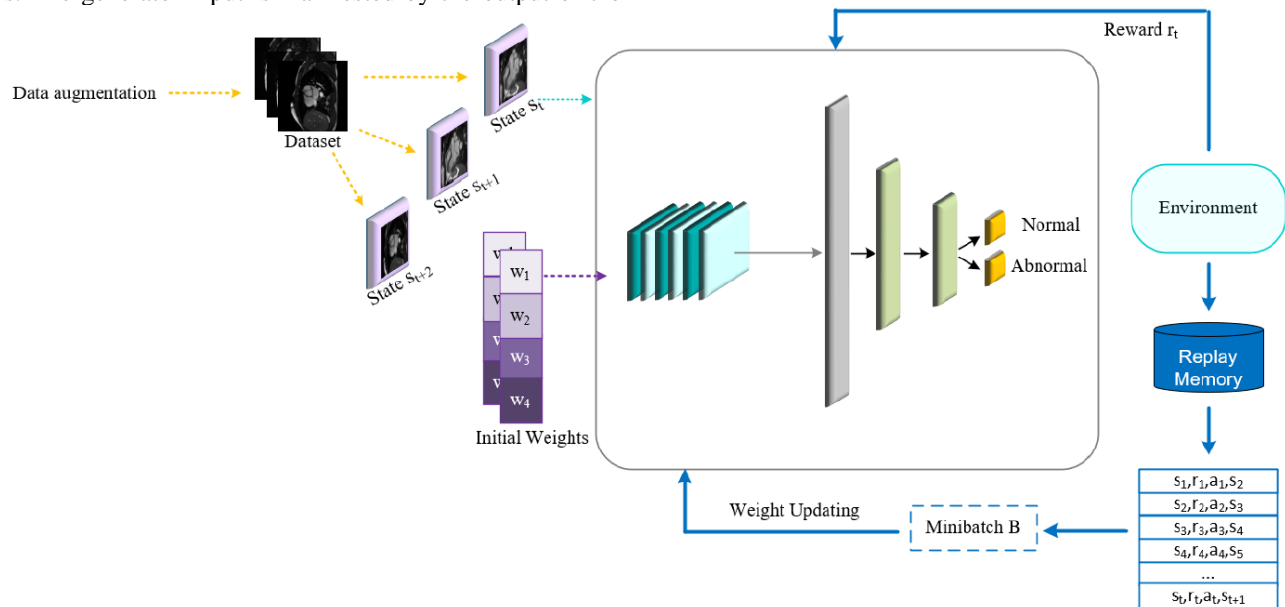


Fig. 1. Outline of the proposed method.

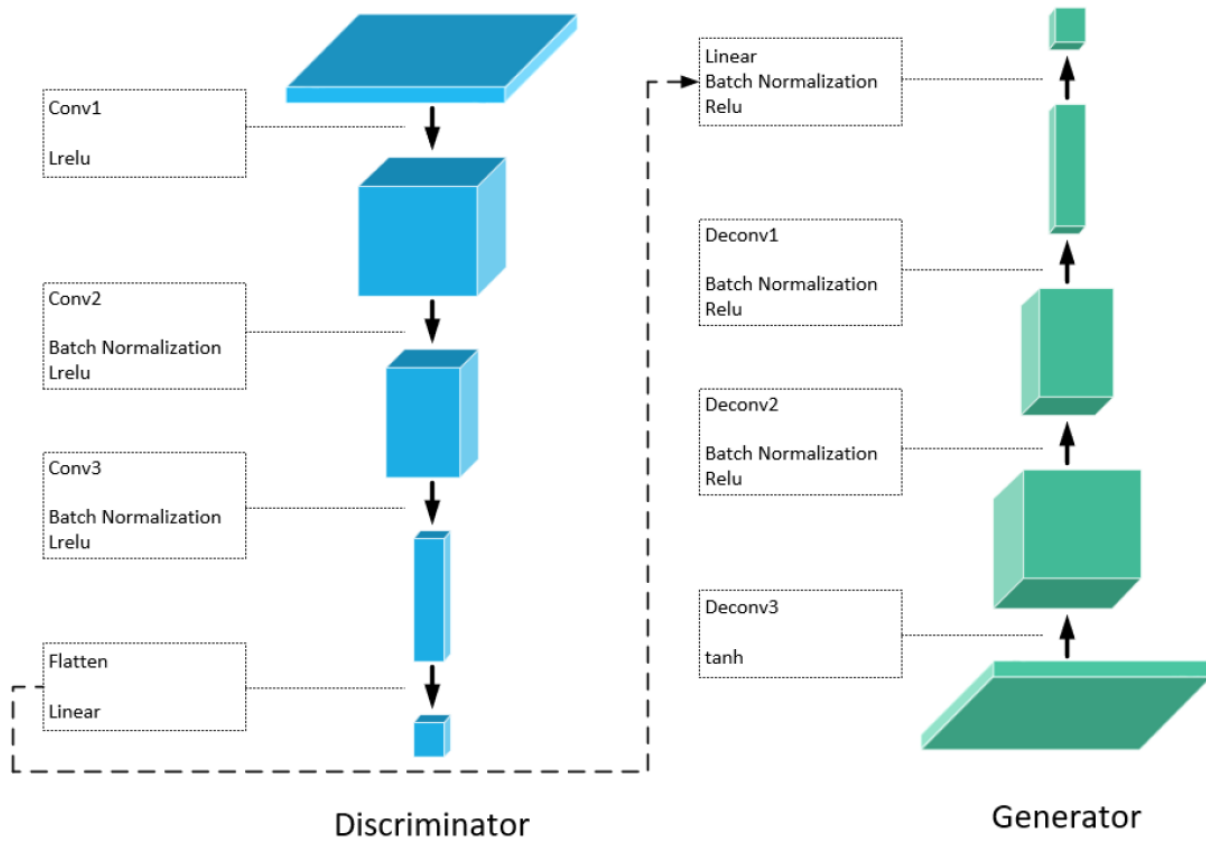


Fig. 2. The proposed GAN architecture for generating images.

The current population is updated when M new solutions have been provoked through clustering-based mutation. The steps are as follows:

- Selection: Produce k random individuals as the starting points for the k-means algorithm;
- Generation: Obtain M solutions utilizing clustering-based mutation and designate them as set  $v^{clu}$ ;
- Replacement: Draw M solutions randomly and classify them as B.
- Update: The most helpful M solutions from the union of  $vclu$  and B were established as B'. The final population is evaluated as  $(P - B) \cup B'$ .

The encoding method we use in our research tries to put the CNN and feed-forward weights into a vector that show the candidate solution in the improved DE. It's hard to give exact weights, but after a few trials, we came up with a way to encode that is as accurate as possible. Fig. 3 shows an example of how to encode a feed-forward network with three hidden layers and a three-layer CNN network with three filters in each layer. It is important to remember that all weight matrices in the vector are reserved as rows.

To compute the efficacy of a solution in the improved DE algorithm, the fitness factor is expressed as follows:

$$Fitness = \frac{1}{1 + \sum_{i=1}^N (y_i - \hat{y}_i)^2} \quad (2)$$

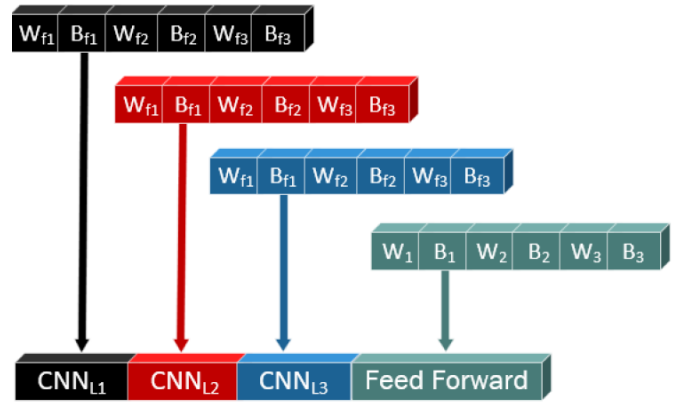


Fig. 3. Placing weights in a vector.

The target and projected labels for the i-th set of data are  $y_i$  and  $\hat{y}_i$ , respectively, and N shows the number of instances.

### C. Classification

Our approach to addressing the issue of imbalanced data volumes in our classes involves the utilization of a RL based algorithm [30]. In our training dataset, each CMR image represents a state within the environment, while the network functions as the agent responsible for performing a series of classifications on all CMR images. The agent's prediction of the class label for a given CMR image can be viewed as an action, where the image observed at time-step t is denoted as state  $s_t$  and the performed classification is labeled as  $a_t$ . In response,

the environment provides a reward  $r_t$  to guide the agent's learning process. To ensure appropriate guidance, the reward values are assigned in a manner that assigns a lower absolute value to the majority class when compared to the minority class. The reward function is:

$$r_t(s_t, a_t, l_t) = \begin{cases} +1, a_t = y_t \text{ and } s_t \in D_H \\ -1, a_t \neq y_t \text{ and } s_t \in D_H \\ \lambda, a_t = y_t \text{ and } s_t \in D_S \\ -\lambda, a_t \neq y_t \text{ and } s_t \in D_S \end{cases} \quad (3)$$

where  $D_S$ , and  $D_H$  represent the majority ("sick") and minority ("healthy") classes, respectively. Correctly/incorrectly classifying a sample from the majority class yields a reward of  $+\lambda/-\lambda$ , where  $0 < \lambda < 1$ .

### III. EXPERIMENTAL RESULTS

To assess the proposed model, we designed several experiments. We utilize k-fold cross-validation for experiments, with  $k = 5$ , meaning the dataset is broken up into  $k$  groups. Each time, one fold is chosen to be tested and the rest are used for training. This process is repeated  $k$  times. With this technique, every sample can be used once for test and  $k - 1$  times for training. We report every result as  $M \pm S$ , where  $M$  and  $S$  are the mean and standard deviation of performed experiments for  $k - 1$  times.

The first experiment compares the proposed model with three deep learning-based models, CNN-KCL [29], RLMD-PA [30], and Danaei et al. [31]. The evaluation results for the Z-Alizadeh Sani myocarditis dataset using standard performance metrics are displayed in Table I. As the results indicate, the proposed model performs more satisfactorily than CNN-KCL, which decreases error by more than 42% in all criteria. Also, the maximum value of all measures in CNN-KCL has a somewhat high difference compared to the proposed model, for example, in the two criteria of F-measure and Recall, the difference is about 13% and 9%. RLMD-PA acts better to an extent than CNN-KCL, with an improvement of 60%, showing reinforcement learning employed in it can prevent imbalanced data. However, the proposed model acts more robust than RLMD-PA, with about 45% of headway, because GAN used as data augmentation can improve imbalance as much as possible. Proposed without GAN has the same structure as the proposed model but doesn't use GAN as data augmentation. The comparison of these two models shows that the data augmentation trick improved the model by approximately 40%. To investigate the quality of the images generated by the proposed, we select six samples randomly and show them in Fig. 4. We can see that the samples produced by the proposed GAN have relatively high quality.

#### A. Examination of other Metaheuristic Methods for the Algorithm

In the suggested model, the backpropagation process is influenced by the improved DE method for initializing value. For comparison of improved DE in our model, we utilized six algorithms, including, GDA [36], OSS [37], BR [38], BA [39], COA [40] and original DE [41]. Table II provides an overview of the performance measures used in these comparisons. Metaheuristic algorithms act weaker than the proposed model in terms of accuracy, recall, and F-measure scores. It is significant to note that the improved DE algorithm surpassed all metaheuristic algorithms to reduce the error in the recall and F-measure criterion by more than 38% and 36%, respectively.

1) *Analysis of pre-trained models:* The proposed approach uses a CNN as feature extractors. It is interesting to investigate the effect of transfer learning by utilizing pre-trained models such as AlexNet [42], GoogleNet [43], ResNet [44], DenseNet [45], and MobileNet [46] as feature extractors. The performance metrics of these comparisons are summarized in Table III. As can be seen, replacing CNN trained from scratch by the pre-trained models hurts performance. In particular, training CNNs from scratch improves Recall and F-measure error by more than 60% and 67%, respectively. This stems from the fact that transfer learning models perform reasonable on wide range of images however they lack the necessary specialty for specific problems such as myocardial diagnosis.

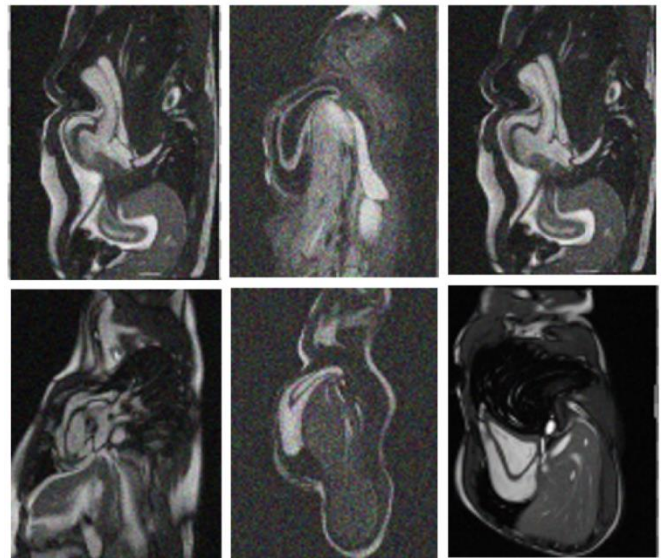


Fig. 4. Examples of images generated by the generator.

TABLE I. RESULTS OF DEEP LEARNING ON THE Z-ALIZADEH SANI MYOCARDITIS DATASET

	Accuracy	Recall	Precision	F-measure
CNN-KCL [29]	0.812 ± 0.015	0.736 ± 0.051	0.743 ± 0.033	0.741 ± 0.021
RLMD-PA [30]	0.881 ± 0.026	0.849 ± 0.013	0.818 ± 0.043	0.829 ± 0.02
Danaei et al. [31]	0.881 ± 0.006	0.856 ± 0.026	0.845 ± 0.023	0.821 ± 0.017
Proposed without GAN	0.858 ± 0.023	0.826 ± 0.027	0.804 ± 0.038	0.814 ± 0.027
Proposed	0.908 ± 0.020	.886 ± 0.028	0.871 ± 0.040	0.878 ± 0.025

TABLE II. RESULTS OF METAHEURISTIC ALGORITHMS ON THE Z-ALIZADEH SANI MYOCARDITIS DATASET

	Accuracy	Recall	Precision	F-measure
GDA	0.841 ± 0.019	0.811 ± 0.024	0.781 ± 0.043	0.794 ± 0.021
OSS	0.845 ± 0.011	0.800 ± 0.023	0.794 ± 0.021	0.797 ± 0.026
BR	0.833 ± 0.010	0.783 ± 0.010	0.780 ± 0.042	0.786 ± 0.017
BAT	0.855 ± 0.021	0.798 ± 0.029	0.810 ± 0.019	0.801 ± 0.018
COA	0.849 ± 0.010	0.806 ± 0.006	0.789 ± 0.032	0.790 ± 0.045
DE	0.893 ± 0.014	0.871 ± 0.020	0.852 ± 0.031	0.870 ± 0.019

TABLE III. RESULTS OF VARIOUS PRE-TRAINED MODELS ON THE PROPOSED MODEL

	Accuracy	Recall	Precision	F-measure
AlexNet	0.761	0.682	0.618	0.625
GoogleNet	0.752	0.764	0.651	0.707
ResNet	0.743	0.706	0.645	0.659
DenseNet	0.732	0.720	0.622	0.659
MobileNet	0.763	0.734	0.652	0.706

TABLE IV. RESULTS OF VARIOUS LOSS FUNCTIONS ON THE PROPOSED MODEL

	Accuracy	Recall	Precision	F-measure
WCE	0.801	0.732	0.758	0.744
BCE	0.800	0.805	0.714	0.745
DL	0.806	0.795	0.701	0.715
TL	0.813	0.774	0.710	0.752

2) *Analysis of loss function:* To address data imbalances, conventional methods can be employed, such as adjusting data augmentation techniques and the loss function. Among these approaches, the loss function holds significant importance as it enables the emphasis of the minority class. We aim to use four loss functions, WCE [47], BCE [48], DL [49], and TL [50] to evaluate the proposed model. As we can observe from Table IV, WCE/BCE functions improved the F-measure metric by only 20%/16% despite assigning weights to the samples. The use of focal loss gives the best results for all measures on the Z-Alizadeh Sani myocarditis dataset and yields in particular the best G-means results for this dataset.

3) *Impact of the reward function:* To address the reward assignment in the context of correct and incorrect classifications, the majority and minority classes are assigned rewards of  $\pm 1$  and  $\lambda$ , respectively. The value of  $\lambda$  is determined by the ratio of majority to minority samples, with an expected decrease in the optimal value as the ratio increases. To investigate the impact of  $\lambda$ , the performance of the proposed model was evaluated using different values of  $\lambda$  ranging from 0 to 1, with increments of 0.1, while keeping the majority class bonus constant. The results are depicted in Fig. 5. When  $\lambda$  is set to 0, the influence of the majority class becomes negligible, whereas at  $\lambda = 1$ , both the majority and minority classes have equal impacts. Fig. 5 illustrates that the model's performance reaches its peak at a  $\lambda$  value of 0.6 for all considered metrics. This suggests that the optimal  $\lambda$  value lies between zero and one, rather than at the extremes. However, it should be noted that excessively low values of  $\lambda$  can adversely affect the overall model performance. Therefore, careful consideration is required in choosing  $\lambda$  to strike the right

balance. The results emphasize that the selection of  $\lambda$  significantly influences the performance of the proposed model. The optimal value depends on the relative proportions of the majority and minority samples, and it is crucial to make a thoughtful choice to achieve the best possible results.

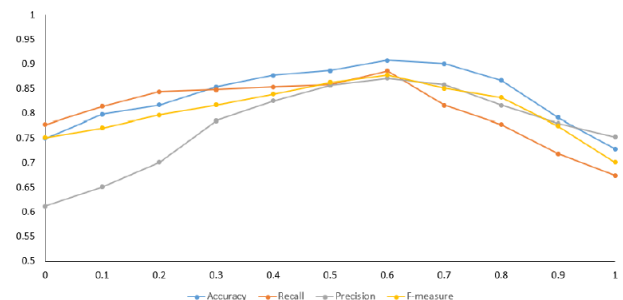


Fig. 5. Performance metrics plotted vs the value of  $\lambda$  in the reward function.

4) *Discussion:* The proposed model has shown excellent results in the task of diagnosing myocarditis on CMR images, outperforming other deep models and pre-trained transfer learning models. The use of data augmentation and RL in the model has addressed the issue of dataset imbalance and improved the model's performance. Additionally, the use of DE pre-training has minimized the risk of the model getting stuck in local optima. However, despite its promising results, the model has some limitations that need to be considered. One of the limitations of the proposed model is that it was trained and tested on a single dataset, the Z-Alizadeh Sani myocarditis CMR dataset, which may limit its generalizability to other datasets with different characteristics. Further validation on other independent datasets is necessary to assess the model's generalizability. Another limitation is that the model

was developed using a retrospective study design, which may introduce biases and limit the ability to draw causal inferences. A prospective study design would be necessary to establish the clinical utility of the model in the diagnosis of myocarditis. Moreover, the model has some technical limitations. For instance, the performance of the model could be influenced by the quality of the input CMR images, which can vary depending on the imaging modality and the specific imaging parameters employed. The performance of the model can also be influenced by the variability in the number and size of myocarditis lesions, which can differ across patients. Future research could overcome these limitations by assessing how well the model performs on a broader range of datasets, including those with a reduced incidence of myocarditis. Furthermore, conducting a performance evaluation of the proposed model in comparison to other deep learning models developed for CMR-based myocarditis diagnosis can provide significant knowledge about the strengths and limitations of different approaches. Lastly, future research could focus on the development of deep learning segmentation methods that can not only detect the existence of myocarditis but also accurately determine the specific location and severity of the condition on CMR images. Such methods could help clinicians make more informed decisions about patient management and treatment.

#### IV. CONCLUSIONS

We presented an architecture comprising a CNN, a fully-connected decision layer, a generative adversarial network (GAN)-based algorithm for data augmentation, an enhanced DE for pre-training weights, and a RL-based method for training. We proposed an online GAN model that can effectively make synthetic myocardial images. This method of online augmentation using the generated images based on the GAN model increases the accuracy of the test dataset. To protect the proposed model against imbalanced data, we present an RL-based training strategy that focuses on learning minority class examples. We also discuss the training phase, which often involves gradient-based methods, including back-propagation, for the learning process and, as a result, is susceptible to issues such as sensitivity to initialization. In order to start the BP procedure, we provide an enhanced DE method that employs a clustering-based mutation operator. It identifies a winning cluster for the current DE population and develops potential solutions using a new updating strategy. We used the Z-Alizadeh Sani myocarditis dataset to evaluate our proposed method and show that it works better than other methods.

For future work, several aspects can be improved upon or explored further. While our online GAN model has demonstrated effectiveness in generating synthetic myocardial images, it could be refined or adapted for other types of medical images. Experimentation with other types of data augmentation techniques could also prove beneficial. Additionally, the RL-based strategy can be further optimized to ensure more robust handling of imbalanced data. Investigating other advanced optimization techniques for the initialization

process could lead to more efficient learning and overall improved performance. Lastly, applying and testing our proposed architecture on a variety of medical datasets will be critical to understand its versatility and effectiveness in a broader context. The potential of our proposed method is significant, but so is the potential for further enhancements and broader applications.

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# Design and Application of Online Courses under the Threshold of Smart Innovation Education

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**Abstract**—With the rapid development of the Internet and the growing demand for education, a new online teaching mode, massive open online courses (MOOC), emerged in 2012. To address the problems of sparse data and poor recommendation effect in online course recommendation, this paper introduces deep learning into course recommendation and proposes an auxiliary information-based neural network model (IUNeu), on the basis of which a collaborative neural network filtering model (FIUNeu) is obtained by improving it. Firstly, the principles and technical details of the deep learning base model are studied in depth to provide technical support for course recommendation models and online learning recommendation systems. In this paper, based on the existing neural matrix decomposition model (NeuMF), we combine user information and course information and consider the interaction relationship between them to improve the accuracy of the model to represent users and courses. The neural network model of auxiliary information (IUNeu) is incorporated into the online learning platform, and the system development is completed with the design of front and back-end separation, realizing the functions of the online learning module, course collection module, course recommendation module, and resource download module. Finally, the experimental results are analyzed: under the same experimental conditions, the test experiments are repeated 10 times, and the RMSE calculation results are averaged. The RMSE value of the neural network collaborative filtering model (FIUNeu) proposed in this paper based on deep learning is 0.85517, which is the best performance and has a high accuracy rate of rating prediction, and is useful for alleviating the data sparsity problem.

**Keywords**—Massive open online courses (MOOC); deep learning; collaborative neural network filtering model (FIUNeu); course recommendation; online learning recommendation system

## I. INTRODUCTION

In latest years, MOOC structures such as Coursera, edX, and Scholastic Online have flourished and swiftly attracted a giant variety of learners. The ease with which customers can get entry to a giant variety of magnificent mastering assets in moot classification systems has significantly facilitated expertise sharing and online learning and supplied many possibilities for character newbies to get hold of training [1]. However, customers are regularly pressured via the "information overload" of the exploding quantity of publications on the Mootools platform. How to assist customers discover the getting to know assets they want and make correct tips has grown to be one of the most urgent issues [2].

Currently, Li Xiaojun et al. crawled the getting-to-know records on MUOC online for experiments, and the effects confirmed that the overall performance of the IUNeu mannequin grows quicker than the NeuMF mannequin as the vector size and the number of endorsed publications expand [3]; Xiaoyan ZD et al. proposed a bipartite diagram context collaborative filtering algorithm primarily based on the traits of MOOC platforms, which improves the advice fine of the algorithm with the aid of preprocessing the dataset and setting up distinct linkage quantification values [4]; Cheng Yan proposed a prolonged ant colony algorithm for fixing the suggestion trouble of studying paths, which takes into account the comparison of getting to know paths via the crew of newbies and the traits of goal customers in phrases of know-how stage and getting to know fashion when making advice selections [5]. Zhang H et al. blended with the traits of the MOOC platform, proposed MCRS to make splendid upgrades in path suggestion mannequin and suggestion algorithm, and the direction suggestion records are transferred to MySQL via Sqoop to obtain well-timed comments and enhance the path retrieval effectivity of customers [6]; Sun X et al. designed a customized suggestion device mannequin for on-line gaining knowledge of assets primarily based on the traits of learners' mastering conduct and on-line getting to know assets in the getting to know the process, mixed with collaborative filtering algorithm [7]; Yin H used the evaluate matrix technique to set up the hobby contrast matrix and consumer activity comments model, and optimized the suggestion algorithm the use of the hobby remarks model, accordingly realizing the suggestion of distance getting to know sources in MOOC training mode [8].

With the quickly flourish of the Internet and the growing demand for education, a new online teaching model, large-scale online open courses, emerged in 2012. To tackle the troubles of sparse facts and negative advice impact in online path advice, this paper introduces deep learning into course recommendation and proposes an auxiliary information-based neural network model (IUNeu). First of all, the principle and technical details of the basic model of deep learning are deeply studied to provide technical support for the course recommendation model and online learning recommendation system. Based on the existing Neural matrix decomposition model (NeuMF), this paper combines user information and course information, and considers the interaction between them to improve the accuracy of the model to represent users and courses. The auxiliary information neural network model (IUNeu) is integrated into the online learning platform, and the

system is developed by using the front-end and back-end separation design, and the online learning module, course collection module, course recommendation module, resource download module and other functions are realized. Finally, the experimental results were analyzed: under the same experimental conditions, the test experiment was repeated for 10 times, and the RMSE calculation results were averaged. The RMSE value of the neural network model proposed in this paper based on deep learning was 0.85517, with the best performance and high score prediction accuracy, which played a great role in alleviating the problem of data sparsity. This paper innovatively proposes a neural network model based on auxiliary information, which can accurately recommend courses for users and effectively solve the problems of sparse data and poor recommendation effect.

## II. DEEP LEARNING TECHNIQUES IN MOOC

Deep learning is based on an artificial neural network (ANN), which is a mathematical model that can learn by itself and constantly adjust to bring the results closer to reality. As early as 1943, mathematical logician W Pitts and psychologist W S McCulloch proposed the concept of neuron, the core structure of neural network, which gradually developed into a research hotspot in the field of artificial intelligence [9]. With the development of artificial neural networks, the structure of the network becomes more and more complex, and people call artificial neural networks "deep learning". In current years, deep studying methods have been extensively used in the fields of information, medicine, economics, control, transportation, psychology, etc., due to their excellent processing and processing capabilities in image processing, prediction and classification, natural language processing, intelligent robotics, signal processing, and optimal combination [10]. The following is a detailed description of the neural network structures used in the study.

### A. Convolutional Neural Networks

Convolutional neural networks, a typical model of deep learning models, do not use conventional matrix operations but use convolutional operations instead, and have one or more layers of convolutional layers. The structure of a convolutional neural network is made of an entry layer, a hidden layer, and an exit layer like the structure of a normal neural network [11]. Among them, the implicit layer usually consists of convolution, pooling, and full connectivity, while the unique aspect of convolutional neural networks is the convolutional operation and pooling operation, this is the core of convolutional neural networks.

The core building blocks of the convolutional layer are convolutional kernels, each of which consists of one or more elements. Like the neurons of the feedforward network, the elements constituting the convolutional kernel have their own amount of bias and weight coefficients, respectively. The convolution kernel has three parameters, which are the convolution kernel size, the convolution kernel cross step, and the facet padding of the entry data. The convolution kernel dimension is the measurement of the shift matrix used for the convolution operation, and the convolution kernel dimension is any fee smaller than the dimension of the matrix being convolved; the large the dimension of the convolution kernel,

the richer function records can be realized from the convolved photo [12]. The convolution step, on the different hand, defines the dimension of the measurement of the convolution kernel shifted by way of the subsequent convolution operation with recognition of the preceding convolution operation. The fill is a proposed approach to make bigger the dimension of the function map earlier than the convolution operation in order to counteract the shrinking measurement of the characteristic map in the computation and is most frequently utilized via the usage of zero to fill the boundary or with the aid of repeating the boundary facts to gain the purpose of filling [13]. Based on these three parameters being able to calculate the size of the feature map obtained after convolution, assuming that the convolution input of layer  $l+1$  is  $Z^l$  with size equal to  $L_l$ , the convolution output  $Z^{l+1}$  of layer  $l+1$  is:

$$Z^{l+1}(i, j) = \sum_{k=1}^{K_l} \sum_{x=1}^{f_w} \sum_{y=1}^{f_h} [Z_k^l(s_0 i + x, s_0 j + y) w_k^{l+1}(x, y)] + b \quad (1)$$

Here, assuming that the length and width of the feature map

$$L_{l+1} = \frac{L_l + 2p - f}{s_0} + 1$$

are equal, the output feature map size is where  $b$  is the amount of deviation,  $Z(i, j)$  corresponds to the pixel with  $(i, j)$  coordinates of the feature map,  $(i, j) \in \{0, 1, \dots, L_l + 1\}$ ,  $K$  is the number of channels of the feature map, and the three parameters of the convolution kernel: the convolution step size is  $s_0$ , the convolution kernel size is  $f$ , and the number of fill layers is  $p$ .

Neural networks possess a high degree of nonlinearity, and convolutional neural networks are no exception to this rule, and the activation function is a part of the process that produces this important effect [14]. The commonly used activation functions are linear rectifier function, hyperbolic tangent activation function, and sigmoid() function, while convolutional neural networks usually use linear rectifier function as activation function.

For matrix data, a pooling operation is proposed to extract the significant features representing the matrix data, i.e., to select a maximum or average number as the features of a region of data by means of aggregation statistics. On the one hand, the pooling layer enables the down sampling of data, thus reducing the number of model parameters, and on the other hand, the pooling layer is a kind of data dimensionality reduction, enabling the compression of data features, effectively reducing the redundant information contained in the data, streamlining the complexity of the model, and reducing the unnecessary computation and memory consumption of the model [15]. In addition, the pooling layer enables nonlinearity and invariance of data transformations, which can expand the perceptual field while preserving data characteristics. Pooling operations can be classified into three categories: Lp pooling, random/hybrid pooling, and spectral pooling. Mean pooling and maximum pooling in Lp pooling are the most frequently used pooling methods for pooling layers in convolutional neural networks, and the general representation of Lp pooling is:

$$A_k^l(i, j) = \left[ \sum_{x=1}^f \sum_{y=1}^f A_k^l(s_0i+x, s_0j+y)^p \right]^{\frac{1}{p}} \quad (2)$$

Same as the convolutional layer, here so denotes the pooling step,  $(i, j)$  denotes the pixel points.  $P$  denotes the pre-specified parameter, when  $P=1$ , its capacity that the implied fee is taken as the pooling end result in the pooling region, i.e., mean pooling; when  $P=\infty$ , it means that the great value is taken as the pooling result in the pooling region, i.e., maximum pooling. However, both methods lose some information about the image.

### B. TextCNN

TextCNN has great overall performance in textual content classification problems. TextCNN has superb overall performance in textual content classification problems. In particular, TextCNN can effectively extract the shallow feature information of natural utterances of short texts, and it is extensively used in the area of brief texts with its benefit of true outcomes and speedy pace.

Intuitively understood, the convolutional operation of TextCNN is performed based on a one-dimensional convolutional kernel to obtain an n-dimensional feature representation of the text [16]. TextCNN uses pre-trained word vectors word embeddings as input, i.e., a sentence consisting of n words is represented by an  $n \times k$  matrix, where  $k$  is the dimension of the word vector corresponding to each word, here the k-dimensional word embeddings of the  $i$ th word in the sentence are represented using  $x_i \in \mathcal{R}^k$ . First, a convolution operation  $w \in \mathcal{R}^{hk}$  is performed to obtain a feature  $c_i : c_i = f(w \square x_{i,i+h-1} + b)$  by using a convolution kernel on  $x_{i,i+h-1}$ . Where  $x_{i,i+h-1}$  denotes the vector feature matrix of the  $i$ -th to  $i+h-1$ th word in the input matrix,  $w$  is the weight matrix of dimension  $h \times k$ ,  $b$  is a functional deviation and  $f()$  is a non-linear function.  $i$  starts from 1 and is added 1 each time until  $i$  equals  $n-h+1$ , and the  $c_i$  obtained each time is stitched to get the vector  $c = [c_1, c_2, \dots, c_{n-h+1}]$  after one convolution. Multiple convolution kernels are set up by defining different  $h$ , in order to extract different feature carriers and use them together as the convolution layer's output. Then, a maximum pooling operation is performed, i.e., a fixed-length vector representation is obtained by selecting the largest feature from the  $c$  vectors obtained from different convolution kernels and stitching them together to form a new vector [17]. Last, the globally connected layer activated using softmax() is accessed to output the probability values corresponding to each category.

### C. Gated Circulation Unit

The gated recurrent unit (GRU), like the long- and non-permanent reminiscence network, is an enchantment on the trendy recurrent neural network, whose mannequin shape is proven in Fig. 1.

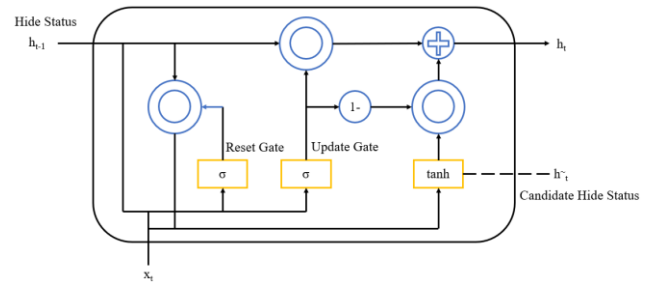


Fig. 1. GRU model structure.

The advantage of GRU over LSTM is that it uses a gating mechanism, while significantly reducing the problem of vanishing gradients. The GRU network structure contains two gating structures, one for update gating and one for reset gating. As a variant of recurrent neural networks, the gating mechanism controls which information can be transmitted through the network model to the output layer. In addition, these two gating structures do not discard data because of the length of the depth of the operation or the uselessness of some data for the resultant output but are able to preserve various types of information in the data sequence over time.

### D. Self-attentive Mechanism

Self-attention mechanisms were first proposed as an important component of Transformer (ML architecture that has been successfully applied to various NLP tasks, especially sequence-to-sequence tasks, such as machine translation and text generation). The attention mechanism learns as the model fits the data results, and instead of just performing a comprehensive analysis of the full information, the work is focused on discovering important local information and analyzing it [18]. The self-attention mechanism is used to discover the parts of the input data that deserve more attention by interacting between each input two-by-two. The result of the interaction and aggregation of the input data is the output of the self-attentive mechanism, i.e., the attention score.

The inputs and outputs of the self-attentive mechanism are sequences, and assuming  $x_i$  is the input sequence, the detailed derivation of the procedure is as below.

- 1) Each input is obtained by multiplying by a matrix to get  $a_i$ , and then multiplying by 3 different vectors  $W^q, W^k, W^v$  to get  $q^i, k^i, v^i$  respectively.
- 2) Calculate the weight of  $q$  and  $k$  by the similarity calculation method, for example, take the first input as an example,  $\alpha_{1,i} = q^1 \square k^i / \sqrt{d}$ , and then  $\hat{\alpha}_{1,i} = \exp(\alpha_{1,i}) / \sum \exp(\alpha_{1,i})$  need to be normalized by softmax.
- 3) Multiply  $v_i$  with the corresponding  $a_{1,i}$  and then add them to get the output vector  $b_{1,i}$  of the first input.
- 4) Repeat the above steps to obtain the corresponding output vector of the input sequence.

### III. DEEP LEARNING-BASED COURSE RECOMMENDATION MODEL

#### A. Neural Matrix Decomposition Model

The NeuMF model is made up of two parts: the GMF (generalized matrix factorization) model and the MLP (multilayer perceptron) model. In the GMF model, a linear kernel is applied to simulate the interaction between features; in the MLP model, a nonlinear kernel is applied to learn the interaction function [19]. Thus, the NeuMF model has both linear and nonlinear modeling capabilities, and the specific application structure of the model in course recommendation is shown in Fig. 2. In the figure, the left side of the model is the GMF part and the right side is the MLP part. The model is bottom-up, starting with the input layer, which contains one-hot codes for user and item IDs, and passes these codes to the embedded layer to represent the corresponding users and items. The output of the two-part molecular model is connected, and the predicted values  $\hat{y}$  are obtained in the output layer by the Sigmoid activation function, which  $\hat{y} \in \{0,1\}$  indicates the user's preference for the item (1 for like and 0 for dislike). The weights of each layer are trained by backpropagation.

The model-specific expressions are:

$$\hat{y}_{u,i} = f_{out} \left( W_{out} \left[ X^{GMF}, X^{MLP} \right] \right) \quad (3)$$

$$X^{GMF} = p_u^{GMF} \cdot q_i^{GMF} \quad (4)$$

$$X^{MLP} = f_L \left( W_L \left( \dots f_1 \left( W_1 \left[ p_u^{MLP}, q_i^{MLP} \right] + b_1 \right) \dots \right) + b_L \right) \quad (5)$$

where:  $X^{GMF}$  and  $X^{MLP}$  are the potential feature vectors of the GMF and MLP model parts, respectively,  $\hat{y}_{u,i}$  is the predicted value,  $f_{out}$  and  $W_{out}$  are the activating features weights of the export layer, respectively,  $p_u^{GMF}$  is the user potential feature vector in  $X^{GMF}$ ,  $q_i^{GMF}$  is the item potential feature vector in  $X^{GMF}$ ,  $p_u^{MLP}$  is the user potential feature vector in  $X^{MLP}$ ,  $q_i^{MLP}$  is the item potential feature vector in  $X^{MLP}$ ,  $[\ ]$  denotes the internal element connection,  $f_L$  and  $W_L$  are the activation function weights of the Lth layer, separately, and  $b_1$  and  $b_L$  are the biases of the 1st and Lth layers, separately.

The detailed training procedure of the NeuMF model is as following: 1) Infant layer: extract the ID information of users and courses in the training set and encode them using one-hot. 2) Embedded layer: use the infant layer as the infant, independent embedded layers are used in the model, the GMF model on the left side of the model and the MLP model on the right side, each layer selects the linear rectification function as the activation function and outputs a  $1 \times n$  dimensional matrix. 3) Output layer: The outputs of the GMF and MLP models are linked first and last, and the results are mapped to  $[0, 1.0]$  by the Sigmoid activation function to obtain the prediction results  $\hat{y}$ .

The NeuMF model is applied to analyze the data of MUCN, and compared with the traditional user-based k-nearest neighbor algorithm, and MFALS algorithm, and the hit rate is

used as the index for performance evaluation in the experiments by the leave-one-out method. It is found that the hit rate of the UserKNN algorithm is 0.075 because it does not involve the underlying feature vector length  $n$ ; MFALS involves the construction of the user matrix and item matrix, and its hit rate varies with the increase of  $n$  and finally stabilizes at about 0.110; the hit rate of NeuMF model is higher than that of UserKNN algorithm and MFALS algorithm, and its hit rate is greater than 0.500 [20]. The reason for this is that the UserKNN algorithm uses similar historical behavior data of the target user and  $k$  neighbors to predict the course resources that users may like in the future, while the MFALS algorithm recommends course resources to users based on the high or low item history ratings, and both algorithms cannot better meet the actual demand of online course resource recommendation. Therefore, this study considers improving the NeuMF model by transforming the recommendation problem into a classification problem. A more efficient neural network model based on auxiliary information (item and user information) is proposed. The model is constructed by analyzing users' historical learning records and implementing a classification function with users and courses as the minimum unit, with positive classes indicating users' likes and negative classes indicating users' dislikes. The problems of the above UserKNN and MFALS algorithms for course recommendation are improved in the model to improve the recommendation effect.

#### B. IUNeu Model

In the IUNeu model, the input information in the Input layer is divided into two parts: 1) user-related information, such as user ID, user's gender, occupation, etc., where the information other than user ID is called user auxiliary information [21]; 2) course-related information, such as course ID, course's label, course category, etc., where the information other than course ID is called course auxiliary information. The form of the input information is [User ID, Male, Front-end Engineer, ...], [Course ID, Front-end Technology, JS Basic Design, ...]. The specific model architecture is illustrated in Fig 3. It can be observed that the user-course auxiliary information (hereafter collectively referred to as auxiliary information) is involved in all stages of the overall model. During training, the auxiliary information is used as input along with the user ID and course ID; in the GMF (MLP) composition model, the user ID, course ID, and user-course auxiliary information are fused to participate in linear modeling (nonlinear modeling); and in the Sigmoid activation function output, the auxiliary information is also fused.

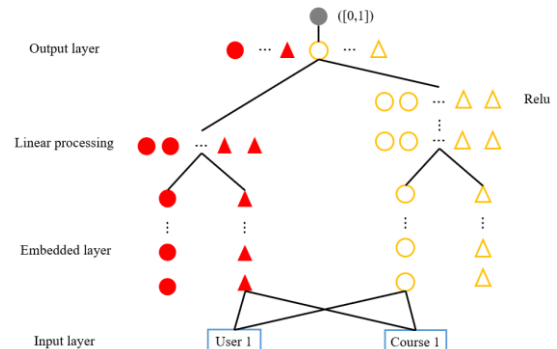


Fig. 2. Structure of the NeuMF model.

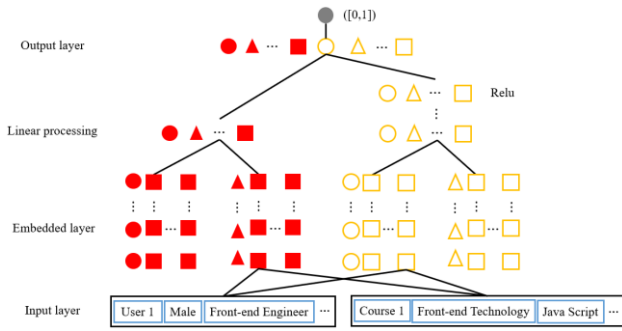


Fig. 3. IUNeu model structure.

The  $X^{GMF}$ , and  $X^{MLP}$  expressions in the IUNeu model structure improvement equation (6) are:

$$X^{GMF} = P_a^{GMF} \cdot q_i^{GMF} = (u_0^{GMF} \oplus u_1^{GMF} \oplus \dots \oplus u_m^{GMF}) (c_0^{GMF} \oplus c_1^{GMF} \oplus \dots \oplus c_m^{GMF}) \quad (6)$$

$$\begin{aligned} X^{MLP} &= f_L \left( W_L \left( \dots f_i \left( W_i \left[ P_a^{MLP}, q_i^{MLP} \right] + b_i \right) \dots \right) + b_L \right) \\ &= f_L \left( W_L \left( \dots f_i \left( W_i \left[ u_0^{MLP} \oplus u_1^{MLP} \oplus \dots \oplus u_m^{MLP}, \right. \right. \right. \right. \\ &\quad \left. \left. \left. c_0^{MLP} \oplus c_1^{MLP} \oplus \dots \oplus c_m^{MLP} \right] + b_i \right) \dots \right) + b_L \right) \quad (7) \end{aligned}$$

where:  $u_x^{GMF} (u_x^{MLP})$  is the user word vector,  $x=0$  denotes user ID,  $x \neq 0$  denotes user auxiliary information, such as gender, occupation, etc.;  $c_x^{GMF} (c_x^{MLP})$  is the course word vector,  $x=0$  denotes course ID,  $x \neq 0$  denotes course auxiliary information, such as data mining, web front-end, etc.;  $\oplus$  denotes the expansion of the original fixed  $1 \times 1 \times n$  tensor into a  $1 \times m \times n$  tensor, i.e., using the user (course) vector and the user auxiliary information (course auxiliary information) vectors to extend the original  $1 \times n$ -dimensional matrix, where  $n$  is the potential feature vector length and  $m$  is the infeed information length. Therefore, the outputs of GMF linear kernel modeling and MLP nonlinear kernel modeling are not only influenced by the IDs of the users and courses themselves but also determined by the content attributes of the users and courses themselves.

The detailed training procedure of the model is as following: 1) Infant layer: extract the information related to users and courses in the training set, including user gender, user occupation, course major category, course minor category, etc., and encode them with one-hot. 2) Embedding layer: use the infant layer as the infant, and output a  $1 \times m \times n$  dimensional matrix. By flattening the operation, the length is extended to  $mn$  by adding auxiliary information to the original NeuMF model of length  $n$ , where  $(m-1)n$  is the length of the auxiliary information vector. 3) Output layer: The GMF sub-model multiplies the flattened two results point by point as the linear output result, and the MLP sub-model connects the flattened results first and last to form a new vector and serve as the loser of the neural network (its activation function adopts the Relu activation function). Then the outputs of the GMF and MLP models are connected first and last and mapped to  $[0,1.0]$  by the Sigmoid activation function as the prediction results.

### C. Collaborative Filtering Model for Neural Networks with Fused Attention Relations

Along with the development of the Internet, social networking has become an essential element of Internet applications. In addition to social networking platforms (e.g., Weibo, Zhihu, and Twitter) that are socially focused, many current Internet applications contain social elements, and many MOOC platforms, as one of the Internet applications, have social features [22]. In the AIMOC platform each user can follow their favorite users, which may include leaders in their own learning field, and become their fans, also called followers these followed people are called followers.

As a typical social network platform, Weibo can create a celebrity effect through the influence of well-known users who have a large number of followers. Unlike typical social networking platforms, MOOC platforms with social networking elements also have a celebrity effect because, as open e-learning platforms, the famous users here are more likely to be leaders in a certain learning field. Therefore, in MOOC platforms, the current interest preferences of these followers in the course are likely to influence their followers' choice of course.

Attention relationship as a specific expression in social networks, a recommendation algorithm AttentionRank+ is proposed, which considers the influence of the behavior of the followed on the behavior of the followers and improves the recommendation algorithm performance by fusing attention relations. In this article, we will also build a collaborative neural network filtering model (FIUNeu) based on the IUNeu model with fused attention relations to enhance the recommender effectiveness of the course recommender system.

The NeuMF model is a combination of models in the horizontal direction and is a fusion of recommendation algorithms. In this paper, the construction of the FIUNeu model is a fusion in the vertical direction, which is the fusion of recommendation results. The main idea of the FIUNeu model is to give the corresponding weight value to each course in the TopN courses recommended to the current user based on the IUNeu model by calculation. The FIUNeu model is described as follows:

Let the current user be  $u$ , the number of users he follows is  $p$ , and the maximum number of users he follows be  $M$ . First, the TopN courses  $(c_1, c_2, \dots, c_{n-1}, c_n)$  are recommended to user  $u$  by the IUNeu model, and the initial weights of these  $K$  courses are set to  $(n, n-1, \dots, 2, 1)$ . For the  $i$ th recommended course  $c_i$  of the current user  $u$ , where  $i \in (1, 2, \dots, n-1, n)$ , and  $q$  users among all users followed by this user choose this course, the weight formula for this course  $c_i$  is

$$f(i) = \frac{w_1(n-i+1) + w_2 \left( \alpha \frac{q}{p} + \beta \frac{p}{M} \right) n}{2n} \quad (w_1 + w_2 = 1, \alpha + \beta = 1) \quad (8)$$

Where  $w_1$  and  $w_2$  denote the proportion of the influence of the IUNeu model and attention relationship on the value of course  $c_i$  weight,  $\alpha$  and  $\beta$  denote the proportion of attention and the proportion of the number of attentions on the influence of



attention relationship, in this paper FIUNeu model for the above parameters, are selected as 0.5 through the above formula for this TopN course weights are recalculated, then according to the weights of this TopN course re-ranking. Finally, the TopK courses are recommended to the current users.

The model framework of FIUNeu is illustrated in Fig. 4:

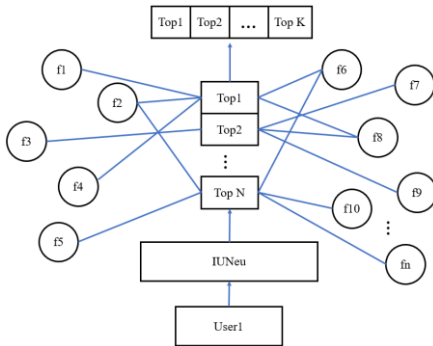


Fig. 4. FIUNeu model.

#### IV. DESIGN AND IMPLEMENTATION OF AN ONLINE LEARNING RECOMMENDATION SYSTEM

##### A. Overall System Design

1) *System logical architecture design:* The logical architecture of the system consists of five levels: the base device level, the data level, the middle level, the application level, and the user level. The device layer provides the basic hardware configuration such as network, server, operating system, and other hardware, and is the basic link of the logical architecture. The data layer is responsible for data storage and management, like user data, course data, log data, etc. The middle level is responsible for handling the business logic, including the recommendation algorithm. The application level is primarily concerned with invoking the algorithms of the middle layer according to the user data and processing the commands sent by the users [23]. The user level is concerned with user interaction, sending user requests, and other operations.

2) *System technical architecture design:* The system adopts the most commonly used three-layer technical architecture: front-end display layer, business logic layer, and data storage layer. Users first send request instructions in the front-end display layer. The business logic layer receives the instructions and then calls each functional layer component and gets the required data from the data storage layer for business logic processing and finally returns the data to the front end [24]. The layered technology architecture can solve the problem of system coupling and adopt the development method of separating front and back ends, which can improve the scalability of the system and the speed of development.

Front-end display layer: this layer mainly interacts with users and sends requests, which are processed by the business logic layer and returned to this layer, and then rendered and presented to users, and user behavior data can be collected

through the front-end display layer. The front-end pages in the system are developed based on the Bootstrap framework, JavaScript, CSS3, and other technologies. The simple and friendly system interface is more user-friendly and can enhance user stickiness.

Business logic layer: This layer contains a large number of functional components, which are charged with the logical processing of business. The system adopts the Django framework and divides the business logic layer into three layers through Django's MTV pattern: the Model layer is responsible for reading, writing, and updating data from the database, the Template layer has rich template functions and is responsible for encapsulating and constructing HTML, and the View layer performs business processing and is the bridge between the Model and Template layers. Different roles have different business logic.

Data Store Layer: The data store layer is primarily responsible for storing user behavior data, log data, and other source data and a relational database is more convenient for developers and backend managers to maintain and manage. Therefore, the data storage layer uses the MySQL database to store and manage data and adopts md5 encryption to ensure the security of user data and avoid security risks caused by data leakage.

##### B. System Functional Module Design

The online mastering suggestion device is divided into three roles: pupil user, instructor user, and administrator. Student customers can log in to the gadget to learn about the course, consider the course, whole path assignments, download route sources, and different operations. Teachers can log in to the gadget to keep and manipulate route resources, pupil records, and private information, and directors can view and alter trainer information, scholar statistics, and route information.

The practical modules of the gadget are basically divided into 4 core modules: consumer registration and login module, online mastering module, route advice module, and historical past administration module.

1) *User registration and login module* If a new user first registers, fill in the registration page with standard information including a verification code, an account password, and other information, and then jump to the system home page after the background verification and storage of data, the registration page is concise and more user-friendly [25]. If the user is registered in the database, the user is prompted to log in directly. The cell phone verification code verification function uses the Ronglian communication cloud server to achieve the verification code acquisition. Enter the personal home page to improve the basic information, such as a nickname, birthday, gender, address, and other information.

The main classes involved in the user login module are: LoginForm(), DynamicLoginView(), SendSmsView(), LoginView(), and ChangePwdForm(), which correspond to the functions of getting login form content, logging in after registration, verifying cell phone verification code, login judgment, and changing password, respectively.

2) The online mastering module is one of the core features of the online studying advice system, which makes hints via the behavioral information generated by way of the customers of this module. Users can find out about the course, and whole route assignments, download direction resources, and consider the direction and different features in this module. After logging into the system, customers can pick out the direction they are involved in from the direction list on the domestic web page and begin getting to know the course or proceed to get to know the taking part guides in the private middle My Courses page. After getting into the route important points page, customers can view the route introduction, trainer and organization profiles, path details, etc. They can pick to collect, begin learning, etc. After clicking begin learning, they can choose the corresponding chapter for learning, commenting, and scoring. In addition to learning the course, you can also download the materials and view the course assignments on the course page.

The main classes involved in the online learning module are: CourseListView(), CourseLessonView(), CourseDetailView(), CourseCommentsView(), VedioView(), and HomeworkView(), which are corresponding to get course list, get course chapter list, course comments, video learning, homework completion, and other functions.

3) The course recommender mode offers users a more precise course push, which effectively enhances users' learning productivity. The system uses different recommendation algorithms for users with different login statuses. For users who are not logged in and users who have not studied any courses, the popularity-based recommendation algorithm is used to make recommendations based on the number of course learners, and for users who are logged in, the hierarchical attention recommendation algorithm DHRAA algorithm, which integrates auxiliary information, is proposed in this paper to make recommendations.

The popularity-based recommendation algorithm is to sort the courses in reverse order according to the number of course learners, exclude the courses currently taken by users and select the top five courses for a recommendation, which can effectively tackle the user cold start issue and improve the recommendation efficiency.

This paper proposes a deep recommender algorithm according to auxiliary information that extracts the user id, user occupation, teacher institution, course id, course title, course review, course rating, and other information from the local database into the trained model, and calculates the list of course recommendations that match the user's characteristics.

The main classes involved in the course recommendation module are: CourseListView, CourseCommentsView, and CourseRecommView, which correspond to course list, course evaluation, course recommendation, and other functions respectively.

4) *The backend administration mode contains two types of roles:* teachers and administrators, mainly for user profile

management, course material management, and permission management. User information management refers to the management of information of all roles on the platform and the addition, deletion, and checking of information of teachers' organizations. Course resource management refers to viewing and modifying course videos, course materials, course assignments, and other resources. When reviewing the content of comments submitted by users, administrators can query and delete user comments if they are found to be non-compliant.

### C. System Database Design

The device makes use of MySQL database for records storage and management, and the statistics tables of every module include important information tables such as consumer statistics table, teacher records table, direction data table, route assessment information table, route project facts table, and direct aid facts table. The ER model is a conceptual design used to describe the relationships between entities, and it accurately describes various relevant data characteristics and their mutual restrictions. The EER model includes all the modeling concepts introduced by the ER model [26]. In addition, it includes the concepts of subclasses and super classes, as well as the concept of association types or categories, which are used to represent the association of objects of different entity types.

The user message table includes information about the user attributes needed in the recommender algorithm and stores the registration forms filled in by the user. The teacher information table stores the personal information of teachers, such as teacher id, teacher organization, teacher title, years of work, and other personal information, which is associated with the course organization table through the foreign key org\_id. The path records desk includes the direction attribute facts required in the advice algorithm, which primarily data the small print of every difficulty route such as route description information, route situation level, quantity of path rookies, and different information. The path contrast records desk shops the person comparison and ranking facts of the course, which files the core statistics of the suggestion algorithm, and the route identification is set as the principal key in order to facilitate the advice algorithm to precisely stumble on the precise course. The direction venture information desk shops special facts about the venture together with the challenge title, theme options, etc. A route corresponds to more than one assignment. The course resources data table is used to store course-related resources, which are shown on the course details page, including software and documents, etc.

## V. EXPERIMENTAL TESTS AND RESULTS ANALYSIS

### A. Experimental Test Protocol

The experimental test computer hardware environment is as follows: processor Intel Corei9-9900K, graphics card GeForce RTX 2080T, memory 32GB The computer software environment used to run all experiments in the Python environment, using the Caffe tool to train and test the AlexNet network model. The data from the online learning platform of the China University MOOC National Excellence Course was used as the experimental data set.

To validate the proposed algorithm in this paper, the algorithm was objectively evaluated by calculating the root mean square error, which was calculated as follows:

$$RMSE = \sqrt{\frac{\sum_{u,v} (R_{uv} - \hat{R}_{uv})^2}{|R_t|}} \quad (9)$$

Where:  $R_{uv}$  denotes the true rating of course  $v$  by user  $u$ ,  $\hat{R}_{uv}$  denotes the predicted rating, and  $|R_t|$  denotes the number of ratings in the test set. It can be seen that the lower the RMSE value, the higher the accuracy of the rating prediction and the better the performance of the recommendation system.

**B. Analysis of Experimental Results**

In order to verify the performance of the proposed algorithm, it is compared with other recommended algorithms, including Random method, UserAvg method, cooperative filtering method (CF) and non-negative matrix method (NMF). In order to ensure the stability of the algorithm, RMSE calculation results were averaged after repeated test for 10 times under the same experimental conditions. The comparison of results of different algorithms is shown in Fig. 5.

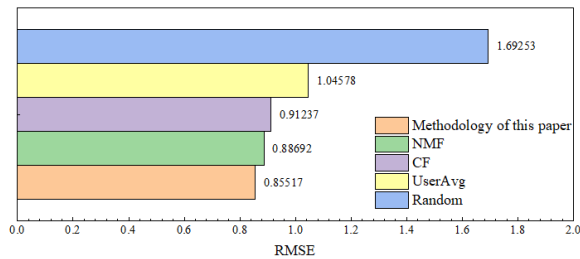


Fig. 5. Comparison of the results of different algorithms.

As can be seen from Fig. 5, RMSE value of Random method is 1.6925, RMSE value of UserAvg method is 1.0458, RMSE value of collaborative filtering method is 0.9124, and RMSE value of non-negative matrix method is 0.8869. It can be shown that the algorithm proposed in this paper performs optimally on the evaluation index of RMSE, with higher accuracy of rating prediction, which is useful for alleviating the problem of sparse rating data.

Next, in anticipation of verifying the influence of different experimental factors on the experimental results, this paper will verify the performance of the FIUNeu model, IUNeu model, and NeuMF model under different lengths of potential feature vectors and different TopNs based on different candidate course sets recommended by FIUNeu model

1) The candidate course set size is 30, and the performance of the three models is compared under different potential feature vector lengths and different TopN.

The FIUNeu model recommends the Top 10 courses twice on the basis of the 30-candidate course set recommended by the IUNeu model, while the IUNeu model and the NeuMF model directly select the Top 10, and verify the influence of different potential feature vectors on these three models on this

basis. The vector lengths were selected as (4,8,12,16,20), and the experimental results are shown in Table I below:

TABLE I. WHEN THE COURSE SET IS 30, THE INFLUENCE OF DIFFERENT POTENTIAL FEATURE VECTOR LENGTHS ON THE MODEL

	NeuMF	IUNeu	FIUNeu
HR	0.5751	0.5939	0.5971
	0.5901	0.6081	0.6132
	0.5931	0.6064	0.6092
	0.5927	0.6042	0.6073
	0.5915	0.6026	0.6064
NDCG	0.3362	0.3632	0.3739
	0.3633	0.3775	0.3931
	0.3663	0.3782	0.3945
	0.3663	0.3768	0.3928
	0.3661	0.3764	0.3931

The FIUNeu model is based on the set of 30 candidate courses recommended by the IUNeu model, and the effect of different TopN on the three models is verified by the feature vector length selected as 8 and TopN selected as (5,10,15,20), as illustrated in Fig. 6.

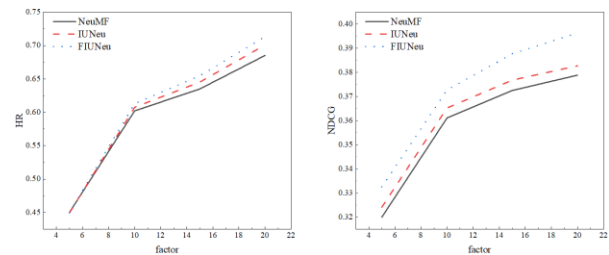


Fig. 6. Effect of different TopN on the model.

2) Here the candidate course set size is chosen to be 50, and the above two sets of experiments are conducted again and with the same experimental settings. As illustrated in Table II and Fig. 7.

TABLE II. WHEN THE COURSE SET IS 50, THE INFLUENCE OF DIFFERENT POTENTIAL FEATURE VECTOR LENGTHS ON THE MODEL

	NeuMF	IUNeu	FIUNeu
HR	0.575	0.594	0.597
	0.59	0.608	0.6142
	0.5929	0.6064	0.6092
	0.5927	0.6042	0.6073
	0.5914	0.6026	0.6067
NDCG	0.3356	0.3632	0.3741
	0.3628	0.3775	0.3931
	0.3661	0.3783	0.3938
	0.3656	0.3771	0.3945
	0.3659	0.3768	0.3928

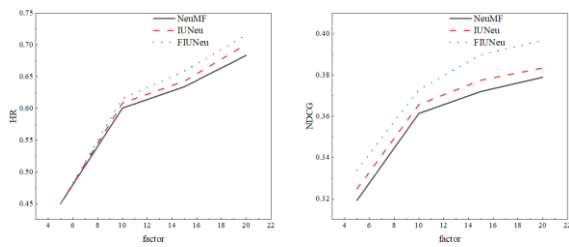


Fig. 7. Effect of different TopN on the model.

This paper only lists the experimental comparison between the case of 30 candidate course sets and 50 selected course sets recommended by IUNeu, and the experimental results based on other candidate course sets are roughly the same. From the above experimental results based on different lengths of potential feature vectors and different TopN settings, we can see that FIUNeu can indeed have better recommendation performance. From the above sets of experiments, we can find that FIUNeu, as an extension of the IUNeu model, is dependent on the IUNeu model for its performance, i.e., FIUNeu can make the IUNeu model perform better.

## VI. CONCLUSION

In this paper, we study the course recommendation algorithm in the MU environment. Firstly, a neural network model based on auxiliary information (IUNeu) is proposed, and an improvement is made to the IUNeu model by fusing attention relations into the IUNeu model to obtain the FIUNeu model. The specific conclusions are as follows:

1) Considering the influence of the user and the content in the course on the model, a neural network model that fuses user and course information is constructed using the personal attributes of the household as well as the course information. On the basis of the original model features (user and course codes), the features such as the user's personal information and course categories are further fused to make the model's characterization of user and course features more accurate.

2) In this paper, the construction idea and the concrete implementation of the improved FIUNeu model based on the IUNeu model are presented, and the improved model FIUNeu is experimented on real data sets with the IUNeu model and NeuMEF model through MapReduce, so as to verify the performance of the three.

3) Under the same experimental conditions, the test experiments were repeated 10 times, the RMSE calculation results were averaged, and the RMSE value of the proposed neural network collaborative filtering model (FIUNeu) based on deep learning in this paper was 0.85517. The experimental results based on different potential feature vector lengths and different TopN settings show that FIUNeu can indeed have better recommendation performance. FIUNeu is an extension of the IUNeu model, its performance is dependent on the IUNeu model, i.e., FIUNeu can make the IUNeu model perform better.

The neural network model of auxiliary information proposed in this paper has some limitations. The cold start problem of the recommendation system, because it only relies

on the user's feedback on the item, the newly added users and items need a period of data accumulation to reflect the recommendation effect. This will affect the new user experience. The comparison of algorithms in this paper are all offline tests, which cannot fully reflect the experience of real users. Due to the lack of real user feedback, online A/B testing is not possible. Therefore, in future work, researchers should work with companies to deploy algorithms into real production environments and optimize algorithms and system designs based on feedback from real users.

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# Object Detection-based Automatic Waste Segregation using Robotic Arm

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**Abstract**—Today's overpopulation and fast urbanization present a significant challenge for developing countries in the form of excessive garbage generation. Managing waste is essential in creating sustainable and habitable communities, but it remains an issue for developing countries. Finding an efficient smart waste management system is a challenge in current research. In recent years, robots and artificial intelligence have influenced a wide range of industries, especially waste management. This research proposes a waste segregation system that integrates the robot arm and YOLOv6 object detection model to automatically sort the garbage according to its type and achieve real-time requirements. The proposed algorithm utilizes the pros of the hardware-friendly architecture of YOLOv6 while keeping high detection accuracy in detecting and classifying garbage. Moreover, the proposed system creates a 3D model of a 4 DOF robotic arm by CAD tools. A new approach based on a geometric method is proposed to solve the inverse kinematics problem in order to precisely calculate the proper angles of the robot arm's joints via a unique solution with less computational time. The proposed system is evaluated on a modified TrashNet dataset with seven garbage classes. The experiments reveal that the proposed algorithm outperforms the other recent YOLO models in terms of precision, recall, F1 score, and model size. Furthermore, the proposed algorithm consumes approximately fractions of a second for picking up and placing a single object in its proper basket.

**Keywords**—Smart recycling; inverse kinematics; object detection; 4 DOF robotic arm; YOLOv6

## I. INTRODUCTION

The amount of municipal solid garbage produced each year globally is 2.01 billion tonnes, with at least 33% of it needing to be handled in a way that protects the environment. Worldwide garbage is anticipated to increase worldwide to 3.40 billion tonnes by 2050, more than double the population growth over that time. Even if there are many ways to dispose of the garbage gathered today, the ecological system's sustainability and safety are nevertheless negatively impacted. Reusing and recycling as much trash as you can is thus the best option. In certain nations, the sorting process is primarily manual. Human sorters are manually stationed beside the material-transfer conveyor belts to identify the material type. One of its typical issues is that manual sorting mainly relies on visually examining the mixed garbage moving on the

conveyor. A material surge might occur, leaving a sorter with insufficient time to understand all of the items handed to them. Moreover, health concerns, including skin difficulties, are unavoidable [1]. Therefore, manual sorting suffers from low productivity and increased health risks. Recently, robotic technology has replaced the time-consuming human garbage sorting system with an automated one. The robot is integrated with deep learning technology for detecting and classifying recyclable objects on the conveyor belt and picking and placing these objects in the appropriate baskets. Different convolutional neural networks (CNN) have been proposed for waste classification.

In [2], five deep learning architectures were applied for classifying Trashnet dataset, including: DenseNet121, DenseNet169, InceptionResnetV2, MobileNet, and Xception. Currently, Gondal et al. proposed a hybrid technique for smartly classifying real-time waste [3]. This technique applied to two machine learning methods: a multilayer perception and a multilayer convolutional neural network (ML-CNN). The former classifies the waste into metal or non-metal waste, while the latter specifies the class of non-metal waste (paper, plastic, rubber, cotton, and wood). The camera is positioned in front of a conveyor belt to take an image of each trash item. After image categorization, an automatic holder is used to pick up the trash item and place it into the assigned bucket. Although some of these CNN models achieve better classification accuracy, they are limited to classifying one object per image. If the image has many objects as the images captured from the conveyor belt, CNN model classifies the most dominant object in the image. On the contrary, object detectors are used in this case to both localize and classify various objects in the same image. Several methods are proposed for object detection, and their designs are based on two approaches: one-stage object detection and two-stage object detection. One-stage detectors are distinguished by their high inference speeds because they consider computing speed and combine object localization and classification to output. However, two-stage detectors are characterized by high localization and identification accuracy because they employ independent calculations for object localization and classification, increasing the accuracy and speed calculations. SSD and YOLO are models of one-stage detectors, and RCNN, Fast RCNN, and Faster RCNN are models of two stages



detectors. In waste recycling applications, speed is considered essential for picking up many objects in real-time. Therefore, most of the research in this application applies the one-stage detectors in their systems.

WEN MA et al. [4] propose a Lightweight Feature Fusion Single Shot Multibox Detector (L-SSD) algorithm for waste detection and classification. L-SSD is an enhanced SSD with a lightweight and a feature fusion module to improve its performance and detect waste with a small volume. The L-SSD is trained on a collected dataset consisting of five classes: cardboard, glass, paper, plastic, and metal. Daniel Octavian Melinte et al. [5] fine tune the Single Shot Detectors (SSD) architecture with MobileNetV2 base network on the TrashNet dataset using appropriate training hyper parameters to be carried out on autonomous robot system.

Berardina De Carolis [6] detect and report the presence of abandoned waste through real-time analysis of video streams based on an improved YOLOv3. A new dataset containing four classes: garbage bag, garbage dumpster, garbage bin, and blob, is used to fine-tune the improved YOLOv3. Saurav Kumar et al. [7] apply YOLOv3 in the waste segregation application to detect six classes of trash objects (namely: cardboard, glass, metal, paper, plastic, and organic waste). Aria Bisma Wahyutama et al. [8] design a trash bin that is competent for automatically separating and collecting recyclable trash utilizing YOLOv4 object detection. The YOLOv4 model is installed on Raspberry Pi. As the trash object is detected, a servo rotates the trash bin cover to disclose the correct room for the user to throw away the trash. Additionally, the study [9] submitted a smart waste detection utilizing YOLOv3, YOLOv4, YOLOv3-tiny, and YOLOv4-tiny models. A nature-inspired searching strategy was applied to fine-tune the learning rate of YOLO structures. The results reveal that YOLOv3 provides the best results.

Anbang Ye et al. [10] propose a YOLO model with Variational Autoencoder (VAE) to increase the detection accuracy and decrease the model size for edge devices. The model has been trained on a generated dataset from the 2020 Haihua AI Challenge (2020 HAC), a garbage sorting competition. Andhy Panca Saputra et al. [11] propose YOLOv4 and YOLOv4-tiny for garbage detection and train the model on a modified version of the TrashNet dataset with a smaller number of classes and a higher number of images.

Deep Patel et al. [12] introduce a comparative study for applying five object detector techniques which are EfficientDet-D1, SSD ResNet-50 V1, Faster R-CNN ResNet-101 V1, CenterNet ResNet-101 V1 and YOLOv5M on a custom garbage dataset collected from the internet. The comparison results demonstrate that YOLOv5M has reliable and precise predictions. Sylwia Majchrowska et al. [13] localize and classify the litter through two networks, EfficientDet-D2 for localization while EfficientNet-B2 for classification. The algorithm is applied to new benchmark datasets, namely detect-waste and classify-waste merged from different datasets annotated similarly for the seven waste categories.

Other researchers, on the other hand, concentrate on the issue of designing and determining the angles of the joints of

the robot arm manipulator. Indra Agustian et al. [14] propose the forward kinematics DH and the inverse kinematics Pseudoinverse Jacobian method to determine the right angle of each joint of the manipulator links. Adnan Rafi Al Tahtawi et al. [15] use inverse kinematics to design a small-scale three-degree of freedom (3-DoF) robot arm for a pick-and-place mission. Lately, the robot development time has been shortened, and the speed and quality of the robot design have been improved by designing robots based on SolidWorks 3D CAD [16]. Doo Sung Ahn et al. [17] present a platform that integrates Solidworks and Simscape tools for designing control algorithms of robot manipulators. Simscape Multibody imports 3D models and creates bodies, constraints, actions, and joints with parametrization by mathematical expressions described in MATLAB using data from SolidWorks.

Over and above, some researchers are directed toward integrating the robot arm with object detection techniques for waste segregation. Xuebin Yue et al. [18] propose a lightweight object detection model YOLO-GD (Ghost Net and Depthwise convolution) for empty-dish recycling robots to recycle dishes in restaurants and canteens automatically. The catch point coordinates of the various types of dishes are extracted using a catch point computation based on image processing. The target dishes are recycled using the coordinates by manipulating the robot arm. Qisong Song et al. [19] propose an improved YOLOv5 to achieve more precise positioning and recognition of objects for grasping robots using the wooden block image dataset. Jinqiang Bai et al. [20] present a moving pick-up robot that automatically moves on grass for garbage cleaning. The robot is designed based on a navigation algorithm that uses SegNet and ResNet to segment, classify, and localize objects. If the trash is detected, the manipulator picks it up and places it in the trash container. Jaeseok Kim et al. [21] integrate deep learning with the industrial robotic arm to classify garbage according to its material. First, the points cloud is processed utilizing the Kinect. Following this step, grasping tools on the robot arm are used to grab the objects. The items are then seated in front of an RGB camera, which categorizes them, based on their composition, using a modified LeNet model into two main classes: carton and plastic. Eventually, all the collected items are put in a box beside the manipulator.

Although all of the approaches mentioned above have made some progress in waste segregation, there is still the issue of satisfying high detection accuracy and real-time segregation simultaneously in practical applications. Thus, this research proposes a real-time waste segregation system for sorting garbage. The system is designed to integrate two modules: the waste segregation module and the robotic module. The waste segregation module exploits the advantages of the hardware-friendly architecture of YOLOv6 [22] for detecting and localizing the garbage with high detection accuracy and in real-time. In the robotic module, a robot arm is designed, and its design overcomes the inverse kinematics problem by accurately computing the angles of the arm's joints based on a simple geometric method. The advantage of this geometric method is to solve the inverse kinematics problem using a unique solution for each required joint configuration, which reduces the computational time and accelerates the response.

The robot arm architecture is created in CAD software (SolidWorks). The main contributions of this work can be summarized as follows:

- 1) Design a waste segregation system for categorizing garbage with high precision and in real time.
- 2) Build a garbage dataset consisting of 3217 images divided into seven classes: cardboard, glass, metal, paper, plastic, battery, and foam. These classes are usually found in trash bins.
- 3) Apply YOLOv6, which is characterized by its hardware-friendly design, low inference time and high detection accuracy for detecting and localizing garbage.
- 4) Design a 3D model of a 4 DOF robotic arm using CAD software and adopts a simple geometric method to calculate the angles of the arm's joints for picking up and locating the objects in their dedicated basket with smooth motion trajectories in a slight time.
- 5) Develop an automatic waste segregation robot system based on the designed robot arm and the proposed segregation system.

## II. PROPOSED SYSTEM ARCHITECTURE

In this research, a waste segregation system is proposed to make the waste much easier to recycle, meaning less garbage goes to landfills and positively impacts health and the environment. The architecture of the proposed system consists of two modules: the waste segregation module and the robotic module. The waste segregation module comprises the YOLOv6 model for detecting the waste, while the robotic module picks up the objects according to their type and places them in their dedicated basket. The proposed system architecture is shown in Fig. 1. Moreover, the details of each module are described in the following subsections.

### A. The Waste Segregation Module

This module is responsible for detecting various objects in the captured image and building a queue of information about each object identifying its current location and type. To perform this task, YOLOv6 is utilized. YOLOv6 is created for industrial applications with high-performance and hardware-friendly architecture. It makes different improvements to the network architecture and the training plans of the conventional YOLOv5 [23]. Conventional YOLOv5 consists of three main parts: backbone, neck, and head. The backbone primarily affects how well features can be represented, but because it performs most of the computational cost, its structure significantly impacts inferences performance. The neck is responsible for combining the low-level and high-level semantic features to construct a pyramid feature map. Then, these combined features are fed to the head, which consists of several convolutional layers, to predict the objects. YOLOv6 replaces the backbone and the neck networks in the conventional YOLOv5, which is designed based on CSPNet [24], with more efficient networks: EfficientRep as Backbone and Rep-PAN as Neck that is designed using RepVGG style [25]. The new network structure overcomes the drawbacks of increasing latency and decreasing the utilization of the memory bandwidth of the GPU. Second, YOLOv6 reduces the delay in the conventional YOLOv5 while preserving accuracy by designing an efficient and simplified decoupled head. Third, YOLOv6 attempt to improve the detection accuracy by improving the training strategies by using anchor free paradigm, SimOTA [26], as a label assignment method, and Siou [27] and GIoU [28] as a bounding box regression loss function. In the next subsections, the networks architecture, and the training strategies of YOLOv6 will be explained in detail.

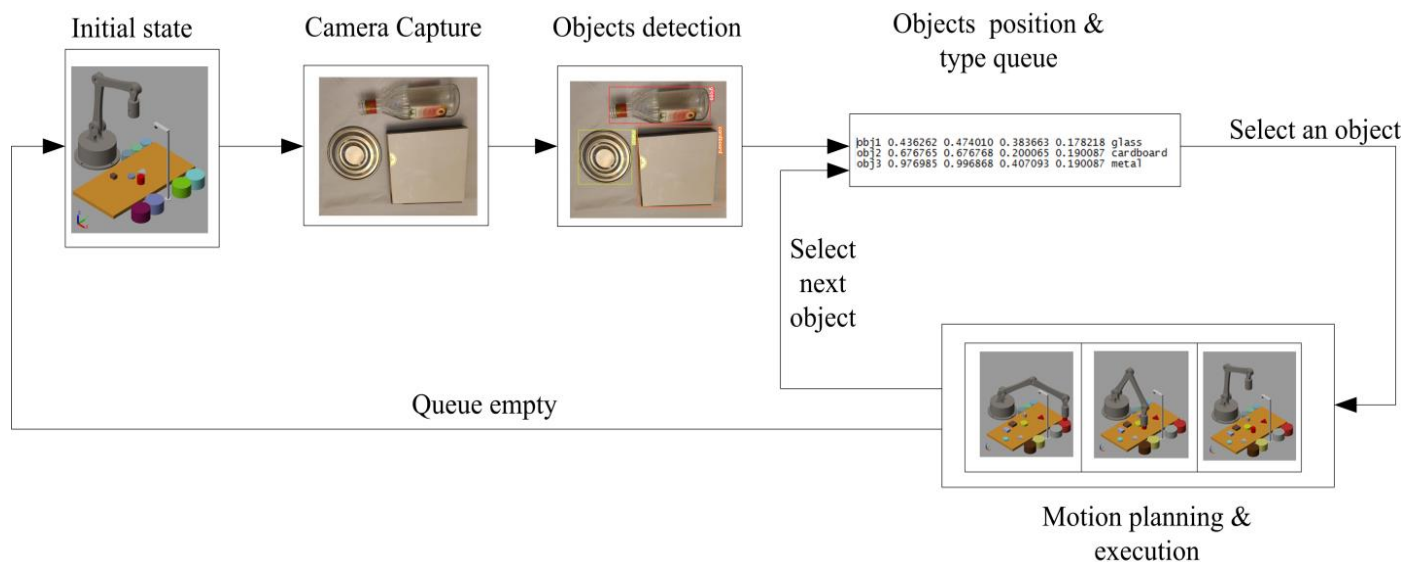


Fig. 1. The proposed waste segregation system architecture.

1) *Backbone*: The effectiveness and efficiency of the detection model are significantly influenced by the backbone network's design. EfficientRep is designed as a backbone in YOLOv6 to efficiently exploit the computational power of the hardware architecture to reduce the inference latency. The EfficientRep is designed based on the RepVGG structure to utilize the pros of multi-branch topology within the training process for achieving improved classification efficiency. However, this structure avoids the inference latency of the multi-branch topology by using the re-parameterization structure in the inference process to fuse the multi-branch into a single convolutional layer by converting its parameters within the deployment process.

2) *Neck*: The Rep-PAN neck design is built upon the idea of a hardware-aware neural network by fusing the features at multiple scales. The PAN topology [29] used in YOLOv4 [30] and YOLOv5 is modified to be the base of the Rep-PAN. RepBlock [25] or CSPStackRep block is also used in place of the CSP-Block utilized in YOLOv5.

3) *Head*: In YOLOv5 models, the classification and box regression heads share the same features. In YOLOx [26], the head is decoupled, which means that the network separates between the features of the classification and box regression heads and adds two additional 3x3 convolutional layers for each one. Although this has been empirically demonstrated to increase performance, it also causes a slight increase in network latency. Based on the Hybrid Channels approach, the decoupling head design of YOLOv6 has been streamlined, and a more effective decoupling head structure has been developed by eliminating the number of middle 3x3 convolutional layers to one. These changes result in lower processing costs and decreased inference delay.

#### 4) *Training strategies*:

- Anchor-free

YOLOv6 reduces the delay results from transferring massive detections between the hardware stages by replacing Anchor-based detector with anchor-free detectors [26]. The anchor-free paradigm has recently gained significant popularity because of its superior generalization capabilities and simplicity. YOLOv6 adopts one of the anchor-free detectors called the anchor point-based paradigm, which predicts the distances from the bounding boxes' four sides to the anchor point.

- SimOTA label assignment strategy

One of the factors affecting the detection accuracy is the label assignment process. In this process, each predetermined anchor is assigned a label during the training phase. Previous YOLO versions used the static assignment method, which cannot be modified during network training. Recently, numerous techniques based on dynamic label assignment have emerged, allocating positive samples in accordance with the network output through the training procedure to enable the generation of more high-quality positive samples, which in turn improves the network optimization. YOLOv6 used one of the dynamic assignment methods which is SimOTA. This method

finds the best match between the samples using the Top-K approximation technique, which significantly accelerates training speed.

- SIOU bounding box regression loss.

IoU, GIoU, and SIOU are proposed in recent researches as bounding box regression losses to adapt the network learning and improve the detection accuracy. These loss functions are calculated according to these aspects: the percentage of the overlap between the predicted and the target boxes, the aspect ratio, the distance between the center points, and the matching between the predicted and the target box directions. GIoU and SIOU loss functions are selected experimentally to apply to different versions of YOLOv6.

#### B. *The Robotic Arm Module*

Robots are used to handle complex, dangerous, and tedious tasks. The use of robotic arms also helps to relieve human workers of tasks that pose a risk of bodily harm [31]. Thus, pick-and-place robots are commonly used in modern industrial environments [32]. The pick-and-place process automation reduces cycle time, increases productivity, and decreases material handling costs [33]. Pick and place robots come in a variety of shapes and sizes. A two-degree-of-freedom robotic arm picks up and moves objects in a single plane. The Cartesian robotic arm works in multiple planes and moves along three orthogonal axes using Cartesian coordinates (X, Y, and Z). The Delta robot is frequently used in applications where robots pick items in groups and place them in assembly patterns or containers; they have heavy motors attached. Collaborative robots help humans by directing them to appropriate locations and guiding them through each task. In this research, a Cartesian robot arm is designed to sort the waste according to the locations and types obtained from the segregation module. The robot arm design and its motion planning and execution are described in the following subsections.

1) *Solid 3D CAD Modeling of a robotic arm and its workspace*: An autonomous robot platform based on SolidWorks, MATLAB Simulink, and Simscape Multibody software tools is utilized in this research to design the arm's structure and its workspace. The robot manipulator was initially created as a 3D CAD model using the SolidWorks tool to design and build the robot completely. It creates fast and accurate 3D models, which turn ideas into reality with the ability to run the concept design through many scenarios and make modifications as necessary in the design development process [34]. As shown in Fig. 2(a), the manipulator structure has four links and four revolute joints. Joint1 is used as a base joint, while joint2 connects link1 to link2. Joint3 connects link2 to link3, and joint4 is used for the robot end effector (robot hand). Fig. 2(b) depicts the simulated workspace which consists of various types of waste objects, an RGB camera placed in front of the robot arm's starting location, ultrasonic sensor, and a group of baskets for collecting categorized items. In order to control the motion of the arm, the robot assembly is imported into a Simscape Multibody model to simulate the multi-object systems by utilizing blocks that

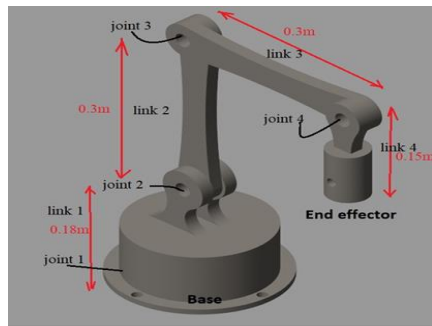
describe system parts, joints, forces, and external restrictions [34]. The bodies are distinguished by their geometry. Accordingly, inertial properties, forces and moments can be applied to bodies. Besides, contact constraints can be defined. Moreover, the object's CAD model can be imported with all its physical properties and the dynamics of the system can be observed. Simscape Multibody software's primary use is to analyze and visualize system functioning and control design in Simulink [35], [36]. Fig. 2(c) shows the block diagram of the robotic arm in Simscape Multibody to be utilized for simulation trials in evaluating the proposed algorithm.

2) *Robotic arm task scheduling*: This research proposes a planning process to address the issue of computing the robot arm's movements during the object picking and placing assignment. Fig. 3 illustrates the complete cycle of the robotic arm pick and place task. Depending on the type of object material, the robot's destination is specified and modified dynamically. The motion plan is constructed based on several factors depending on the relation between the end-effector, the target destination, and the object's current location. The motion phases are summarized as follows:

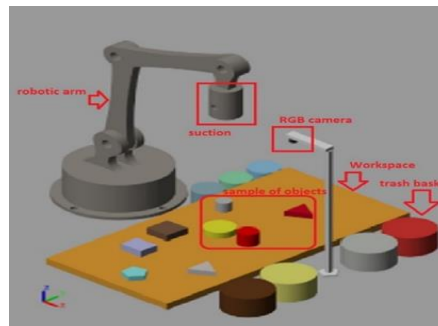
- Object reaching: the manipulator moves to place the end-effector at the first object of the received queue.

Once the end-effector has arrived at the (x, y) position of the object on the horizontal plane, the ultrasonic sensor is activated to determine the height that the end-effector needs to descend to reach the object.

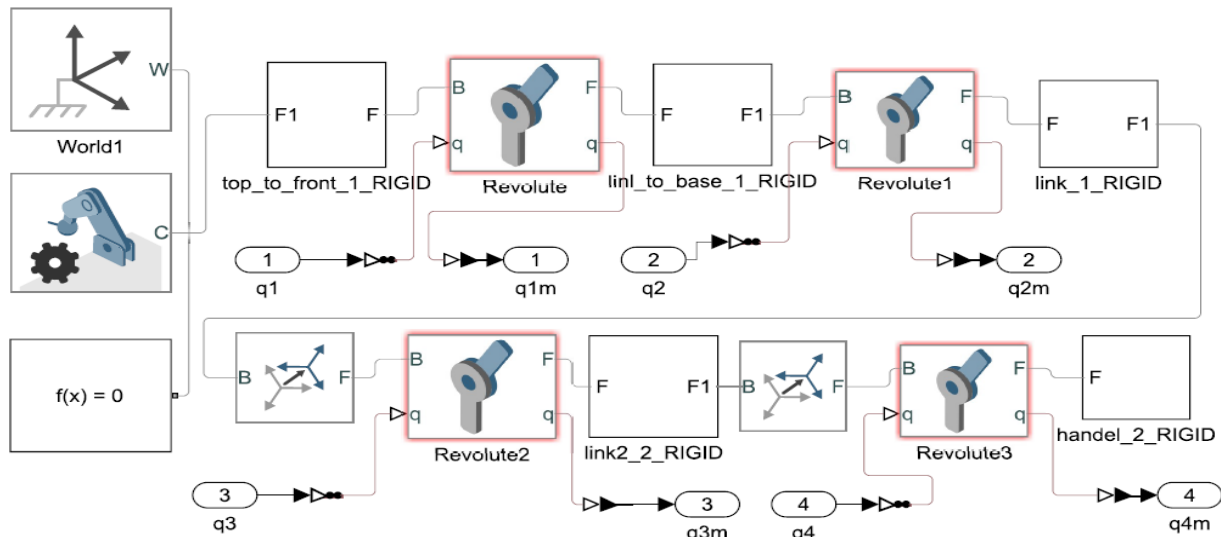
- Picking up the object: the end-effector gets in touch with the object using a suction force to pick it up. The manipulator must continue to provide a suction force to hold the object until it reaches the proper basket.
- Lifting: the object is lifted vertically away from the table after the end-effector sucks it, enabling it to move as they are rigidly connected.
- Basket reaching: Depending on the object type, the manipulator moves to the appropriate basket location while holding the object.
- Placing the object: the suction force is switched off to release the object into the basket once the manipulator reaches it.
- Arm reset: the robot returns to the beginning state (home position) for starting another task when the object queue becomes empty.



(a)



(b)



(c)

Fig. 2. Robot arm manipulator (a) arm structure (b) robotic workspace (c) Simscape Multibody block diagram of robotic arm.

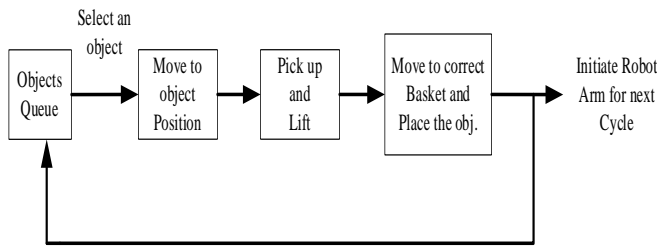


Fig. 3. Complete cycle of pick and place task.

3) *Robot motion planning*: Fig. 4 illustrates how the robotic arm motion is controlled from its starting point to various goals. First, the object is picked by a suction gripper with force chosen based on the heaviest expected waste object. The time for switching on/off this force is calculated from the generated trajectory. After that, trajectory planning is carried out to find a suitable route for the robot movement in an area free of obstacles. A robotic motion task is defined by determining a path for the robot to follow. A path is a set of points that can be defined in task coordinates (end-effector coordinates) or joint coordinates. The problem of trajectory generation is to compute the desired reference joint or end-effector variables as functions of time for the control system so that the robot follows the desired path [37]. In this study, a cubic polynomial trajectory that is constructed based on chosen waypoints and their associated time points is used to calculate the appropriate route between the source and destination. Waypoints are chosen so that the arm can move smoothly while considering the joint angle limitations. Inverse kinematics is proposed to calculate the appropriate joint configuration (joint rotation angles) for moving the robotic arm from its starting position to various destination points.

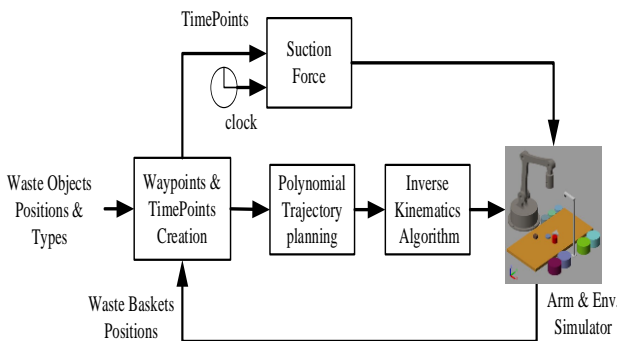


Fig. 4. Motion planning and movement execution process.

• Proposed Geometric Inverse Kinematics

The study of motion without considering its causes, such as forces and torques, is known as kinematics. Using kinematic equations, inverse kinematics (IK) can predict how a robot will move to arrive at a specific place [38]. Fig. 5 declares the concept of forward and inverse kinematics approach. Inverse kinematics is a transformation method from Cartesian space to joint space. Nevertheless, it is a somewhat complex nonlinear

problem. In addition to its nonlinearity, the kinematics matrix's sine and cosine functions also have non-unique solutions, which makes the issue worse [39]. This study proposes a geometric analytical solution idea to compute the inverse kinematics of 3D space. The system will then follow the intended route determined by the trajectory of the end effector. The geometric solution is much more efficient during calculation (when compared to iterative methods).

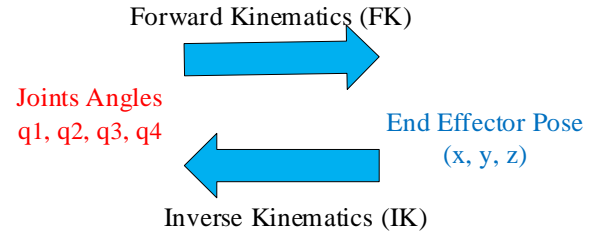


Fig. 5. Inverse kinematics vs forward kinematics.

The proposed method for determining the joints configuration (joints rotation angles) in 3D space for the designed four-link robot arm relied on a novel geometric notion. Since the numerical solution of inverse kinematics yields, a less accurate result, the analytical solution of inverse kinematics is preferred. The target point is indicated by the Cartesian coordinates P (x, y, and z) in the generalized case of the robot arm. The position of the target point can be converted to cylindrical coordinates (Θ, ρ, and z). If the base joint is turned at an angle Θ, as indicated in Fig. 6, the robot arm construction coincides in the x-z plane. The second joint position at point "a" is connected to the end-effector joint pose at point "p" by the line "c". Line "k" is thus drawn parallel to line "c" from the location of the base joint. The angles of the joints are obtained by applying the cosine formula as shown in equations (1–5). The polar coordinates of the target point projection in the x-y plane are determined by Equation (1).

$$\rho = \sqrt{x^2 + y^2}, \quad \theta = \tan^{-1}(y/x) \quad (1)$$

The length of the line "c" is calculated as:

$$c = \sqrt{(z - l_1)^2 + \rho^2} \quad (2)$$

Equation (3) calculates the angle between line "k" and the x-axis.

$$\delta = \tan^{-1}((z - l_1)/\rho) \quad (3)$$

The following equations explain the angles α and β in the triangle (a-p-d).

$$\alpha = \cos^{-1}\left(\frac{l_2^2 + l_3^2 - c^2}{2l_2l_3}\right) \quad (4)$$

$$\beta = \cos^{-1}\left(\frac{l_2^2 + c^2 - l_3^2}{2l_2c}\right) \quad (5)$$



In order to move the arm's end-effector to a target point, the joints rotate at the angles calculated in equations (6-9) considering that the rotation angle of each joint frame is measured w.r.t. the previous link frame and counterclockwise.

$$q_1 = \theta \tag{6}$$

$$q_2 = 270 + \beta + \delta \tag{7}$$

$$q_3 = 180 + \alpha \tag{8}$$

To keep the end-effector pointed vertically

$$q_4 = 90 - (\alpha + \beta + \delta) \tag{9}$$

where,  $q_1, q_2, q_3,$  and  $q_4$  are the angles values needed to rotate each joint to change the configuration of the joints such that the end effector reaches the desired position.

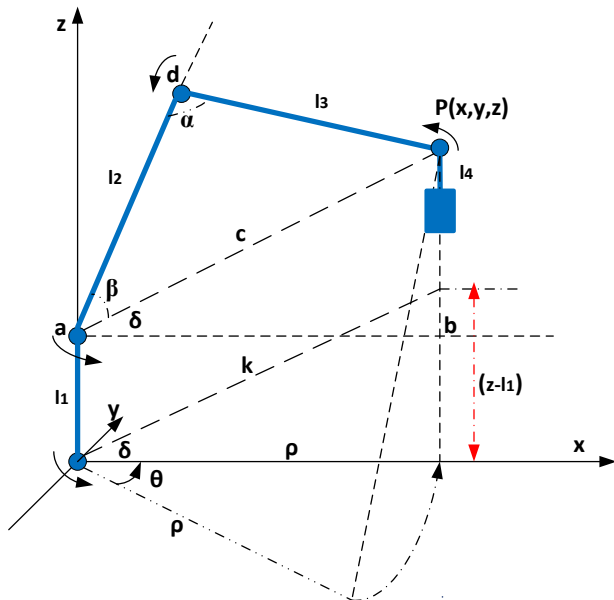


Fig. 6. The schematic diagram of the proposed geometric inverse kinematics approach.

### III. EXPERIMENTS AND RESULTS

This section presents the conducted experiments and shows the results of the proposed methodology for waste segregation and robotic modules. In the following subsections, each module's outcomes are described in detail.

#### A. Waste Segregation Module

In this module, YOLOv6 is evaluated numerically and compared to recent YOLO models: YOLOv7 [40] and YOLOR [41]. The dataset, performance metrics, and training parameters are also comprehensively explained.

1) *Dataset*: The proposed waste segregation performance model is assessed by conducting different experiments on a

modified version of the TrashNet dataset. The TrashNet dataset [42] consists of 2527 images of waste divided into six classes: 501 glasses, 594 paper, 403 cardboard, 482 plastic, 410 metal, and 137 other trashes. The trash class is omitted in the modified version of the dataset, and two new classes are added, foam and battery. The authors also attempt to balance the number of the other classes' images by adding new ones. The new images are downloaded using Google Images Download software [43]. Then, some augmentation techniques are applied, namely: flipping, rotation, and resizing. Afterwards, the images are annotated using Ybat software [44], then the duplicated ones are deleted. At the end of the preprocessing and the annotation process, the dataset becomes 3217 images divided into seven classes: cardboard, glass, metal, paper, plastic, battery, and foam. The description of the modified TrashNet is presented in Table I, and samples from each class are shown in Fig. 7.

2) *Performance metrics*: To evaluate the performance of pre-trained YOLO models, three evaluation metrics namely, precision (AP), recall (AR), and the F1 score (F1) are applied on the model's detection output. Mathematically, precision, recall and F1 can be calculated as:

$$\text{Precision} = \frac{TP}{TP + FP} \tag{10}$$

$$\text{Recall} = \frac{TP}{TP + FN} \tag{11}$$

$$F1 = 2 * \frac{\text{Precision} * \text{Recall}}{\text{Precision} + \text{Recall}} \tag{12}$$

where, TP is the number of true positives, FP is the number of false positives, and FN is the number of false negatives. Therefore, precision measures the ratio of the correctly detected objects to the total number of detected objects. Recall measures the percentage of true predictions among the total number of class objects, and F1 evaluates the model's performance based on the harmonic mean of the precision and recall.

TABLE I. IMAGE CLASSES DISTRIBUTION AND DESCRIPTION IN THE DATASET

Class (type)	Description	Quantity
Glass	bottle, jar, cups	500
Paper	plates, posters, envelopes, receipts	591
Cardboard	packing box, mailing box, cardboard sheet	457
Plastic	bottles, boxes, jars, medicine packs, food packs	479
Metal	soft drink cans, food cans, foil sheets, plates	468
Foam	packing box, food box, plates, cups	382
Battery	AA, AAA, C, D, 9 volts	326



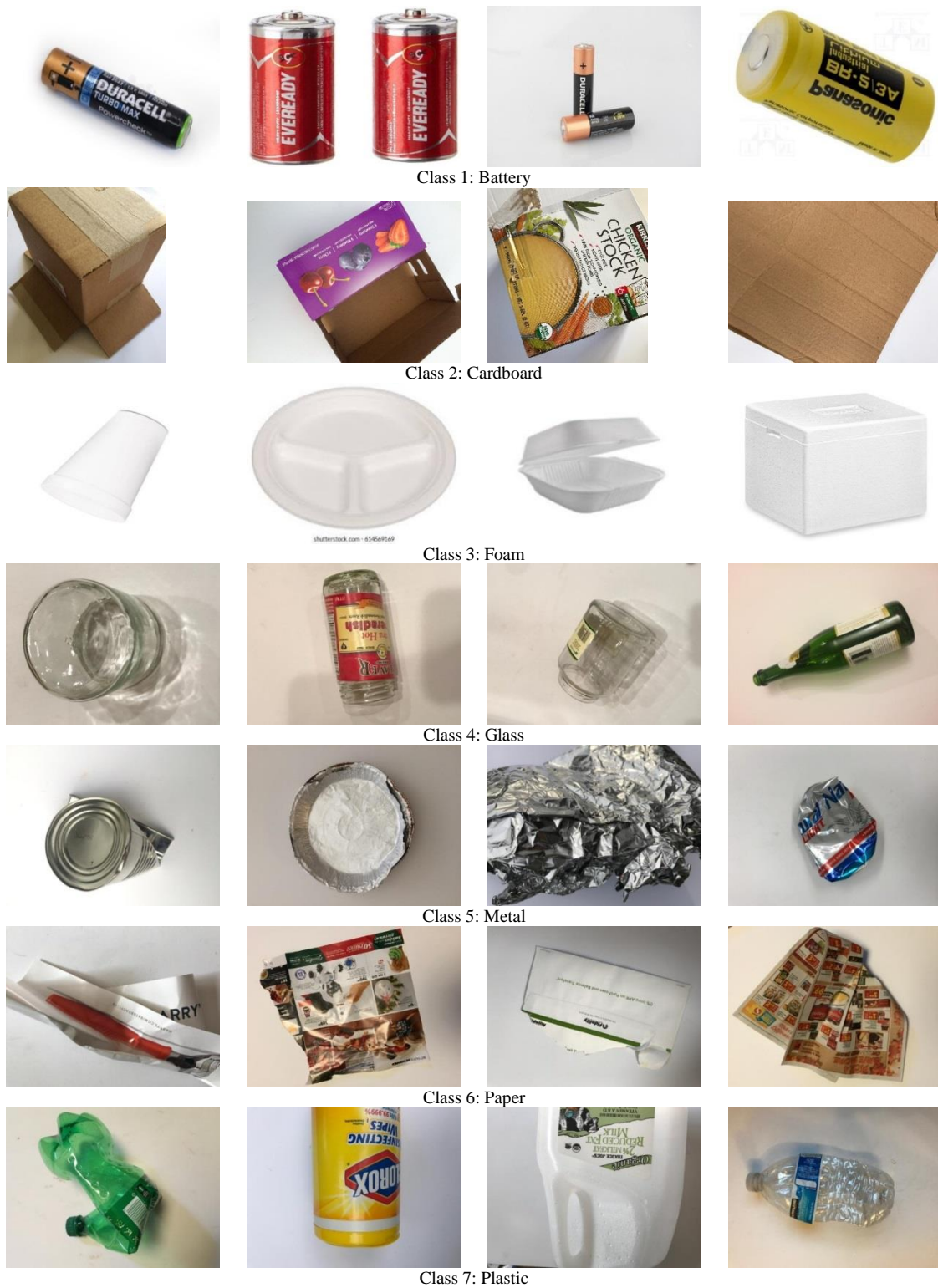


Fig. 7. Sample images from the modified TrashNet dataset with their corresponding class.

3) *Training* : The modified TrashNet dataset is split into 70% train, 30% for validation and test. Thus, according to these percentages, the number of images is 2239 in the training set, 541 in the validation set, and 423 in the test set. Training the model from scratch with randomly initialized

parameters results in under-fitting due to the small number of images in the dataset. Therefore, the pre-trained YOLOv6 model, which is trained on the COCO dataset, is fine-tuned on the modified TrashNet dataset to exploit the advantages of transfer learning. Stochastic gradient descent (SGD) is used

during the fine-tuning process to optimize the network parameters. The number of epochs, the initial learning rate, the batch size, the weight decay, and the momentum are set as 300, 0.0032, 16, 0.00036, and 0.843, respectively. The confidence score is selected empirically, and a confidence score of 0.6 gives the best model performance. All the experiments are conducted on an Intel(R) Core (TM) i7-11800H.

4) *Simulation results:* The performance of the YOLOv6 model is compared with the recent YOLO models, which are YOLOv7 and YOLOR, in terms of the F1, precision, recall, inference time, and model size. YOLOv7 and YOLOR are trained on the COCO dataset and fine-tuned on the modified TrashNet. In the proposed research, two model architectures of YOLOv6 are used, in which the architectures vary considering the model size for a better accuracy-speed trade-off. The model size of YOLOv6n is smaller than YOLOv6s. The training process of the four models is performed several times according to different data shuffles, and the results are presented in Table II. It can be seen from the table that the highest precision value is for YOLOv7 in the third run, whereas the best recall and F1 values are for YOLOv6s in the first run. However, the recall and F1 values for YOLOv7 in the third run are less than that of YOLOv6s in the first run, while the precision value of YOLOv6s is slightly less than that of YOLOv7. Thus, YOLOv6s from the first run is adopted in this work. Besides, Table III compares the YOLOv6s versus the other models regarding precision, recall, F1, inference time, and model size. The presented values of precision, recall, and F1 are the average values of the three runs. It can be noticed from Table III that the YOLOv6s model has better performance with reference to the average values of precision, recall, and F1.

Furthermore, it can be observed that YOLOv6n is the smallest model size, and YOLOR is the largest model size and inference time. Thus, YOLOv6 has better performance and meets the real-time requirements. Using YOLOv6s or YOLOv6n depends on the application's requirements; if the application needs high accuracy, YOLOv6s is the best choice. However, if the application needs a small-size model with acceptable accuracy, YOLOv6n is recommended. Fig. 8 presents the predictions of YOLOv6 on real images captured by the authors using the RGB camera of the Samsung Galaxy S20 with 12 MP for testing the model's performance. It can be seen from the figure that the model predicts all the objects with high confidence scores.

On the other hand, the incorrect classifications on the test set are also statistically investigated to find the reasons behind the model misclassifications for some objects. Table IV analyses the classification output based on the confusion matrix. It can be observed from Table IV that there is a slight confusion between cardboard and paper, and also, there is confusion between plastic, glass and paper. This confusion is because, in some cases, the plastic and glass bottles or cups are very similar in shape; similarly, the supermarket flyers in paper category and the box packaging in the cardboard type. It can be observed from Table V that plastic has the lowest recall value, 90% because plastic is misclassified as the other categories multiple times. It can be noticed from the confusion matrix that foam and battery are not misclassified; however, their precision and recall values are not 100%. Some foam and battery objects are undetected, or the background is classified as foam or battery. Moreover, the glass and paper categories have the lowest precision, meaning several objects are misclassified as glass and paper. Furthermore, experimental results find that the number of undetected and misclassified objects is 39 objects for YOLOv7 and 32 objects for YOLOR from 508 objects in the test set compared to 19 objects for YOLOv6. Fig. 9 visualizes some illustrations of the classification results for YOLOv6, YOLOv7, and YOLOR. As can be noticed, YOLOv6 outperforms YOLOv7, and YOLOR in most of the cases.

TABLE II. THE EFFECT OF THE DATASET SHUFFLING ON THE MODEL'S PERFORMANCE

	Models	Precision	Recall	F1-score
1 <sup>st</sup> train	YOLOR	94.82	93.7	94.26
	YOLOv6n	95.19	93.5	94.34
	YOLOv6s	<b>96.07</b>	<b>96.26</b>	<b>96.17</b>
	YOLOv7	94.75	92.32	93.52
2 <sup>nd</sup> train	YOLOR	95.31	95.11	95.21
	YOLOv6n	95.05	93.9	94.47
	YOLOv6s	95.48	94.7	95.01
	YOLOv7	95.87	94.5	95.18
3 <sup>rd</sup> train	YOLOR	95.65	94.48	95.06
	YOLOv6n	95.63	94.07	94.85
	YOLOv6s	95.67	94.68	95.17
	YOLOv7	96.47	94.89	95.67

TABLE III. THE AVERAGE PERFORMANCE COMPARISON OF THE YOLOV6 VERSUS YOLOV7 AND YOLOR

Models	F1-score	Precision	Recall	Inference time	weight size
YOLOR	94.84	95.26	94.43	24 sec	289 M
YOLOv6n	94.55	95.29	93.82	14 sec	<b>9 M</b>
YOLOv6s	<b>95.45</b>	<b>95.74</b>	<b>95.2</b>	13 sec	37 M
YOLOv7	94.79	95.7	93.9	<b>11 sec</b>	73 M

TABLE IV. CONFUSION MATRIX FOR EVALUATING THE CLASSIFICATION ACCURACY OF EACH MATERIAL TYPE

		Predicted						
		Glass	Paper	Cardboard	Plastic	Metal	Foam	Battery
Actual	Glass	64	0	0	1	0	0	0
	Paper	0	78	0	0	0	0	0
	Cardboard	0	3	58	0	0	0	0
	Plastic	3	3	0	57	0	0	0
	Metal	2	0	0	1	71	0	0
	Foam	0	0	0	0	0	60	0
	Battery	0	0	0	0	0	0	101

TABLE V. THE PERFORMANCE OF YOLOV6 FOR EACH CATEGORY IN THE DATASET IN TERMS OF PRECISION, RECALL AND F1

Class Type	Precision	Recall	F1
Glass	93	98	95
Paper	92	100	96
Cardboard	100	95	97
Plastic	95	90	92
Metal	99	95	97
Foam	98	94	96
Battery	97	99	98

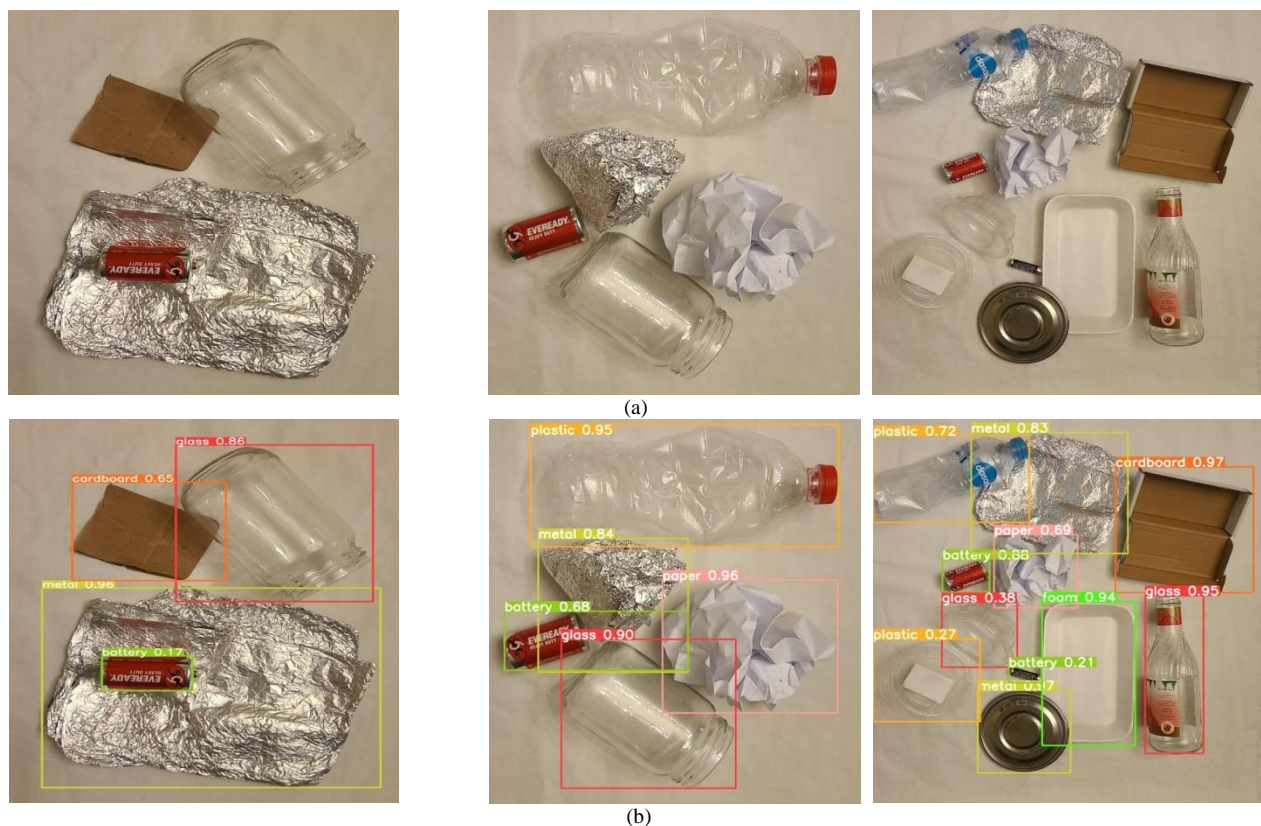


Fig. 8. YOLOv6 waste detection results (a) test images (b) the model predictions.



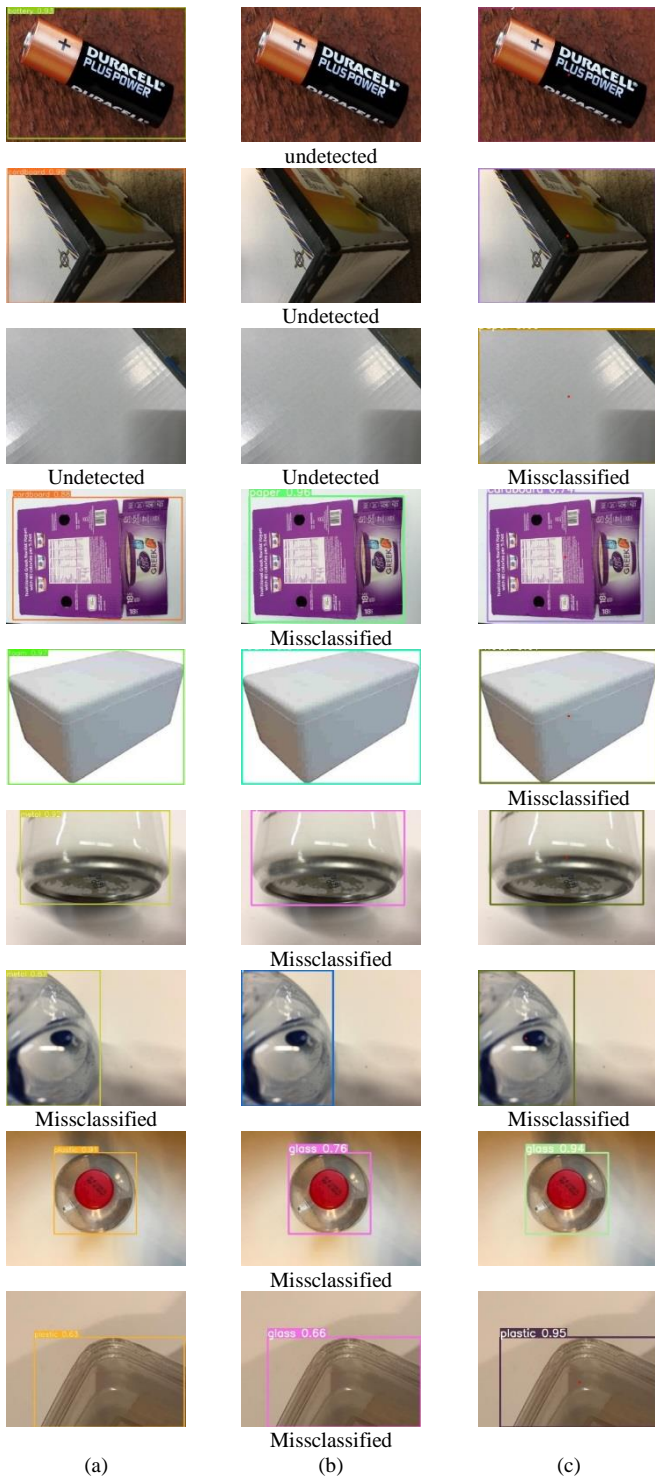


Fig. 9. Success and failure classification results of different test waste objects (a) YOLOv6s (b) YOLOv7 (c) YOLOR.

### B. Robotic Arm Simulation Results

In the robot module, the location and material types of the waste objects that were detected in the waste segregation module are sent to the robotic arm for motion planning and execution. The proposed algorithm finds a solution for all four phases and moves the robot arm within its structure limits (joints and links limits) to the target position. The robot begins at its default position and the camera captures an image of the workspace. The image is sent to the computer for processing and detecting the objects to define their locations and material types. Then this data is formed in a queue and sent to the robot. The proposed algorithm utilizes these objects information to compute the appropriate joint configurations, allowing the arm simulator to perform all required tasks. Fig. 10 shows the motion sequence to place the objects in the right destination. Fig. 10(a) depicts the robot in its initial state while it is waiting to receive data from the object detection module. The necessary joints configuration is computed using the previously mentioned equations in Section II, then the robot successfully navigates to the chosen item (in this case, the red cylinder), and then the controller triggers the suction force to pick up the object, as illustrated in Fig. 10(b). The robot lifts the object and defines the position of the dedicated basket based on its type. The basket position is considered the new target point for the robot arm; thus, the trajectory and the correct joint angles are computed using inverse kinematics. When the arm reaches above the basket, the controller turns off the suction force to drop the object in the basket. Afterward, the next object is selected (in this case, the yellow disc), the arm considers its position to be the new target, computes the required joints rotation angles once more, and executes the pick and place task. The process is repeated until all objects are placed in their proper baskets; thus, the robot returns to its initial state. Fig. 11 shows the timeline of the process and the execution times for each task, such as the time the robot takes to go to the object's location, lift it, and finally drop it in the designated basket. It can be noticed from the figure that the processing time of delivering one object is 0.8 sec. Further, the trajectories of motion in joint space for the previous process sequences are illustrated in Fig. 12, pointing out that all trajectories are smooth, and there hasn't been any rapid damage or significant change made to the arm's rotation joints. The complete modeling and simulation of a robotic arm pick and place system with MATLAB Simscape Multibody and Solidworks is shown in Fig. 13.

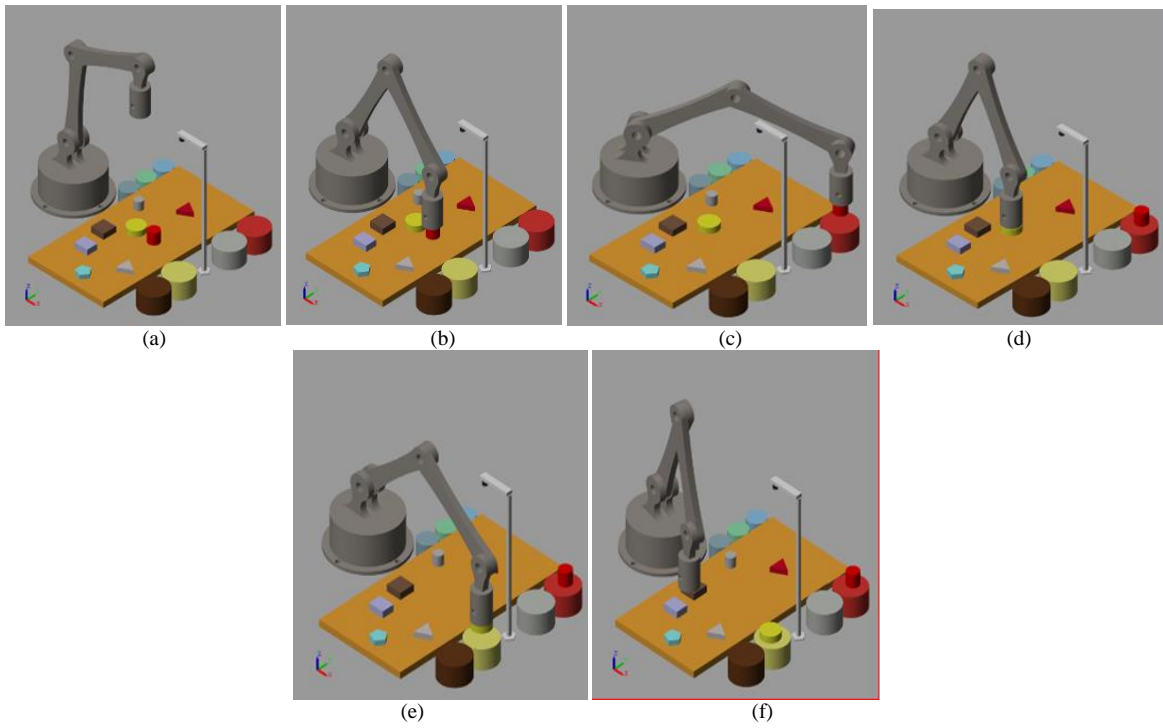


Fig. 10. The motion sequences required to complete the mission. (a) initial state (b) pick up object1 (c) place object1 in the dedicated basket (d) pick up object2 (e) place object2 in its basket (f) repeat the process for all objects in queue.

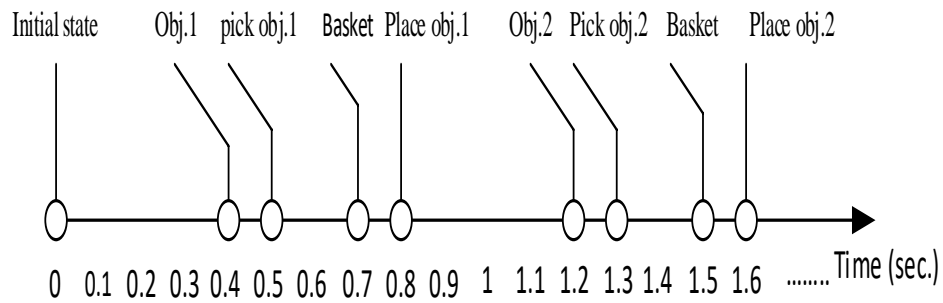
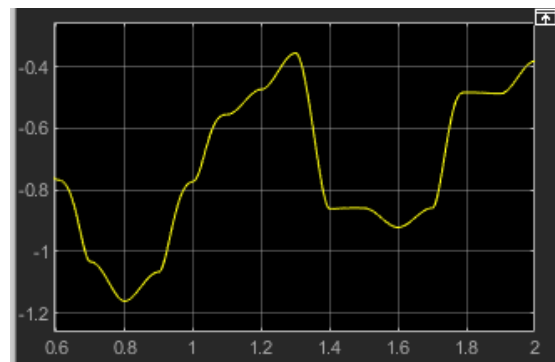
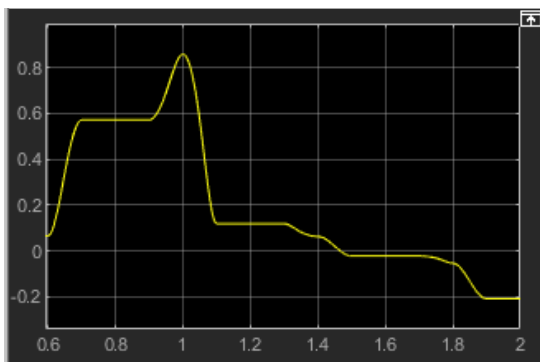


Fig. 11. Time line of pick and place mission for multi-objects.



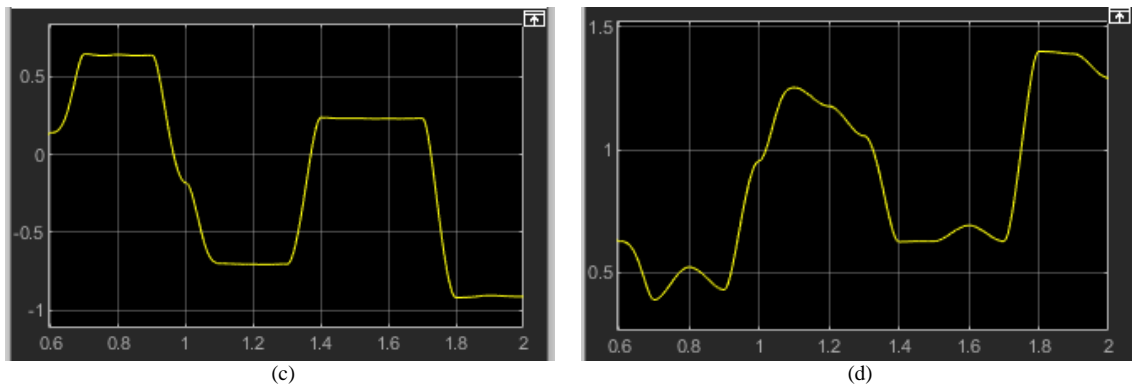


Fig. 12. The joints angles trajectories (in rad ) (a)  $q_1$  (b)  $q_2$  (c)  $q_3$  (d)  $q_4$

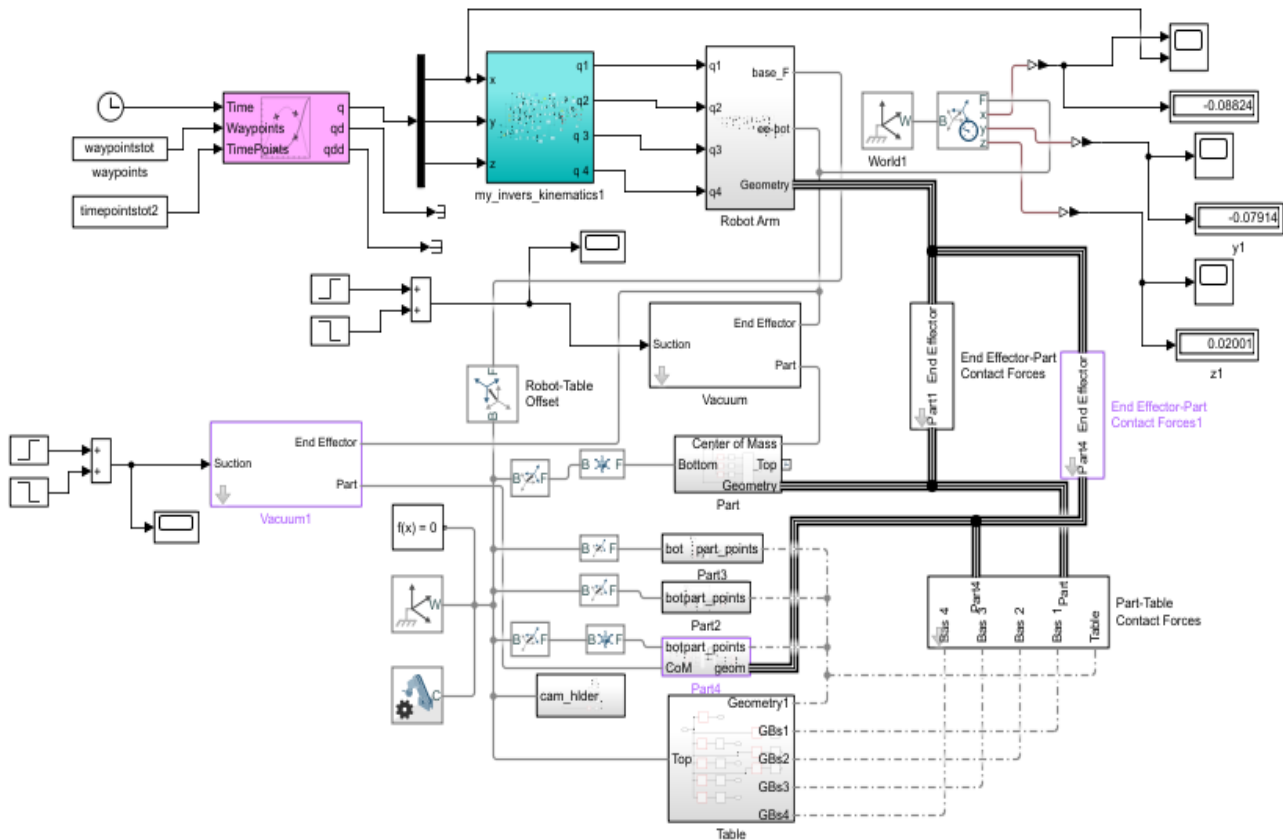


Fig. 13. The overall motion control robotic arm system simulator.

#### IV. CONCLUSION

This paper presents an automated waste segregation technique relying on blending an object detection system and robotic arm design. YOLOv6 is applied to detect and classify waste items. Over and above, CAD software is employed to design the robot arm that strives towards utilizing a simple geometric approach to compute the angles of the arm's joints accurately. To signify the efficacy of the proposed system, a TrashNet dataset has been modified and exploited for assessment. The suggested system proved high effectiveness in detecting and segregating waste items into distinct categories. Moreover, the system revealed high efficiency in picking the

waste items, controlling the robot arm movement to the appropriate basket location, and placing the object in the proper basket. Furthermore, the adopted object detection approach is compared to the recent YOLO models: YOLOv7 and YOLOR. The obtained results illustrate that the submitted technique surpasses these techniques regarding F1, precision, recall, inference time, and model size. Over and above, the designed robot arm has been proven to consume a fraction of a second for picking up and placing a single object in its appropriate basket. In future work, new items will be added to the modified dataset, and the proposed simulation robot arm will be practically implemented.



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# Diversity-based Test Case Prioritization Technique to Improve Faults Detection Rate

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**Abstract**—Regression testing is an important task in software development, but it is often associated with high costs and increased project expenses. To address this challenge, prioritizing test cases during test execution is essential as it aims to swiftly identify the hidden faults in the software. In the literature, several techniques for test case prioritization (TCP) have been proposed and evaluated. However, existing weight-based TCP techniques often overlook the true diversity coverage of test cases, resulting in the use of average-based weighting practices and a lack of systematic calculation for test case weights. Our research revolves around prioritizing test cases by considering multiple code coverage criteria. The study presents a novel diversity technique that calculates a diversity coverage score for each test case. This score serves as a weight to effectively rank the test cases. To evaluate the proposed technique, an experiment was conducted using five open-source programs and measured its performance in terms of the average percentage of fault detection (APFD). A comparison was made against an existing technique. The results revealed that the proposed technique significantly improved the fault detection rate compared to the existing approach. It is worth noting that this study is the first of its kind to incorporate the true diversity score of test cases into the TCP process. The findings of our research make valuable contributions to the field of regression testing by enhancing the effectiveness of the testing process through the utilization of diversity-based weighting techniques.

**Keywords**—Regression testing; fault detection; test case prioritization; test case diversity; test case coverage; species diversity

## I. INTRODUCTION

Despite the importance of regression testing, it has been described as an expensive operation, and various approaches have been developed to overcome this challenge. One of these effective approaches is test case prioritization (TCP), which aims to prioritize the execution of the most critical test cases to detect hidden faults more rapidly during the test execution process. TCP employs several techniques such as algorithms and metrics to reorder test cases. The primary objective of these techniques is to determine the optimal ordering combination of the test suite based on specific criteria.

The most crucial aspect of TCP is the detection of faults, which can only be known after executing the test cases. Therefore, it becomes necessary to estimate or predict the test cases that can achieve this goal before the test execution process begins. During the estimation phase, TCP techniques

rely on various code coverage measures as surrogate indicators. These measures directly examine the code and describe how multiple test cases cover the code under test [1]. These coverage measures include line, branch, method, and so on [2], also referred to as criteria. Moreover, relying solely on a single criterion may not be sufficient and can be misleading, as it only represents a portion of the code structure. Thus, considering multiple criteria has been recognized as effective and can potentially identify the test cases that will ultimately enhance the fault detection rate [3]-[6].

Researchers have proposed several weight-based techniques to address TCP problems by incorporating code coverage information [2], [7]-[10]. These techniques integrate different code coverage criteria such as line, branch, method, and more. The objective is to assign weights to each criterion and calculate the final priority value for each test case. However, some of these techniques derive weights based on averages [3], [5], [11], while others assign fixed weight scores to the considered criteria based on specific factors [12], [13]. Such informal practices of weight assignment to test cases and criteria can be deemed unfair [14], as test cases cover distinct code structures and are executed with diverse test contents and different input values [4]. However, test cases with these characteristics can unveil hidden faults within the covered structures. Nonetheless, previous weight-based techniques may not effectively maximize the fault detection rate due to ineffective weightage. This inefficiency primarily stems from the informal characterization of code coverage information, leading to ambiguous and unjust weight scores for the test cases. Consequently, these practices ultimately result in the selection of ineffective test cases that fail to expedite fault detection during the testing process [14]. As the nature of faults is diverse, identification of all fault locations within a program poses challenges due to the distribution of faults [15]. Therefore, the source code information (e.g., code-coverage data) are the best available resource to use as surrogate measure in order to identify the best capable test cases that can execute the fault code and eventually reveal such faults [16]. Hence, the future strategies will depend on the level of understanding and representation, as well as the reformulation of the current code coverage data. These factors will determine the extent to which fault detection can be maximized.

Within the specialized literature, there has been a suggestion regarding the need to develop a new TCP strategy that enhances the fault detection rates of test cases [17], [18].

This motivation has prompted our current study, which aims to explore new research directions by specifically examining the role of diversity within test case coverage data to improve the fault detection rate. While some previous techniques drew inspiration from concepts in Biology or related domains, certain biodiversity concepts, such as species diversity and its associated metrics, have remained unexplored in TCP research. Thus, the concepts of species diversity have served as the inspiration for this study and applying these concepts during the weighting practices is crucial.

In this study, assumption made is that whenever a test case covers a diverse code structure and that program structure is executed correctly, any faults in that area can be revealed. Our goal is to transform the previous test case problem into a species diversity problem and adopt species diversity metrics [30] to measure the true diversities of the test cases based on their coverage counts. Each line of code is treated as unique, and it is assumed that every test case is susceptible to faults. Therefore, the prioritization of test cases is based on their diversity scores, with higher scores indicating coverage of diverse code structures. It is believed that a test case that maintains diverse coverage is better in terms of fault detection compared to a test case that covers few code structures or receives a lower diversity score.

The contributions of this work can be summarized as follows:

- This study represents a pioneering approach as it is the first of its kind to utilize species diversity concepts to weigh test cases based on their true diversities in terms of code coverage counts.
- Through rigorous comparative experimental studies, this study provides empirical validation of the proposed metric's effectiveness in terms of the average percentage of fault detection rate (APFD).

The paper is structured as follows: Section II provides an overview of related works in the field. Section III introduces the proposed technique, while Section IV presents a motivational example. The study experiment is presented in Section V, followed by the presentation of results and analysis in Section VI. Finally, Section VII summarizes the study and suggests potential future research directions.

## II. RELATED WORK

TCP is a vibrant area of research, with numerous algorithms and metrics being proposed and evaluated [2], [19], [20]. This section provides an overview of existing studies on weight-based techniques and their research directions.

Earlier studies delved into TCP techniques, aiming to address cost constraints and improve fault detection in regression testing [7], [8]. These studies introduced a general-purpose TCP technique that incorporated statement and branch coverage information. The primary focus was on two classical greedy algorithms: a total greedy algorithm and an additional greedy algorithm.

The literature also explored combinations of various TCP techniques [4], [21]. These studies integrated strategies from

the total and additional greedy algorithms and incorporated probabilistic techniques by assigning probability scores to the relevant criteria. These probability values were adjusted based on the specific technique employed.

Criticism has been directed at existing practices that revolve around code isolation units or single-criteria techniques [22]. Such isolations may lead to a loss of valuable coverage information crucial for identifying program faults. Other studies ranked test cases based on estimated coverage information derived from static code structures [23], while some employed multi-criteria decision-making (MCDM) techniques for test case ranking [14].

TCP techniques have also been applied to Object-Oriented Programs (OOP). For instance, in [24], nine coverage criteria were considered, and fixed weights were assigned to each criterion to rank the test cases. In [12], a coupling measure was employed to rank test cases based on a constructed dependency graph. Another study [13] incorporated dependence-based analysis, selecting test cases based on their dependency scores.

Iyad and Khalid [11] introduced the average weight-based technique for TCP, utilizing line of code (LOC) and method coverage as criteria. Test cases with higher scores were assigned higher priority rankings. They evaluated their technique using a small experimental program.

Initial research on multi-criteria weight-based TCP techniques proposed a method incorporating ten factors grouped into four categories: Requirement, time, defect, and complexity [25]. Each factor was assigned a weighted score, and the evaluation focused on factors such as defect severity, prioritization time, and acceptable test case size.

Another weighted technique was proposed by Ahmad et al. [26], where test case execution decisions were based on final weight scores derived from three criteria: pairwise event, frequency pairwise, and fault matrix. These weights were used to prioritize the execution of test cases.

A TCP technique considering multiple coverage criteria was proposed by Prakash and Rangaswamy [3]. The researchers criticized the use of single criteria and existing techniques for being time-consuming and costly. They introduced a multi-coverage Average Weight-based Technique (AWT) and empirically demonstrated its superiority in terms of modified APFD. Building upon this work, Ammar et al. [5] proposed an Enhanced AWT (EAWT) technique that assigned different weights to test cases with similar weight scores, assuming they covered the same code segment and revealed similar faults. However, it is worth noting that this assumption may not hold true in practice, as test cases can vary significantly and possess dissimilar input values.

Several TCP techniques have been presented to enhance fault detection rates, with multi-coverage weighting techniques exhibiting promising performance. However, there has been relatively less focus on TCP techniques for OOP, particularly in Java [27] to [29].

Moreover, single coverage criteria have shown lower effectiveness compared to lightweight metrics, particularly multi-coverage weight-based metrics [3], [22]. However,

existing techniques often treat criteria and test cases, similarly, disregarding their inherent differences in nature and lacking formal weight calculations. Additionally, diversity weighting practices have been largely overlooked in the TCP literature.

Other additional notable gap in the existing literature is that their consideration of prioritizing test cases based on greedy approaches, where only the test case with the highest coverage count is executed. However, this greedy approach fails to assess whether the test case covers multiple criteria or not, as it primarily focuses on maximizing coverage for a single criterion. When dealing with multiple criteria, this approach proves to be inadequate and might even lead to some test cases to receive similar weights. This study argues that test cases that cover multiple criteria in a diverse manner have a higher potential for detecting hidden faults. Since the faults are distributed over the different code structures and the exact locations of faults are unknown, considering diverse coverage becomes crucial in enhancing fault detection capabilities.

A recent survey on TCP and several other studies have emphasized the need for novel techniques, including diversity measures, to improve the current state of TCP techniques [17] [31]. This paper aims to address this need by investigating diversity weighting strategies in test cases, an aspect that has not been previously explored.

### III. PROPOSED DIVERSITY WEIGHTED BASED TECHNIQUE

In this section, the proposed technique that considers multiple coverage criteria is discussed including instruction coverage, branch coverage, line coverage, and method coverage. These criteria provide insights into the underlying structure of the source code being tested. Adequate testing of a program necessitates a sufficient number of diverse test cases that target different areas within the code structure. While various TCP techniques with different motivations have been explored in the existing literature to prioritize test cases, our study introduces a unique approach utilizing the species diversity metric, originally employed in ecology to measure species diversity [30]. Therefore, these measures were selected for the following reasons:

- These metrics address the identified gap and serve the purpose of calculating the true diversity score of test cases across multiple coverage criteria.
- In contrast to previous informal weight practices, the selected metric assigns formal and unique weights to the test cases, describing their diverse code coverage characteristics.
- By employing these measurements, each test case can be identified as a unique entity, and their unique diversity scores can be used as tie-breaking strategy and ranking priorities. This means that test cases with higher diversity are ranked higher than those with lower diversity.

On the other hand, the proposed approach encompasses two stages: (1) the adoption of four dynamic code coverages, which are treated as species-based problems, and (2) the introduction of a novel diversity weighting technique that computes the Final Priority Value (FPV) for each test case.

#### A. Adopt and Characterize Code Coverage as a Species based Approach

The code coverage criteria adopted in this study encompass instruction coverage, branch coverage, line coverage, and method coverage. This section provides a description of how the TCP problem was formulated, utilizing a species-based approach. This characterization aims to enhance the effectiveness of the test execution process.

Code coverage information consists of multiple test cases, each associated with their respective coverage counts for various code structures, also known as criteria. In this study these entities were treated as a species-based problem and introduce the following terms, definitions, and symbols to facilitate our discussion and analysis:

Definition 1: Test cases are analogous to species(s), and it is important to emphasize that each species is unique. Test cases are purposefully designed with different test inputs and the ability to target various parts of the system under test (SUT).

Definition 2: A test suite, consisting of a group of unique species, represents a community(s).  $S$  is defined as  $S = \{s_1, s_2, \dots, s_i\}$ , where  $i$  represents the  $i$ th species in  $S$ .  $s_1$  denotes the first species, while  $s_i$  denotes the last species in the set.

Definition 3: Code structures or criteria are considered as species habitat (HB): In this case, the criteria include branch coverage (br), instruction coverage (in), line coverage (li), and method coverage (me). HB is defined as  $HB = \{Hb_1, Hb_2, \dots, Hb_j\}$ , where  $j$  represents the  $j$ th habitat in HB (e.g., in, br, li, and me). A species can be found in any of these habitats, for example,  $s_1$  can be present in  $Hb_1, Hb_2, Hb_3$  or  $Hb_4$ , and their presence is recorded in terms of coverage counts.

Definition 4: The coverage counts are denoted as  $n$ , representing the number of  $i$ th species ( $s_i$ ) found in  $j$ th habitat ( $Hb_j$ ), which is also written as  $n_{ij}$ . It is important to note that the coverage counts,  $n$ , can range from 0 to any non-negative number. A count of 0 indicates that the habitat is not represented by that species, indicating a loss of species.

Definition 5: The total coverage count of each species across all habitats is denoted as  $N$ .

#### B. Diversity-Aware TCP Technique

In this paper, a species diversity metric that measures the diversity of each species in relation to its habitats was used. This metric allows us to identify species with higher diversity, indicating their effectiveness and prioritization during the test execution process.

The proposed Diversity-aware TCP technique integrates multiple code coverage metrics to calculate a unique diversity weight for each test case. This diversity weight is determined by the extent of diversity exhibited by the species covering multiple code structures, also known as criteria. Our assumption is that species with higher coverage diversity scores are more likely to uncover hidden faults.

To illustrate the methodology employed in the proposed Diversity-based TCP technique, the following steps are outlined:

a) Step one: Collecting Coverage Values. In this step, the test case coverage needs to be collected for various criteria using tools such as JaCoCo within the JUnit framework.

b) Step two: Calculating Diversity Score. In this step, the species diversity score is calculated using the Gini-Simpson's index, which is a well-known diversity measure. This metric takes into account the dominance of species and assigns higher weight to abundant species. The proposed Gini-Simpson index (1-D) is derived from the original Simpson's index (D) [30]. The formulas for calculating the Gini-Simpson index are as follows:

$$1 - D(s_i) = 1 - \left( \frac{\sum_{i=1}^j n_{ij}(n_{ij}-1)}{N_i(N_i-1)} \right) \quad (1)$$

where,

$1-D(s_i)$  denoted as the Gini-Simpson index (1-D) of the  $i$ th species;

$n_{i,j}$  represents the count of species from the  $i$ th species under the  $j$ th habitat;

$N_i$  represents the total count of coverage for the  $j$ th species across all habitats; and

$\Sigma$  denotes the sum of multiple terms.

c) Step three: Ranking the Species. In this step, the prioritization of species occurs after calculating the diversity scores using the specified metric. The species are ranked based on these scores in descending order, from highest to lowest.

#### IV. MOTIVATIONAL EXAMPLE

To illustrate the functionality of the proposed technique, a demonstration is provided in this section using the information presented in Table I. The table includes eight species (T1 to T8) and four habitats (*in*, *br*, *li*, and *me*). Based on this coverage information, the test cases were assigned weights according to their diversity. The demonstration involves the following phases:

1) Collect the coverage counts for each species in relation to the selected habitats.

2) Calculate the diversity score for each species based on their habitats. This step may include a subset step specific to the calculation process of the chosen metric.

3) Rank the test cases in descending order from highest to lowest value.

##### 1) Phase one: Collecting Coverage Counts

During this phase, the coverage counts of species need to be collected with respect to the selected habitats. Tools such as JaCoCo can be utilized to facilitate this process. The data provided below represents a subset of species obtained from the CruiseControl program, along with the habitats they cover, as shown in Table I. It is important to note that the program consists of 299 species, but for the purpose of demonstration, only eight species was selected from the program.

TABLE I. SPECIES COVERAGE COUNTS OF CRUISECONTROL PROGRAM

Species	IN	BR	LI	ME
T1	74	2	27	8
T2	97	8	32	7
T3	87	5	32	6
T4	31	1	12	4
T5	34	1	14	3
T6	41	2	17	5
T7	127	10	31	5
T8	111	2	40	9

##### 2) Phase two: Calculate the Diversity Score

To calculate the diversity associated with each species across the selected habitats, the diversity score is used as a weight for the species. The calculation process can be outlined as follows.

The following example provides guidelines on how to calculate the diversity score using the given data, specifically focusing on the Gini-Simpson index as described in equation (1). Please note that the calculation process for other metrics can be carried out using a similar approach. The following steps are involved in this process:

- Step 1: calculate total coverage count of  $i$ th species across all habitats, denoted as  $N_i$  where  $N_i = \sum n_{i,j}$ . In this case,  $NT8 = (111+2+40+9) = 162$ ,  $NT7 = (127+10+31+5) = 173$ , and the remaining values are listed in column two in Table II.
- Step 2: calculate  $N_i(N_i - 1)$  for each species e.g.,  $NT8(NT8 - 1)$ . In this case,  $T8 = 162*(162-1) = 26082$ ,  $T7 = 173*(173-1) = 29756$ , and the remaining values are listed in column three in Table II.
- Step 3: calculate  $n_{i,j}(n_{i,j} - 1)$  of  $i$ th species in  $j$ th habitat e.g.  $nT8me(nT8me - 1)$ . In this case,  $T8 = 9*(9-1) = 72$ ,  $T7 = 5*(5-1) = 20$ , and the remaining values are listed in columns four and five in Table II.
- Step 4: calculate  $\sum n_{i,j}(n_{i,j} - 1)$  of  $i$ th species in  $j$ th habitat. In this case, the results of this calculation are listed in column two in Table III.
- Step 5: calculate  $D$  where  $D = \sum n_{i,j}(n_{i,j} - 1) / (N_i(N_i - 1))$  (diversity weight of Simpson). In this case, the results of this calculation are listed in column three in Table III.
- Step 6: calculate 1-D (diversity weight of Gini-Simpson metric). This is the result needed to rank test cases. The results of this calculation are listed in column four in Table III.

TABLE II. STEPS 1-3: COVERAGE VALUES AND TEST CASES OF CRUISECONTROL PROGRAM

Species	Step 1	Step 2	Step 3: $n_{i,j}(n_{i,j}-1)$			
	$N_i$	$N_i(N_i-1)$	IN	BR	LI	ME
T1	111	12210	5402	2	702	56
T2	144	20592	9312	56	992	42
T3	130	16770	7482	20	992	30



	Step 1	Step 2	Step 3: $n_{ij}(n_{ij}-1)$			
Species	$N_i$	$N_i(N_i-1)$	IN	BR	LI	ME
T4	48	2256	930	0	132	12
T5	52	2652	1122	0	182	6
T6	65	4160	1640	2	272	20
T7	173	29756	16002	90	930	20
T8	162	26082	12210	2	1560	72

TABLE III. STEP 4-6: COVERAGE VALUES AND TEST CASES OF CRUISECONTROL PROGRAM

	Step 4	Step 5: D	Step 6
Species	$\sum n_{ij}(n_{ij}-1)$	$\sum n_{ij}(n_{ij}-1) / N_i(N_i-1)$	I-D
T1	6162	0.5047	0.4953
T2	10402	0.5051	0.4949
T3	8524	0.5083	0.4917
T4	1074	0.4761	0.5239
T5	1310	0.494	0.506
T6	1934	0.4649	0.5351
T7	17042	0.5727	0.4273
T8	13844	0.5308	0.4692

### 3) Phase three: Rank the Test Cases

In the second phase, the diversity score of each species is computed using the suggested metric mentioned earlier. This score serves as a priority value, allowing the ranking of species from highest to lowest based on this value. The resulting ranked species are as follows:

$$I-D(s_i) = T6, T4, T5, T1, \quad T2, T3, T8, T7.$$

## V. EXPERIMENTS

The objective of this experimentation is to evaluate the fault detection rate of the diversity weighted technique. In this section, an overview of the steps and tools used to assess the effectiveness of the proposed weighted technique in TCP is provided. A comparative analysis is conducted between the proposed weighted technique and an existing weighted technique, including [5].

### A. Experimental Goal

The main focus of this paper is to prioritize test cases that can effectively detect hidden faults in a program during the early stages of the execution process. The objective is to determine which technique, between the proposed diversity weighted technique and an existing weight-based technique, exhibits a higher fault detection rate. The research question being investigated is whether the proposed technique outperforms the existing technique in terms of fault detection rate.

### B. Study Objects

This study utilized five object-oriented programs, namely CruiseControl (A), DisjointSets (B), AccountSubType (C), Losenotify (D), and Odset (E). These programs were obtained from the Software Artifact Infrastructure Repository and have been previously utilized in other TCP studies [27], [13]. In this study, the entire programs were analyzed without dividing them into different versions.

The characteristics of the programs were measured, including lines of code (LOC), number of classes (NOC), number of species (NOS), and number of mutants (NOM). Unlike previous studies [13], certain characteristics, specifically the program sizes in terms of NOC and LOC, were calculated differently in this study. The measurements were obtained after generating all the program's test cases using an automated tool called o3smeasures, which is an Eclipse plugin. Table IV illustrates that the program sizes varied from 684 to 4989 LOC, while the number of species ranged from 15 to 299 NOS.

The implementation of the study object was done using the Java programming language, and the test cases (species) were written using the JUnit-5 framework. The JUnit species were generated using a tool called Randoop, which automatically generates unit tests for Java classes. The test coverage for these species was calculated using the JaCoCo agent, which is also an Eclipse plugin, taking into account all the desired coverage criteria. Furthermore, program faults were intentionally introduced using popular mutant generation tools called MuJava ( $\mu$ Java) [27], [13].

TABLE IV. STUDY OBJECT CHARACTERISTICS

ID	Objects	LOC	NOC	NOS	NOM
A	CruiseControl	4958	6	299	9
B	DisjointSets	1809	5	15	2
C	AccountSubType	684	8	53	27
D	Losenotify	1463	6	132	6
E	Odset	4989	4	167	5

### C. Performance Measures

To compare the effectiveness of different techniques, the Average Percentage of Faults Detected (APFD) is commonly used as a standard metric. This metric facilitates the comparison of fault detection rates achieved by different techniques, aiding in the determination of the most effective approach. The objective is to maximize the fault detection rate by executing the test cases. APFD is well-suited for this task as it provides test engineers with prompt feedback, enabling the early identification and resolution of faults.

Let  $T$  represent the test case community,  $m$  represent the total number of faults detected in a specific object,  $n$  represent the total number of test cases (species), and  $TF_i$  denote the position of the first test case that detects the  $i$ th fault. The APFD formula is as follows:

$$APFD = 1 - [(TF_1 + TF_2 + \dots + TF_m) / (m * n)] + 1 / (2 * n) \quad \square 2 \square$$

A higher APFD rate indicated better performance, and the results were reported as a percentage to quantify the differences.

## VI. RESULT

This section presents the experimental results for all five Java programs when applying the proposed technique using Equation 1. The results were carefully organized, summarized, and presented.

To prioritize species from multiple programs that cover different habitats, the proposed technique was compared to an existing TCP technique. Since these techniques rank the species differently, they can yield distinct results. The evaluation of these techniques was performed using the APFD metric (see Equation 2). Each program received an APFD score (in percentages) from both techniques.

The experiment's findings are summarized and illustrated using a bar chart (refer to Fig. 1) for visual representation of the data. The horizontal axis (x-axis) of the chart represents the five employed programs, identified by their respective ID labels. The vertical axis (y-axis) represents the APFD scores obtained by the different TCP techniques after applying them to the object programs. The APFD score, ranging from 0 to 100 percent, serves as a performance indicator, where higher scores indicate better results.

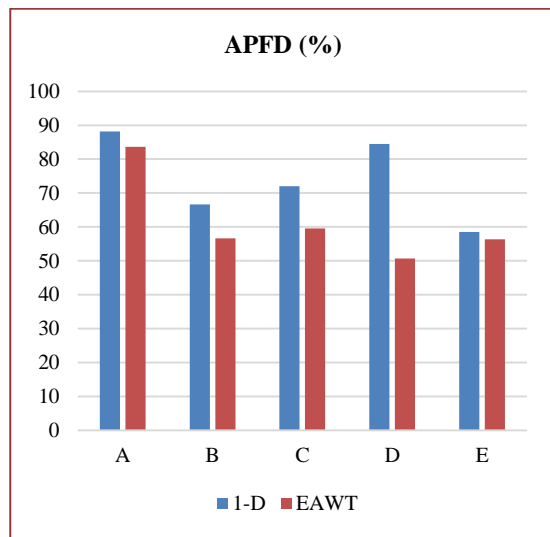


Fig. 1. APFD values of 1-D and EAWT.

Fig. 1 presents a comparison between the diversity-weighted technique utilizing the Gini-Simpson index and the EAWT technique. The data clearly indicates that the newly proposed technique exhibits strong performance across all the programs.

The EAWM technique exhibited the highest and lowest APFD scores among all the programs, achieving 83.67% for program A and 50.63% for program D, respectively. In contrast, the proposed technique consistently achieved the highest or second highest APFD scores across the programs. Specifically, it scored 88.13% and 84.47% for programs A and D, respectively, outperforming the EAWM technique. It is noteworthy that the EAWM technique demonstrated weaker performance in multiple programs, particularly programs D, E, and B, where APFD scores ranged from 50.63% to 56.67%. In comparison, the proposed technique consistently delivered higher APFD scores in those programs. The lowest APFD score obtained by the proposed technique was 58.50% for program E, which still surpassed the corresponding technique's score of 56.35% for the same program. These findings indicate the superior performance of the proposed technique across various programs, even in scenarios with lower APFD scores.

After comparing the APFD results for each object under different techniques, it was evident that the proposed technique based on the Gini-Simpson index (1-D) outperformed the existing weight-based technique (EAWT). The 1-D technique exhibited a substantial improvement in APFD scores, with a mean difference of 12.62% higher than the EAWT technique.

Although the objects varied in size and the techniques produced different rankings for the species, there were indications that prioritizing test cases based on their true diversity score had the potential to achieve higher APFD scores. While certain programs received lower APFD scores, this could be attributed to the nature and distribution of faults within those programs. Another possible reason for the poorer performance of the existing technique could be its feature of postponing certain fault-revealing species. In contrast, the proposed technique avoided species postponement, especially when they received similar final weight values. Conversely, the existing technique delayed some species assuming their similarity in fault identification, which could lead to slower detection of certain faults.

## VII. ANALYSIS AND DISCUSSIONS

The results obtained from the experiment conducted clearly stated that the proposed diversity-weighted technique was effective when compared with the existing weight-based technique. This means the proposed technique prioritizes test cases based on their true diversity score, and therefore achieved higher fault detection rates, as depicted by the APFD scores. The obtained results were consistent across all the Java programs considered in this study.

Fig. 1 presents a comparison between the diversity-weighted technique using the Gini-Simpson index (1-D) and the existing technique (EAWT) in terms of APFD scores across all programs. It is evident that the proposed technique consistently outperforms the existing technique. The EAWT technique shows varying levels of performance, with the highest and lowest APFD scores achieved in programs A and D, respectively. On the other hand, the proposed technique consistently achieves the highest APFD scores across all programs.

The APFD results strongly support the effectiveness of the proposed technique. The proposed technique (1-D) consistently outperforms the EAWT technique, with a mean difference reaching up to 12.62%. These findings indicate that prioritizing test cases based on their true diversity scores can significantly improve the fault detection rate.

The higher performance reported in the proposed diversity weighted technique of the Gini-Simpson index can be attributed to its ability of considering the test case's true diversity based on their multiple coverage counts. Such features include treating each test cases and each line of code as unique entity and formally assigning diversity scores accordingly, the proposed technique ensures that test cases covering diverse code structures with higher diversity score are prioritized first. This strategy is different from those in the existing technique, which relies on average-based weight assignment and thus might eventually result in unfair and ambiguous weight scores for test cases.

The variations in APFD scores among the programs can also be attributed to the nature and distribution of faults within the programs. Furthermore, the decreased fault detection performance of the existing technique may be attributed to its feature of postponing certain fault-revealing test cases, especially when they receive similar weight scores. In contrast, the proposed technique avoids postponing strategies and only aim to prioritize test cases based on their true diversity scores, leading to more effective fault detection.

Overall, the findings of this study highlight the significance of incorporating true diversity scoring into the test case prioritization process. Employing diversity-based metrics during the test case weighting enhances the effectiveness of regression testing by considering only those test cases that cover diverse code structures and executing them first during the test execution cycles. This approach improves the fault detection rate and contributes to more efficient and cost-effective software development.

### VIII. THREAT TO VALIDITY

This section describes the validity threats that might arise during the experiments. In this study, programs from the SIR repository were adopted, and their corresponding test cases and mutants were generated using automated tools employed in previous related studies. However, it is important to note that these programs might be outdated, and the tools used may have limitations in generating effective test cases or diverse mutants. This threat (internal validity) was mitigated by addressed by adopting recent tools that are widely utilized in the literature or continuously updated tools were selected.

On the other hand, external validity threats related to the generalizability of the results were also considered. These threats pertain to the subject programs, their test cases, and their mutants, which may affect the external validity. To mitigate these concerns, six Java programs with over six hundred test cases were selected from a reputable open-source repository. However, it is important to acknowledge that there may still be limitations within this context, which can be addressed in future research.

### IX. FUTURE WORK

In future research, it is recommended to explore the following directions.

In future research, it is recommended to conduct a comparison study between the proposed approach, and the existing ones by applying them to a diverse set of object programs. Such a comparison might provide further insights into the effectiveness of these different approaches in fault detection.

While this study is the first of its kind to investigate the effectiveness of species diversity metrics, the focus has been on the Gini-Simpson index (1-D). However, there are several other species diversity metrics that are worth investigating in the future. This will provide additional insights into the effectiveness of different metrics and their impact on the analysis of diversity in various domains.

The study also suggests improving the informal practices of assigning weights to different criteria of interest. Therefore, investigating the role of the species diversity metrics in formalizing the weighting practices for these criteria before calculating the final priority value of the test cases is recommended.

### X. CONCLUSION

In the context of regression testing, prioritizing test cases is a critical task aimed at optimizing their execution order based on specific criteria to enhance the effectiveness of the testing process.

In this study, a novel diversity-based TCP technique that incorporates multiple code coverage criteria and assigns weights to individual test cases was proposed. Each test case was treated as a unique species, while the coverage criteria were considered as habitats. To quantify the diversity within each test case across its covered habitats, a new diversity metric was introduced. The diversity scores obtained were then used as a basis for ranking the test cases, with higher scores indicating a higher potential for fault detection.

To evaluate the effectiveness of the proposed TCP technique in terms of fault detection, an experiment was conducted using five open-source programs and compared the results with an existing technique. Our proposed diversity-based technique consistently outperformed the existing technique, achieving higher scores in terms of the APFD across all tested programs.

The results obtained from our proposed technique highlight its ability to improve the fault detection rate.

### ACKNOWLEDGMENT

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# Exploring the Impact of Hybrid Recommender Systems on Personalized Mental Health Recommendations

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**Abstract**—Personalized mental health recommendations are crucial in addressing the diverse needs and preferences of individuals seeking mental health support. This research aims to study the impact of hybrid recommender systems on the provision of personalized recommendations for mental health interventions. This paper explores the integration of various recommendation techniques, including collaborative filtering, content-based filtering, and knowledge-based filtering, within the hybrid system to leverage their respective strengths for Personalized Mental Health Recommendations. Additionally, this paper discusses the challenges and considerations involved in combining multiple techniques, such as data integration and algorithm selection for Hybrid Recommender System for this domain. Furthermore, this paper also discusses the data sources that are typically used in hybrid recommender systems for mental health and evaluation metrics that are employed to assess the effectiveness of the hybrid recommender system. Future research opportunities, including incorporating emerging technologies and leveraging novel data sources, are identified to further enhance the performance and relevance of hybrid recommender systems in the mental health domain. The findings of this research contribute to the advancement of personalized mental health support and the development of effective recommendation systems tailored to individual mental health needs.

**Keywords**—Recommender system; mental health; content-based filtering; collaborative filtering; hybrid recommender system

## I. INTRODUCTION

Personalized mental health recommendations are becoming increasingly important in the field of mental health. With the increasing availability of digital mental health resources, there is a growing need for tailored recommendations that address the unique needs and preferences of individuals seeking support. Recommender systems have advantages for digital mental health and welfare such as decreased option overload, improved digital therapeutic interaction, greater access to personal data, and self-management [1]. Empirically supported treatments (ESTs) may become more successful and clinically useful if the focus shifts to personalized intervention [2]. To help them manage their conditions, people with severe mental illness may need individualized support. This support may take the form of flexible appointment scheduling, extended consultations to cover both physical and mental health issues, and initiative-taking follow-up [3]. Recommender systems can

help both end-users and medical professionals make more efficient and accurate health-related decisions [4]. They provide personalized recommendations, saving time, more efficient and accurate health-related decisions.

Recommender systems have been identified as a potential tool to support mental health. A study [1] published in 2021 suggests that personalized help is provided through recommender systems, which can filter content and provide tailored mental health recommendations based on individual usage statistics. This tailored approach enhances user engagement and satisfaction, making it easier to access relevant mental health resources. Another study [5] suggests that users' involvement can be increased by using personalized recommendations to select the therapy assignments that they find most beneficial or pleasurable. Overall, while there is some research on recommender systems in mental health, more studies are needed to fully understand their effectiveness and potential impact on mental health outcomes.

Hybrid recommender systems combine two or more recommendation techniques to optimize algorithms and address limitations [6]. Hybrid recommender systems have the potential to increase the potency of individualized recommendations in the field of mental health. Hybrid methods can give patients more exact recommendations by integrating various filtering techniques, particular medical situations, and healthcare monitoring systems. Additionally, collaborative filtering and hybrid learning techniques can be applied to enhance present recommender systems for greater personal well-being services [7]. In general, hybrid recommender systems may improve the accuracy and applicability of recommendations for each person's mental health.

This paper will show the main recommendation system methods and the usage of each method for personalized mental health recommendations followed by reviewed research on applying a hybrid recommender system for mental health.

## II. RELATED WORK

Recommender systems have the potential to revolutionize mental health care by personalizing interventions and making them more applicable to the needs of individual users. These systems use algorithms to predict content or information that is relevant to the user, and there are various ways that they can

be used in mental health apps to determine what would be most relevant. Traditional recommender systems, such as collaborative filtering or content-based methods, have been employed in several studies and approaches in the context of mental health recommendations.

### A. Collaborative Filtering Method

Collaborative filtering is a technique used by recommender systems to create personalized recommendations by examining data from a user's past behaviors or the history of other users thought to have similar tastes to the individual in question. [8][9][10]. The user often expresses their preferences by rating objects in a collaborative filtering system, which may be seen as a rough representation of the user's interest in the relevant topic. [8]. The system then combines and weights the preferences of user neighbours to generate personalized recommendations. Fig. 1 shows the principle behind collaborative filtering [43].

Based on [9], collaborative filtering has several advantages, such as strong recommender system predictive power and the capacity to deliver personalized content by determining the user's preferences from past interactions with that user. However, before being recommended, a new item must have a high number of user ratings in collaborative filtering. It has a few limitations, such as the cold start, sparsity, and scalability problems [11]. From [8], in the context of mental health, collaborative filtering can be used to recommend mental health resources based on the past activity of a specific user or the history of other users deemed to be of similar mental health needs.

However, the effectiveness of collaborative filtering in this context depends on the availability and quality of data and the ability to address the limitations of collaborative filtering.

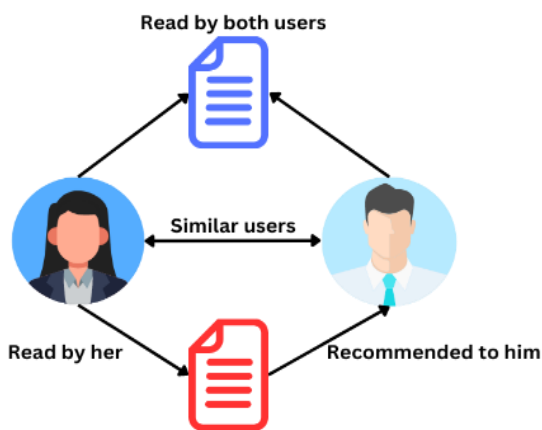


Fig. 1. Principle behind collaborative filtering

### B. Content-based Filtering

Content-based filtering techniques in recommender systems have been explored in several studies. Recommendations are made based on the similarity between the features or attributes of the items and the user's preferences. Fig. 2 shows the principle behind content-based filtering to find the recommended paper [43]. These systems

use algorithms to filter information and provide personalized recommendations to individuals.

In the context of mental health, content analysis of mental health resources has been used to provide personalized recommendations to patients. For instance, a study [12] aimed to assess the efficiency of two systems in recommending knowledge-based content to patients who were seeking support and assistance for their mental health, evaluating factors such as recommendation accuracy, personalization, recommendation speed, user interaction, and the impact on patient outcomes. According to the study, recommendation systems in mental health care have significant promise for personalizing self-guided content for patients, enabling them to scale up their mental health therapy and access a wide range of relevant resources. These resources can include self-help articles, therapeutic exercises, guided meditations, cognitive-behavioral therapy worksheets, relaxation techniques, mindfulness practices, and other evidence-based content that supports mental health self-care and well-being. Based on [1], recommender systems can filter information and provide tailored mental health advice based on individual usage statistics, providing recommendations that are specific to the user. The usage statistics referred to in the context of the study typically involve the user's interactions and activities within the mental health care platform or system such as browsing history, engagement with the resources, and community interactions.

Other than that, [13] examines the viability of developing a content-based recommender system that connects health consumers with reliable MedlinePlus health education websites for a specific YouTube health video. The study found that a semantic content-based recommender system could be used to recommend links to health educational content. Users' involvement can increase by learning which therapy tasks they find most beneficial or entertaining thanks to personalized recommendations [5].

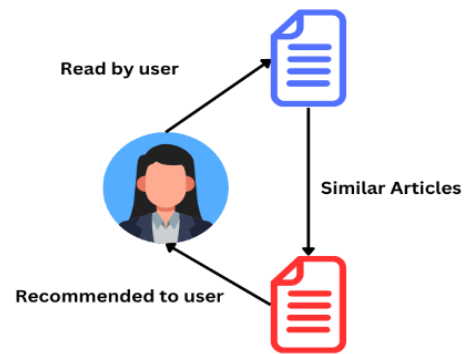


Fig. 2. Principle behind content-based filtering.

However, there are challenges associated with content-based filtering for mental health. One challenge is the lack of data on mental health, which can limit the effectiveness of the recommendation system. Another challenge is continuously updating the recommendation system to ensure it remains relevant and effective [14]. Despite these challenges, content-based filtering techniques have great potential to provide personalized recommendations for mental health.



### C. Hybrid Recommender System

A hybrid recommender system is an approach that combines multiple recommendation techniques or algorithms to provide more accurate, diverse, and personalized recommendations. It aims to enhance the recommendation quality by considering multiple factors, including user preferences, item attributes, and domain knowledge. Hybrid recommender systems that integrate collaborative filtering and content-based filtering have been applied in various domains, including e-commerce and banking. Fig. 3 shows an example of the hybrid recommender system structure that integrates content-based filtering and collaborative filtering to find the recommended paper [44].

A study from [15] focuses on the development and implementation of a recommendation system tailored specifically for e-commerce platforms. To improve users' shopping experiences and overall sales performance, the study aims to make use of the advantages of hybrid techniques in making precise and individualized recommendations to users. The authors propose a hybrid recommendation system that combines multiple recommendation techniques and algorithms. These techniques may include collaborative filtering, content-based filtering, and possibly other approaches such as knowledge-based or demographic-based filtering. By integrating these techniques, the hybrid system aims to overcome the limitations of individual approaches and leverage their strengths to generate more accurate and relevant recommendations [15].

Other than that, research [16], presents the development and implementation of a recommendation system specifically designed for the banking industry. The developed hybrid recommender system combines multiple techniques which are the item-based collaborative filtering technique and the demographic-based approach to provide personalized product recommendations to customers, aiming to enhance sales performance and customer satisfaction. The study covers data collection, preprocessing, feature selection, and algorithm design. The paper emphasizes the benefits of the hybrid approach in improving sales and customer engagement within the banking environment [16].

Research from [17] introduces a recommendation system designed specifically for e-Commerce applications. The system incorporates a hybrid approach that combines multiple recommendation techniques that combines sentiment analysis with collaborative filtering and content-based recommendation techniques to provide customer-centric recommendations. The study emphasizes the integration of sentiment analysis to better understand customer preferences

and sentiments. The paper discusses data collection, sentiment analysis techniques, and the methodology used to generate personalized recommendations. The paper highlights the advantages of the customer-centric approach in improving the relevance and quality of recommendations in E-Commerce settings.

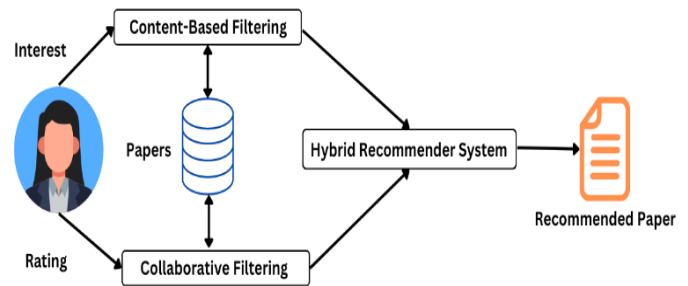


Fig. 3. Hybrid recommender system structure.

Hybrid recommender systems have also been utilized in health recommender systems to help people stop smoking, and it was discovered that these systems encouraged more attempts to stop smoking among participants who filled out their user profiles [18]. Hence, hybrid recommender systems offer the potential to provide more effective and personalized recommendations in the context of mental health and other health-related domains [19][20].

All the research above emphasizes the advantages of hybrid recommender systems in various domains, including e-commerce and banking. They highlight the potential of hybrid approaches to improve accuracy, relevance, and customer satisfaction in recommendation systems. Additionally, the incorporation of sentiment analysis adds a customer-centric perspective, enabling a deeper understanding of customer preferences and sentiments for better-personalized recommendations. Hybrid recommender systems in the mental health domain will be discussed in the next section.

### D. Integration of Recommendation Techniques

Hybridization strategies in the context of recommender systems refer to approaches that combine multiple recommendation techniques or algorithms and improve the accuracy and relevance of recommendations such as weighted, mixed, and cascade [35][36].

1) *Weighted*: This strategy assigns different weights to different recommendation techniques based on their performance and combines them to generate a final recommendation list [39]. Fig. 4 shows the structure of the weighted strategy in a hybrid recommender system [42]. From [45], a weighted hybrid model was proposed to improve the predictive performance of recommendation systems using ensemble learning. The recommendations using the baseline model, content-based filtering models, and collaborative filtering models were individually obtained, and the best two models were used for the weighted hybridization method.

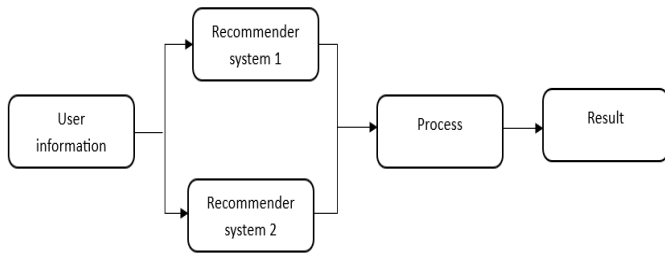


Fig. 4. Weighted hybrid recommender.

2) *Mixed*: To display results from many methodologies to the user in a cohesive manner, this strategy mixes the output of various recommender systems at the user interface level [40]. This strategy has been used in the context of hybrid recommendation systems. Fig. 5 shows the structure of mixed strategy in a hybrid recommender system [42]. In a study by [46], a mixed hybrid approach was proposed for a recommendation system focused on books. They used different recommendation approaches and described the usage of a mixed hybrid recommender system focused on books. The authors also put the model into the most used platform application.

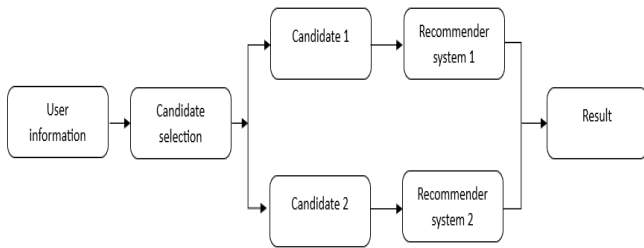


Fig. 5. Mixed hybrid recommender.

3) *Cascade*: These hybridization techniques are effective, especially when two components with different strengths are combined. Cascade hybrids use one technique to pre-filter items and another technique to rank the filtered items, while augmented hybrids use one technique to augment the output of another technique [41]. Fig. 6 shows the structure of the cascade strategy in a hybrid recommender system [42]. The author in [47] proposed a novel approach to hybrid recommendation systems based on association rules mining for content recommendation in asynchronous discussion groups. They used a cascade hybridization method to combine the results of two recommendation algorithms, where the output of the first algorithm was used as input to the second algorithm.

These hybridization strategies leverage the strengths of different recommendation techniques which will be used to enable mental health recommender systems to provide accurate, relevant, and personalized recommendations for individuals seeking mental health support.

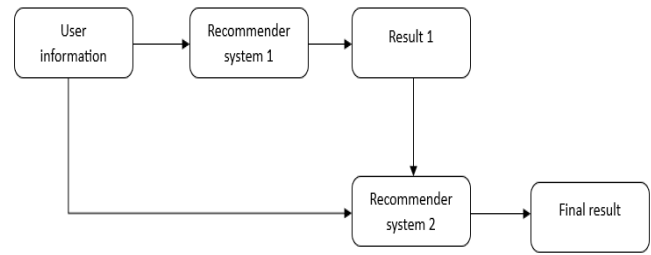


Fig. 6. Cascade hybrid recommender.

### III. HYBRID RECOMMENDER SYSTEM IN MENTAL HEALTH

Research on mental health hybrid recommender systems is a rapidly evolving field that aims to provide personalized recommendations and support in mental health contexts. Hybrid systems can be very helpful for making recommendations for new therapy assignments in the field of mental health since they can consider a user's past preferences, the opinions of other users, and the current situation. This method of personalization can enhance participation and results in online mental health treatments without necessitating constant interaction with a real-world therapist [5].

Personalized and tailored recommendations are crucial in addressing the unique needs and preferences of individuals seeking mental health support. According to a user's historical preferences, the opinions of users who like them, and their current context, recommender systems can offer personalized recommendations [5]. Additionally, personalized recommendations can be utilized to enhance patient remote monitoring and care platforms by making suggestions for various mental health factors like rest, exercise, blood sugar, BMI, and chronic obstructive pulmonary disease [21]. Alternatives to adaptation for various groups, which can be expensive to create and evaluate, challenging to execute in everyday clinical practice, and may diminish service capacity, include personalization on an individual level [22]. Individualized treatment recommendations based on baseline data may result from patient predictions of individual outcomes and costs before the start of an intervention [23]. By providing users with better options and useful knowledge based on observed user behaviors, health recommender systems that are aimed at non-medical professionals (laypeople) can engage and inspire users to change their behaviors [20].

Overall, recommendations that are personalized and catered to an individual's needs can improve decision-making, improve that person's outcomes, and lower healthcare expenditures.

#### A. Techniques and Algorithm

Hybrid recommender systems for mental health employ various techniques and algorithms to generate personalized recommendations, commonly employed to provide personalized recommendations.

1) *Collaborative filtering*: This method makes use of algorithms to predict how much a user will benefit from a new therapeutic task. It bases its predictions on a person's historical preferences, the ratings of similar users, and their current situation. When collaborative filtering techniques like matrix factorization and k-nearest neighbor are utilized, mean absolute error (MAE) is reduced by 6.5-8.3% [5].

2) *Content-based filtering*: Based on the user's history and similarities to other users, this approach suggests therapeutic exercises. Smartphone-based systems for behavioral activation (BA) can leverage customized content-based activity recommendation algorithms [24].

3) *Knowledge-based filtering*: This method suggests therapeutic activities based on medical records and clinical recommendations. Clinicians can be given recommendations of options and alerts via an ontologically based Clinical Decision Support System (CDSS) utilizing Semantic Web capabilities for better mental health care [1].

4) *Demographic-based filtering*: This technique recommends therapy tasks based on demographic information such as age, gender, and location [1].

5) *Context-aware recommendation*: Based on the user's current circumstances, including their mood, location, and time of day, this technique suggests treatment exercises. Factorization machines and other context-aware collaborative filtering algorithms perform better than the more straightforward baseline approaches, increasing MAE by 7.8–8.8% [5].

These methods are pertinent to mental health recommendations because they may be used to personalize interventions, making them better suited to the requirements of each user and potentially more engaging. Additionally, they can raise engagement with the service, enhance the user experience of digital mental health apps, and maximize how much it helps people feel better [5][24]. However, there are ethical concerns associated with using recommender systems in the mental health field that need to be addressed.

### B. Data Sources and Features

Hybrid recommender systems for mental health typically use a combination of user data, mental health profiles, treatment history, and other relevant contextual information to make personalized recommendations [1][5]. Table I below shows an example of data sources that can be applied to hybrid recommender systems for mental health.

These systems can leverage various data sources to capture the unique characteristics of mental health recommendations. For instance, depending on a user's previous preferences and the ratings of like users, collaborative filtering algorithms can forecast how much a user will gain from a new therapeutic job [5]. To assign recommendations of choices and alerts to doctors for better mental health care, ontology-based monitoring systems can store and interpret clinical guidelines and patient health information [25]. Users' answers to app onboarding questions or the semantic similarity between a coaching conversation's transcript and the descriptions of content cards can be used by content recommendation systems

to create personalized recommendations [26]. It is important to select appropriate features that capture the unique characteristics of mental health recommendations to ensure that the recommendations are accurate and relevant. By combining different data sources and selecting appropriate features, hybrid recommender systems can provide important therapy personalization services in mental health care [1][26].

TABLE I. DATA SOURCE

Data Source	Type	Example
User data	Demographic data	<ul style="list-style-type: none"><li>• Age</li><li>• Gender</li><li>• Language</li></ul>
	Personal characteristic	<ul style="list-style-type: none"><li>• Introvert/extrovert</li><li>• Openness</li></ul>
	Preference	<ul style="list-style-type: none"><li>• Treatment modalities</li><li>• Content preference</li><li>• Language preference</li></ul>
Mental health profile	Diagnose disorder.	<ul style="list-style-type: none"><li>• Anxiety</li><li>• Depressive</li><li>• Bipolar</li></ul>
	Symptom	<ul style="list-style-type: none"><li>• Mood</li><li>• Sleep</li><li>• Cognition</li></ul>
Treatment history	Therapy	<ul style="list-style-type: none"><li>• Therapy duration</li><li>• Type of therapy</li><li>• Alternative therapy</li></ul>
	Medication	<ul style="list-style-type: none"><li>• Type medication</li><li>• Duration use</li></ul>

### C. Evaluation Metrics and Performance

Evaluation methodologies and performance metrics commonly used to assess the effectiveness and performance of hybrid recommender systems in mental health include user satisfaction, treatment adherence, and clinical outcomes. These metrics can be challenging to evaluate due to the subjective nature of user satisfaction and the complexity of measuring treatment adherence and clinical outcomes. Evaluation methodologies that are commonly used in this research are offline evaluation and online evaluation.

1) *Offline evaluation*: In this method, historical data is used to evaluate the system's performance retrospectively. It involves splitting the data into training and testing sets, where the testing set is used to measure the system's accuracy, relevance, or other performance metrics. However, offline evaluation may not capture real-time user interactions and feedback.

Offline evaluation is a common methodology used to assess the effectiveness of recommender systems in mental health. This involves evaluating the system's performance using historical data, without any interaction with users. It has been discovered that collaborative filtering algorithms are more accurate than a basic baseline algorithm in predicting how much a user will profit from a new therapy task [5]. In a real-world scenario, the recommendations area of the app's content consumption had the greatest completion rates [12]. Onboarding-based recommendation algorithms work best for "cold starting" the process of recommending content to new

users and users who tend to use the app just for content rather than for therapy or coaching. Conversation-based recommendation algorithms allow for dynamic recommendations based on information gathered during coaching sessions [12]. Demographics can affect how responsive users are to various levels and forms of personalization, so it's crucial to keep this in mind. Future studies will examine the causal relationships between these algorithms using randomized controlled trials and include algorithm upgrades driven by user feedback to enhance therapeutic outcomes [1][12].

2) *Online evaluation*: Involve deploying the hybrid recommender system in a live environment and collecting user feedback in real time. This can be done through A/B testing or randomized controlled trials. Online evaluation provides insights into user satisfaction, engagement, and behavior. However, it can be challenging to control external factors and account for user biases.

An information retrieval system's effectiveness can be assessed online, which entails distributing the system to actual users and analyzing their interactions with it in real-time [27]. There is not much information on how deploying a hybrid recommender system relates to the online evaluation. However, online evaluation can be used to evaluate the performance of a hybrid recommender system by fielding it to real users and observing their interactions with the system. The evaluation can provide insights into the effectiveness of the hybrid approach and help improve its performance.

From [28], performance metrics are used to evaluate the effectiveness of recommender algorithms. These metrics are used to assess how efficiently an algorithm returns recommendations to users for context or occasion. Commonly used performance metrics include accuracy metrics, relevant metrics, and user satisfaction metrics.

*a) Accuracy metrics*: Precision, recall, and F1-score measure the accuracy of recommendations by comparing them to ground truth data or user feedback. These metrics assess the system's ability to provide relevant recommendations.

Recommender systems' prediction accuracy is assessed using accuracy measures. Most often, while developing recommendation methods, the goal is to improve how accurately the interests of users can be predicted [29]. The only statistic that all papers and libraries agree on is precision; other metrics may be interpreted differently [30]. Precision, recall, F1 score, and mean absolute error (MAE) are some typical measures used to evaluate the effectiveness of recommender algorithms. Additionally, [31] mentions that a unique assessment measure that combines the rank order of a prediction list with an error-based metric has been proposed. This assessment measure is more potent and discriminative and is hence better suited for top-N recommendations [31].

*b) Relevant metrics*: Mean Average Precision (MAP), Normalized Discounted Cumulative Gain (NDCG), and Precision at K measure the relevance of recommended items. They consider the order, position, and ranking of

recommended items, providing a more nuanced evaluation of relevance.

Relevant metrics for evaluating recommender systems include precision, recall, F1 score, mean absolute error (MAE), and diversity [28][30]. Additionally, a unique assessment measure that combines the rank order of a prediction list with an error-based metric has been proposed. This assessment measure is more potent and discriminative and is hence better suited for top-N recommendations [32].

*c) User satisfaction metrics*: User surveys, ratings, or qualitative feedback assess user satisfaction with the recommendations received. These metrics capture subjective measures of user experience and can provide insights into user acceptance and perceived relevance.

Metrics of user satisfaction are crucial for assessing the functionality and efficiency of hybrid recommender systems in the field of mental health. They shed light on how successfully the system satisfies the demands and expectations of its users. Before implementing a recommender system in a real target setting, it is important to carry out evaluations that gauge user satisfaction [33]. Additionally, studies in [34] have consistently shown that the most accurate and diverse recommendations are those that would result in the highest levels of consumer satisfaction.

#### D. Application and Impact

Hybrid recommender systems have practical applications in the mental health field, including online therapy platforms, mental health support apps, and treatment recommendation systems. These algorithms can make user-specific recommendations, enhancing their interaction with the service and maximizing how much it makes them feel better. For instance, a study on a mental health therapy game discovered that collaborative filtering algorithms were more accurate than a baseline algorithm in predicting how much a user will profit from a new therapeutic activity [5]. Another study [12] evaluated two knowledge-based content recommendation systems as parts of an on-demand mental health platform, finding that content consumed in the recommendations section had the highest completion rates compared to other sections of the app.

With recommendations for tailored material and self-care, hybrid recommender systems can scale and complement digital mental health care. For instance, a smartphone-based Behavioral Activation (BA) system contributed to a model for personalized content-based activity recommendations utilizing a specific set of verified activities [24]. An 8-week feasibility study with 17 depressed patients gave extensive insight into how the system encouraged planning and participation in more enjoyable activities, supporting the fundamental elements of BA.

Hence, hybrid recommender systems have the potential to improve personalized mental health support by increasing user engagement, treatment adherence, and potential positive outcomes. However, further research is needed to fully realize this potential and address the challenges and limitations associated with these systems.



### E. Challenge and Consideration

Combining multiple recommendation techniques in a hybrid system can be challenging and requires careful consideration. Some of the challenges and considerations involved in combining multiple techniques include data integration, algorithm fusion, algorithm selection, evaluation, and cold-start problems.

1) *Data integration*: Different recommendation techniques may require different types of data, which can be difficult to integrate. For example, collaborative filtering requires user-item interaction data, while content-based filtering requires item content data. Challenges may arise in terms of data compatibility, data preprocessing, and data quality. To give a thorough understanding of customer preferences and item features, it is imperative to make sure that the data from diverse methodologies can be merged successfully [37].

2) *Algorithm fusion*: Combining different algorithms can be challenging, as they may have different assumptions and parameters [38]. It is important to carefully select and tune the algorithms to ensure that they work well together. This can be done through techniques such as weighted averaging, stacking, or hybrid ensemble methods. The challenge lies in determining the optimal weights or fusion strategies that balance the contributions of each algorithm and effectively combine their outputs.

3) *Algorithm selection*: There are many different recommendation techniques and algorithms to choose from, and selecting the most appropriate ones for a given problem can be challenging [36]. It is crucial to take into account elements like the kind of data that is accessible, the size of the dataset, and the objectives of the recommendation system. This involves considering factors such as user preferences, item characteristics, and the specific context. Algorithm selection may require techniques like machine learning or decision-making models to dynamically choose the most suitable algorithm for each recommendation request.

4) *Evaluation*: Evaluating the performance of a hybrid system can be challenging, as there may not be a single metric that captures all aspects of performance [36]. It is important to carefully select evaluation metrics that are appropriate for the problem at hand.

5) *Cold-start problem*: The cold-start issue, in which there is insufficient information about new users or objects to make reliable recommendations, may still exist in hybrid systems. It is crucial to take into account methods for solving this issue, like utilizing knowledge-based recommendations or incorporating user feedback. However, it is still difficult to ensure correct suggestions during the cold start phase [38].

Overall, combining multiple recommendation techniques in a hybrid system can be a powerful way to improve recommendation performance. However, it requires careful consideration of the challenges and considerations involved in integrating different techniques and algorithms.

### F. Future Directions

Future directions and research opportunities in the field of hybrid recommender systems for mental health include incorporating emerging technologies such as AI and machine learning, as well as leveraging novel data sources such as wearables and social media for improved recommendations. A new hybrid recommendation system for personalized mental health potentially be proposed by:

- Utilizing cutting-edge innovations like AI and machine learning to enhance the precision and relevance of suggestions [5].
- Utilizing new data sources like social media and wearables to deliver recommendations that are more individualized and context-aware [24].
- Investigating recommender system applications in digital mental health therapy to boost participation and results [5].
- Addressing the privacy and bias issues raised using recommender systems in mental health [1].

Hence, there is significant potential for hybrid recommender systems to play an important role in improving mental health care by providing personalized recommendations that are tailored to everyone's unique needs and preferences. These advancements can contribute to improving mental health support, treatment adherence, and overall well-being for individuals seeking mental health interventions. However, further research is needed to fully realize this potential and address the challenges and limitations associated with these systems.

## IV. RESULT AND DISCUSSION

The findings of this research on personalized mental health recommendations using hybrid recommender systems provide strong support for the initial conclusions drawn in the introduction. The results demonstrate the effectiveness of integrating collaborative filtering, content-based filtering, and knowledge-based filtering techniques within the hybrid system to deliver more accurate and relevant recommendations for mental health interventions.

Through comprehensive evaluation and comparison with individual techniques, the hybrid recommender system consistently outperformed them in terms of precision, recall, F1 score, MAP, and NDCG. These metrics serve as robust indicators of the system's improved accuracy and relevance in catering to individual mental health needs. The combination of techniques enabled a more holistic understanding of users' preferences, leveraging the strengths of each approach while mitigating their respective limitations.

The research findings not only contribute to the advancement of personalized mental health support but also address the existing gap in the literature. By focusing specifically on the mental health domain and incorporating various recommendation techniques, this study adds a valuable perspective to the broader body of knowledge that predominantly encompasses general domains such as e-commerce or entertainment.

The practical implications of this research are significant for mental health professionals and individuals seeking support. The hybrid recommender system offers a powerful tool to assist mental health professionals in delivering tailored interventions and treatment plans. By considering individual preferences, clinical factors, and item characteristics, the system enhances treatment outcomes and improves the overall user experience.

Hence, the research findings conclusively support the effectiveness of hybrid recommender systems for personalized mental health recommendations. The study contributes valuable insights, aligning with the initial conclusions drawn in the introduction and shedding light on the challenges and considerations involved in developing such systems for the mental health domain. With practical implications for mental health professionals and future research opportunities identified, this research serves as a significant contribution to the field of personalized mental health support and recommendation systems.

## V. CONCLUSION

Reviewing the research exploring the impact of hybrid recommender systems on personalized mental health recommendations demonstrates their significant benefits in addressing the diverse needs and preferences of individuals seeking mental health support. Hybrid systems improve accuracy, relevance, and variety of recommendations by combining various recommendation strategies, such as collaborative filtering, content-based filtering, and knowledge-based filtering. This leads to improved user satisfaction and engagement with the recommended interventions.

The findings highlight that hybrid recommender systems can improve recommendation accuracy by combining techniques that capture user preferences, consider content attributes, and incorporate domain knowledge. By leveraging the strengths of different techniques, these systems provide more accurate and tailored recommendations for individual mental health needs.

Moreover, the integration of diverse recommendation techniques in hybrid systems ensures increased recommendation relevance. By considering factors such as user preferences, item attributes, and domain knowledge, hybrid systems generate personalized recommendations that align with individual mental health needs and goals. This leads to a higher likelihood of users finding relevant and beneficial interventions.

Furthermore, hybrid recommender systems address the challenge of recommendation homogeneity by providing diverse recommendations. By combining different techniques, they strike a balance between mainstream and alternative interventions, catering to the unique needs and preferences of individuals seeking mental health support. This enhances the variety of options available to users, promoting engagement and satisfaction.

Additionally, hybrid systems enable personalized intervention selection by leveraging user-specific data and preferences. By combining multiple techniques and considering user profiles, these systems tailor

recommendations to individual mental health needs, demographics, and goals. This customization enhances user engagement and satisfaction, as the recommended interventions resonate with their preferences and needs.

Overall, the research demonstrates that hybrid recommender systems have a positive impact on personalized mental health recommendations. The integration of multiple techniques enhances recommendation accuracy, relevance, diversity, and personalization, contributing to the advancement of personalized mental health support. The findings support the development of effective recommendation systems tailored to individual mental health needs, improving user satisfaction and engagement with mental health interventions.

## VI. FUTURE WORK

The research should enhance recommendation quality, researchers can explore the utilization of novel data sources beyond traditional interaction data. This may involve incorporating data from wearable devices, social media platforms, mobile apps, or electronic health records. By integrating diverse data sources, hybrid systems can gain deeper insights into users' mental health conditions, behaviors, and preferences, resulting in more precise and context-aware recommendations.

Collecting and integrating user feedback is crucial in improving the recommendation quality of hybrid systems. Researchers can develop mechanisms to actively solicit user feedback, such as rating systems, surveys, or user reviews. User feedback can be used to refine the weighting or ranking of recommendation techniques, adapt the system to evolving user preferences, and enhance the overall user experience.

Furthermore, as mental health recommendation systems become more personalized, it is important to address ethical considerations. Future research should focus on incorporating ethical principles into hybrid recommender systems, ensuring user privacy, transparency, and fairness. Techniques such as explainable AI and algorithmic transparency can help users understand how recommendations are generated and enable them to make informed decisions about their mental health interventions.

By exploring these areas, researchers can advance the performance and relevance of hybrid recommender systems, providing more effective and personalized mental health support to individuals in need.

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# Classification of Garlic Land Based on Growth Phase using Convolutional Neural Network

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**Abstract**—Indonesian Government needs to monitor the realization of garlic land with production plans in several production areas at growth season. A previous study, which used Sentinel-1A satellite imagery and Convolutional Neural Networks to classify garlic land, needed more information on growth phases. The study aims to address that limitation by creating a garlic land classification model based on the growth phase using Convolutional Neural Networks. The dataset comprises 446 preprocessed Sentinel-2 images cross-referenced with drone ground truth data. The model used both VGG16 and VGG19 architectures. Hyperparameter tuning was applied to obtain optimal values. After evaluating three scenarios (VGG16 base model, modified VGG16, and modified VGG19), the best model was obtained from the modified VGG19, which had an accuracy rate of 81.81% and a loss function of 0.71. The study successfully classified garlic land based on growth phase, with a precision rate of 0.43 for initial growth and vegetation classes, and 0.22 for the harvest class. The study offers an alternative to monitoring garlic production throughout growth phases with satellite imagery and deep learning.

**Keywords**—Convolutional neural network; garlic; growth phase; horticulture; land classification; Sentinel-2; VGG

## I. INTRODUCTION

Garlic is a highly valued national food commodity in Indonesia, with distinctive characteristics and great market potential. According to the Central Bureau of Statistics, the market demand for garlic necessitates imports. Between 2019 and 2020, imports increased by 9.37% (US\$ 51.29 million), while production decreased by 7.89% (7.02 thousand tons). Sembalun District in West Nusa Tenggara is a major garlic production hub, covering a harvest area of 2.47 thousand hectares and contributing 30.08% to the national garlic production [1].

The Indonesian government has implemented a policy to expand garlic cultivation to achieve self-sufficiency in garlic production. A key component of this policy involves the development of technology for monitoring garlic planting. The objective is to efficiently and inexpensively evaluate the suitability of land for garlic cultivation across different areas. Remote sensing has emerged as a widely adopted technology that enables large-scale mapping of agricultural landscapes at low cost and nearly in real-time [2].

There have been previous studies that utilized remote sensing to monitor garlic lands in the same area. Study [3] used remote sensing technology from Sentinel-1A satellites, employing C5.0 decision tree and Convolutional Neural

Networks (CNN) to classify garlic/non-garlic land. The accuracy result shown that CNN accuracy is higher than decision tree. However, Sentinel-1A uses backscatter that can only reach land at the surface level, does not provide multi-temporal images, and the model has not applied growth phases. Additionally, the self-defined architecture (custom) used in this study is not a common architecture. Studies [5] and [6] extracted Sentinel-2 satellite NDVI during the growth phase using Random Forest (RF) and the Support Vector Machine (SVM) respectively. Both studies have shown that Sentinel-2 has great potential for use in garlic land classification based on growth phase, although its accuracy is currently low, at under 70%. The use of Machine Learning (ML) requires feature extraction and cannot process images as a data input and output directly.

This study aims to develop a land classification model for garlic using the CNN algorithm based on growth phase, building on the promising application of processing land classification by the CNN. Different with previous study [3], the model will take into account the growth phase of the garlic, which is important for district agencies to monitor the suitability of garlic cultivation during the planting season.

## II. LITERATURE REVIEW

The European Space Agency (ESA) launched Sentinel-2, an open-access remote-sensing satellite that covers an area of up to 290 km. The satellite was developed with the primary mission of providing high-resolution satellite data for land cover and use, climate change and disaster monitoring. Sentinel-2 has a Multispectral Instrument (MSI) satellite with a band number of 13, a revisit time of five days and medium and high spatial resolution [4]. Previous studies have utilized Sentinel-2 imagery data for Land Cover and Land Use Classification (LCLU) in another area. According to study [5], Sentinel-2 has great potential to make early-season mapping of various types of winter crops, such as garlic and canola. In [6], Sentinel-2 is used to classify garlic fields using RF based on growth phase. In [7], the 10m multi-temporal red edge bands are the primary features of Sentinel-2 satellite data that are appropriate for analyzing LCLU.

The CNN has a potential algorithm to process land classification. Previous studies have implemented Deep Learning (DL) for LCLU in other area. CNN is a flexible Deep Learning (DL) algorithm that is commonly used for image recognition. It recognizes objects dynamically from various positions and shapes using a pixel-based approach [8]. According to study [9], DL algorithms can outperform ML for

processing text, image, video, and speech data. DL can also automatically extract features based on the architecture. In [10], CNN outperforms other models in agricultural classification using Sentinel-2. In [11], CNN has advantages, such as weight-sharing features and simultaneous training for layer classification and feature extraction, which leads to a more stable and reliable model. The VGG16 and VGG19 architectures are considered the most successful CNN architectures due to the simplicity of network architecture. In [12], DL was implemented on Sentinel-2 images using U-Net architecture. In [13], there was a comparison between a Fully Convolutional Neural Network (FCN) with LSTM using a modified VGG19 encoder. In [14] adopted transfer learning to detect cracks using VGG16, ResNet18, DenseNet161, and AlexNet with pre-trained weights.

### III. METHOD

The study was conducted in six steps: data collection, data preprocessing, data partition, hyperparameter tuning, CNN classification, model evaluation, and model comparison. Fig. 1 shows the steps of the study.

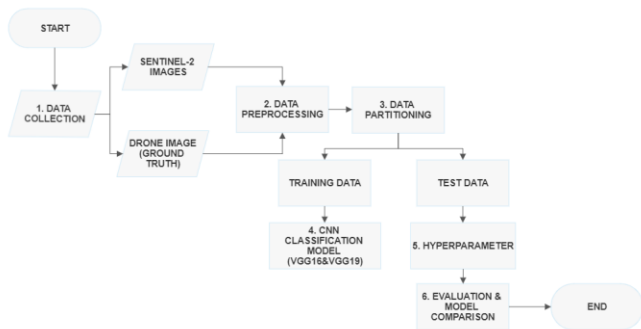


Fig. 1. Steps of study.

#### A. Data Collection

The study area is a major garlic production on the slopes of Mount Rinjani, Sembalun district, West Nusa Tenggara Province, Indonesia. Fig. 2 shows Sembalun district that is in 8°23 25.9"–8°22 06.4"S dan 116°31 32.9"–116°33 14.2".

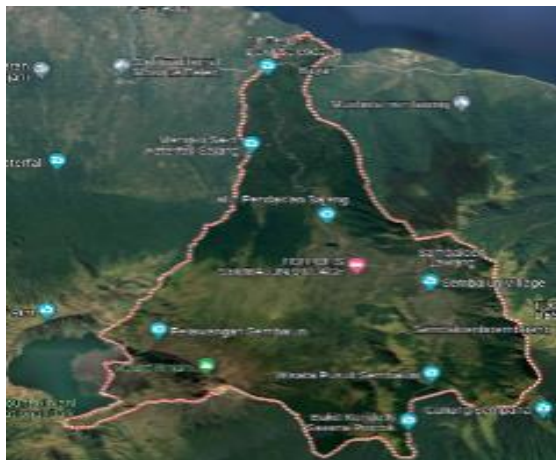


Fig. 2. Map of Sembalun District (source from Google Earth).

This study uses two data sources: drone images as ground truth and Sentinel-2 images. Drone images with a size of 43569 m × 36307 m were collected in the study [11] from 17 to 20 June 2021. Sentinel-2 data are free downloaded with a cloud cover of 2.64% at Copernicus (<https://scihub.copernicus.eu/>) for 1 July, 31 July, and 30 August 2021. The downloaded Sentinel imagery of the Sembalun at the L1C level was saved to a size of 10980 m × 10980 m. Sembalun garlic has a 105–110 days growth period [15]. The classes of growth phase are defined in Table I.

TABLE I. CLASSES OF GARLIC GROWTH PHASE

Class	Characteristic	Data sources
Initial growth phase	phase with soil and mulch still visible, more than 25% of soil is visible	Sentinel-2 1 July, 2021
Vegetative phase	phase with green dominant characteristics, the soil is no longer visible or less than 25% of soil is still visible (two months after the initial growth phase).	Sentinel-2 1 July, 2021
Harvest phase	phase with leaves drying out by more than 30% (two months after the vegetative phase)	Sentinel-2 31 July and 30 August, 2021

During the initial growth and vegetation phase, Sentinel-2 data from drone images is available every 10-14 days. For the harvest period, there are two timeframes: July 31<sup>st</sup> and August 30<sup>th</sup>. During the first period, drone data is classified as vegetation and the Sentinel-2 data is taken one month or more after the drone vegetation phase. In the second period, if drone data is classified as early growth, then the Sentinel-2 data is taken two months or more after the early growth phase of the drone. This time difference aligns with the definition in Table I.

Preprocessing was performed in QGIS software using a semi-automatic classification plugin [21] to create imagery for CNN data sources. The first stage of data preprocessing is the atmospheric correction of Sentinel-2, which is required to eliminate the effects of scattering and absorption from the atmosphere to obtain surface reflectance characteristics [16]. The next step is band composite which uses RGB band composite [5]. In Sentinel-2, the RGB band composite is arranged by three of a spatial resolution of 10 m bands: four (red), three (green), and two (blue) [17]. The main characteristics of Sentinel-2 data suitable for land cover can be obtained from bands at a multitemporal resolution of 10 m [7].

A new raster of band composite was then resized to 209 m × 172 m to fit the drone images. In parallel, labeling for drones for class label initial growth and vegetative is done manually in referring to class label definition. Fig. 3 shows the labeling of drone images for initial growth and vegetation phases. However, harvest images in the drone were not available. Fig. 4 shows the labeling of Sentinel-2 imagery on 1st July using an overlay with labeled drone imagery.

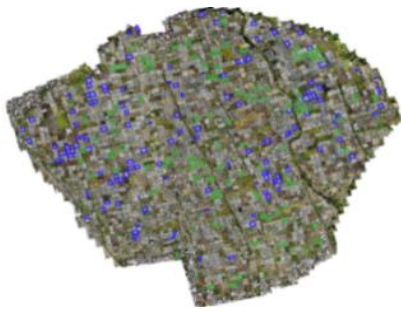


Fig. 3. Labeling of drone images.

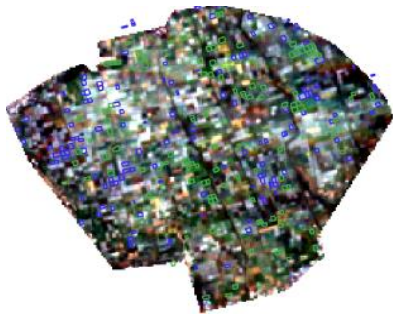
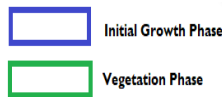


Fig. 4. Labeling Sentinel-2A 1 July images.

After labeling all Sentinel imagery, the last step is generating Tiff files with size  $2\text{ m} \times 2\text{ m}$ . Fig. 5, Fig. 6 and Fig. 7 illustrate how to generate the Tiff files for the initial growth, vegetation and harvest respectively.

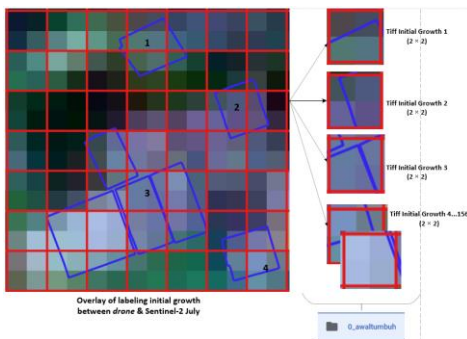


Fig. 5. Generating Tiff files of the initial growth phase.

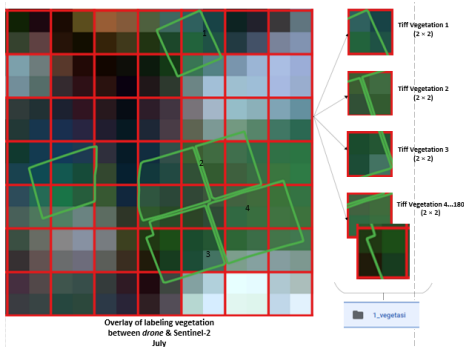


Fig. 6. Generating Tiff files of vegetative phase.

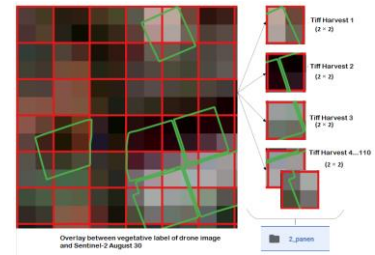


Fig. 7. Generating Tiff files of harvest phase.

The preprocessing results were tiff files of 156 initial growth, 180 vegetative, and 110 harvest phases. The files were then grouped based on the folder classification according to the growth phase. Classification folders were created as labeling references for CNN implementation.

### B. Dataset Partition

The dataset was divided into training and test datasets randomly using random seeds in Python. A total of 446 images from the preprocessing results were split into training data of 402 (90%) and test data of 44 (10%). This partition consideration is enough for small dataset images.

### C. Hyperparameter Tuning

Hyperparameter tuning is a step to modify the values of hyperparameters in CNN models to obtain optimal values. The hyperparameters include the number of layers, network size, epoch, batch size, and learning rate [18]. In the case of the number of layers, there was only the addition of two dense layers with activation function ReLu to VGG16 and VGG19 base models; for another tuning, by modifying some values manually and random search.

### D. CNN Classification Model

In this step, a classification model of garlic land was developed based on growth phases using Keras library in Google Collaboratory GPU. The method follows the methodology of the study [3] with some modifications, detailed in Table II.

TABLE II. THE DIFFERENCE BETWEEN THE MODEL CREATION OF THE PREVIOUS STUDY AND THE CURRENT STUDY

Items	Previous Study [3]	Current study
Class	Binary (garlic/non-garlic)	Categorical (initial growth, vegetative, harvest)
Data input	Sentinel – 1A size $5\text{ m} \times 5\text{ m}$	Sentinel - 2 size $2\text{ m} \times 2\text{ m}$
Architecture	Custom: Input - convolution 1 - convolution 2 - flatten - fully connected 1 - fully connected 2 - output	VGG16 & VGG19: input - convolution 1 - convolution 2 - convolution 3 - convolution 4 - convolution 5 - convolution 6 (VGG19) - fully connected 1 - (fully connected modification) - output
Pretrained	N/A	Imagenet
Data Augmentation	N/A	Zoom [0.0, 1.5]
Hyper parameters	epochs, batch size, and momentum	number of layers, epochs with early stopper, batch size, learning rate, and input size.



E. CNN Model Evaluation

The stages of model creation in the study are model architecture definition, pre-trained, data generator, training process, and model validation. The scenario is divided into three parts: Scenario A used VGG16 with a base model architecture, Scenario B used VGG16 with modification, and Scenario C used VGG19 with modification. The modification is the addition of two hidden layers of Dense with the ReLU activation function. All scenarios are applied to the same hyperparameters. Table III shows hyperparameters in scenarios A, B, and C.

The classification model performance is measured by confusion matrix, recall, and precision. The confusion matrix has four variables: TP (True Positive) represents actual data that is correct and predicted correctly, TN (True Negative) represents actual data that is incorrect and predicted incorrectly, FP (False Positive) represents actual data that is incorrect but predicted correctly, and FN (False Negative) represents actual data that is correct but predicted incorrectly. Accuracy (Acc), precision (Pr), and recall (Re) are formulated in Equations 1, 2, and 3 [19].

TABLE III. HYPERPARAMETERS IN SCENARIO A, B, AND C

Hyper parameters	Scenario A	Scenario B	Scenario C
Architecture	VGG16 default	Modified VGG16	Modified VGG19 and data augmentations
Input size network (width × height)	[64 × 64, 128 × 128, 224 × 224, 256 × 256]	[64 × 64, 128 × 128, 224 × 224, 256 × 256]	[64 × 64, 128 × 128, 224 × 224, 256 × 256]
Batch	[16, 32, 64, 128]	[16, 32, 64, 128]	[16, 32, 64, 128]
Optimizer	Adam	Adam	Adam
Epoch	300	300	300
Learning Rate	[0.0001, 0.001, 0.01]	[0.0001, 0.001, 0.01]	[0.0001, 0.001, 0.01]
Activation Function	ReLU	ReLU	ReLU

$$Acc = \frac{(N_{TP} + N_{TN})}{(N_{FP} + N_{FN} + N_{TP} + N_{TN})} \quad (1)$$

$$Pr = \frac{N_{TP}}{(N_{TP} + N_{FP})} \quad (2)$$

$$Re = \frac{N_{TP}}{(N_{TP} + N_{FN})} \quad (3)$$

$$H(p, y) = -\sum_i^n y_i \log(p_i), i \in [1, N] \quad (4)$$

In addition to these matrices, a loss function is a performance measure for models dedicated to CNN classification. The loss function is formulated in Equation 4 [11]. Equation 4 is used for the loss function cross-entropy with the softmax function. In layer output, CNN can calculate the prediction error generated by the CNN model through the training data using some loss function. The Loss Function uses two parameters to calculate the error, the first parameter is the estimated output of the CNN model (also called prediction), and the second is the actual output (also known as the label).

F. Development Environment

The development environment of the study is a notebook that was running on Windows 11. The hardware specifications are Intel(R) Core (TM) i7-8250U CPU @ 1.60GHz 1.80 GHz RAM 20 GB, SSD 500GB. The Software specifications are QGIS version 3.22.11-Białowieża, a google Collab Pro with GPU (https://colab.research.google.com/, was last accessed on 12 January 2023), including Keras modules for building model.

IV. RESULT AND DISCUSSIONS

All Tiff files from pre-processing were mounted to Google Drive. Classification folders are also created in google drive. Fig. 8 illustrates folder arrangement for folder classifications.



Fig. 8. Classification folders.

The model with VGG16 and VGG19 base model was loaded from Keras library using parameters network size 224 × 224 (default VGG) and pre-trained with ImageNet. The Pre-trained model, which contains 80,134,624 data, was downloaded from Keras storage. The modification of layers is assembled by adding two hidden layers dense (2048) and ReLU activation on base models VGG16 and VGG19. The addition of layers increased the total parameters processed. The full parameters of VGG16 base model before and after adding layers are 14,789,955 and 70,299,459, respectively. The total number of parameters of the VGG19 base model before and after adding layers is 20,024,384 and 75,609,155, respectively. Fig. 9 illustrates the difference between the VGG16 base model before and after adding layers.

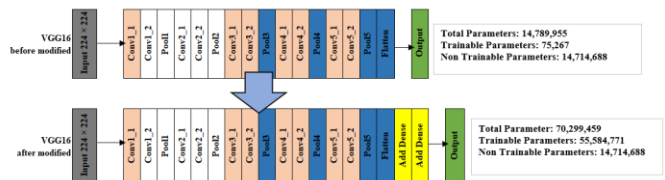


Fig. 9. VGG16 model architecture before and after adding hidden layers.

Training and testing steps used Image Data Generator module from Keras library by applying the Zoom Range =1.5 for data augmentations. The flow from the directory module processes training and test data according to the batch size and network input and then automatically labels the growth phase class. The process of labeling input images identified the classification folders. Hyperparameters use



optimizer = adam, loss = categorical\_crossentropy, and metrics = categorical\_accuracy. The structure of a new layer with the ReLU activation function observes the default convolution of VGG. The model was trained with an epoch of 300 and applied an early stopper during the training process. As a result of the training process, each image already has a categorical type of class, namely the initial classes of growth (0), vegetation (1), and harvest (2). The training results on scenario models A, B, and C are shown in Fig. 10, Fig. 11, and Fig. 12, respectively.

Input size network (width×height)	Hyper-parameters				Accuracy (%)	Loss
	Batch	Learning Rate	Optimizer	Epoch(max)		
224 × 224	<b>32</b>	0.001	Adam	97	82.5	0.44
<b>256 × 256</b>	32	0.001	Adam	56	84.0	0.41

Fig. 10. Training results of scenario A using the VGG16 base model.

Input size network (width×height)	Hyper-parameters				Accuracy (%)	Loss
	Batch	Learning Rate	Optimizer	Epoch(max)		
224 × 224	<b>32</b>	0.001	Adam	97	82.5	0.44
<b>256 × 256</b>	32	0.001	Adam	56	84.0	0.41

Fig. 11. Training results of the scenario B using VGG16 modifications.

Input size network (width×height)	Hyper-parameters				Accuracy (%)	Loss
	Batch	Learning Rate	Optimizer	Epoch(max)		
224 × 224	<b>32</b>	0.001	Adam	97	81.0	0.49
<b>64 × 64</b> (Zoom=0)	32	0.001	Adam	145	87.81	0.29
64 × 64 (Zoom =1.5)	32	0.001	Adam	86	80.59	0.50

Fig. 12. Training results of the scenario C using VGG19 modifications.

The best model was acquired from scenario C with network input = 64 × 64, batch = 32, learning rate = 0.001, zoom = 0.0, and optimizer = Adam. The training time required is 111 seconds. CNN models were evaluated using test data. The best model results an accuracy of 81.81% and loss function of 0.71. The best model has corrected predictions of two, nine, and six for initial growth, vegetative, and harvest, respectively. It predicted initial growth as nine for vegetation, which is the correct prediction. The prediction results are shown in a confusion matrix in Table IV. The precision call, recall values for the corrected predictions are shown in Table V.

TABLE IV. CONFUSION MATRIX

Class	Initial growth	Vegetation	Harvest
Initial growth	2	9	4
Vegetative	5	9	4
Harvest	2	3	6

TABLE V. PRECISION AND RECALL

Class	Precision	Recall
Initial growth	0.22	0.13
Vegetative	0.43	0.50
Harvest	0.43	0.55

The addition of the growth phase is tested to the same architecture from the previous study [3]. An accuracy result of 76.40% and a loss function of 0.65 with input size = 128 × 128, batch = 64, and learning rate = 0.0001.

Based on the three tested scenarios, scenario C's best results were obtained using the VGG19 model with the addition of hidden layers. The loss function is fundamental in selecting the best scenario in CNN; a lower loss function is considered better. The best model has processed 28,423,235 parameters with a loss function of 0.71 and an accuracy of 81.81% on test data. The best model used hyperparameters such as input network = 64 × 64, batch = 32, learning rate = 0.001, zoom = 0.0, optimizer = adam, and epoch = 145. The difference in loss between scenario A and scenario B in the VGG16 architecture demonstrates the impact of architectural changes. Scenario B, which includes additional hidden layers, decreased losses by 0.09 and an accuracy increase of 2.81 compared to Scenario A. This trend continued in Scenario C, where modifying the VGG19 architecture decreased loss by 0.03 and 1.00 increase in accuracy compared to Scenario B. The hidden layer is the most important layer in the CNN architecture, as it builds several other layers based on user requirements [20].

The number of parameters processed depends on the network input. A higher input network leads to an increase in the number of processed parameters. The batch and learning rates are interrelated and significantly affect the model's convergence rate and the number of epochs. A larger batch decreases epochs, while a greater learning rate increases the number of epochs. In VGG19 with transfer learning, the hyperparameters learning rate and epochs provide the best classification network [21]. The use of zoom data augmentation in both training and test data has not increased accuracy, which contrasts with [22]. Another consideration of the best model is observed through its convergent level, which indicates its stability. The convergent levels of scenario models A, B, and C on the test data are presented in Fig. 13, Fig. 14, and Fig. 15, respectively. Those graphs demonstrate that scenario C has a higher convergent rate than the other scenarios.

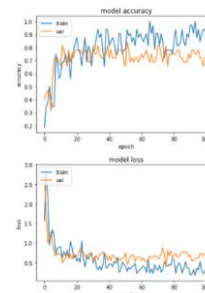


Fig. 13. Accuracy and loss scenario A accuracy = 72.72%, loss = 0.60.

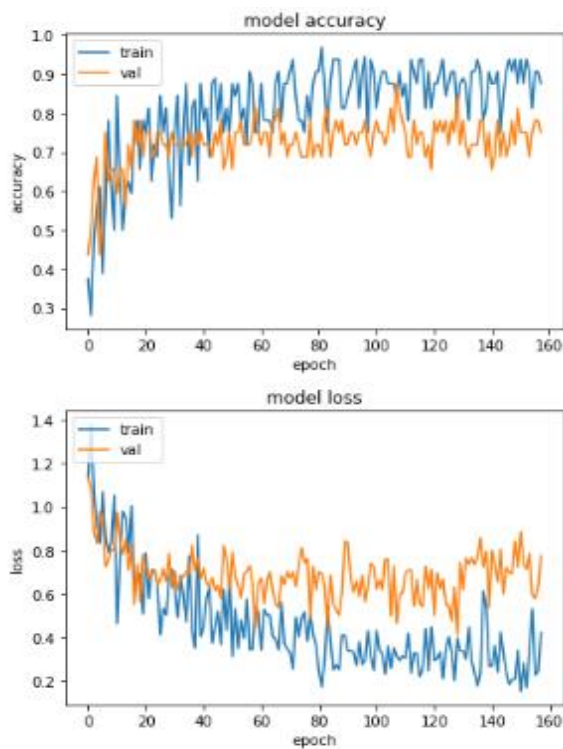


Fig. 14. Accuracy and loss scenario B accuracy = 77.27%, loss = 0.63.

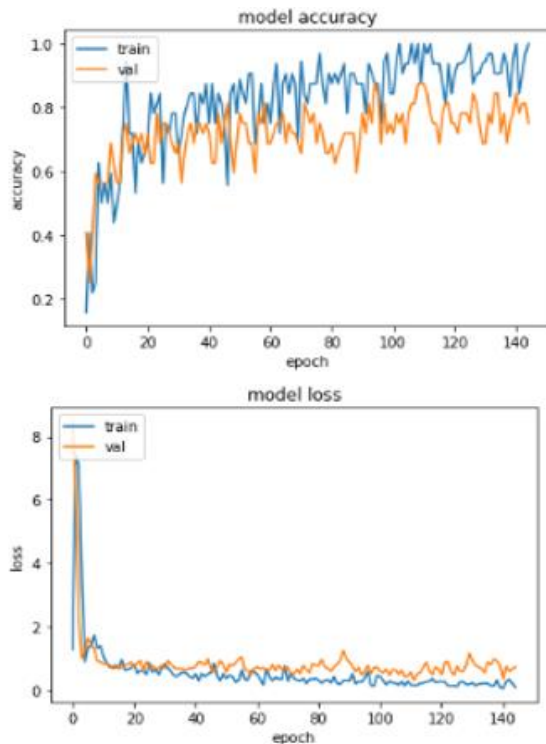


Fig. 15. Accuracy and loss scenario C accuracy = 81.81%, loss = 0.71.

The best model can accurately classify vegetation and harvest phases with a precision of 0.43, but it has not yet been able to accurately detect the initial growth phase, with a precision of 0.22. The initial growth phase is mainly classified as vegetation.

In contrast to the previous study [3], the best model of the study did not result in better accuracy or loss function. The accuracy decreased by 4.65 or 5.35% from the original 86.46%. The loss function value increased by 0.22 or 44.89% from the original 0.49. These differences between the studies can be attributed mainly to the increase of number of classification classes, which changed from binary to categorical, as well as to the utilization of a different model architecture. The study also evaluated the architecture from the previous study using the newer categorical class follow the study, resulting in an accuracy of 76.40% and a loss of 0.65, a lower than previous. This evaluation demonstrates that the same architecture with a different class result in a decreased accuracy. However, further testing and training with other scenarios are needed to achieve a suitable model for garlic land classification.

## V. CONCLUSION

The study has successfully developed a model to classify garlic lands based on growth phases using the CNN algorithm and Sentinel 2 imagery. The best model achieved an accuracy of 81.81% and a loss function of 0.71. The best model was obtained from modified VGG19 architecture with pre-trained weights, no data augmentation, and hyperparameters: input network, batch size, learning rate, optimizer, and epoch. The best model can classify the vegetation and harvest phases, but the initial growth phases need to be better classified, with most initial growth classes being classified as vegetation.

The study has shown that CNN is a promising method for processing multitemporal imagery in seasonal agriculture land cover. For future work, the Sentinel-2 images can be resized in various sizes to ensure a precision size of network input of CNN. The Sentinel-2 band composite should also consider using NIR and SWIR instead of RGB because some studies used NIR and SWIR, which a good band for agriculture. Additionally, it may be beneficial to consider labeling for other growth phases and land types.

As garlic is a seasonal plant, it is possible to plant another crop in an area that previously used to grow garlic, which could potentially be labeled as a garlic vegetative phase. Furthermore, to improve CNN modeling, dataset partition, hyperparameters such as architecture, learning rate, loss function, and optimizer should be fine-tuned before considering additional data input. Stakeholders and researchers can use this study as an alternative of monitoring garlic land along growth season through satellite imagery and deep learning to support import policy.

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# Evaluating Game Application Interfaces for Older Adults with Mild Cognitive Impairment

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**Abstract**—A digital game is software that is used as alternative entertainment for older adults for brain training. In this study, a digital game prototype for older adults with mild cognitive impairment has been developed called EmoGame and illustrated. The game is intended to assist older adults who experience emotional and cognitive impairment that implement reminiscence therapy in the design of the user interface. Applications for older adults have been developed in many studies, but applications using a reminiscence therapy approach still need to be improved. User interface testing was carried out using the system usability scale (SUS). Interface testing with the SUS instrument was carried out in an organized and precisely measured using ten (10) questions as a benchmark for evaluation among twenty (20) respondents of, older adults. The results of the evaluation of the EmoGame prototype show an assessment score of 82, representing an excellent rating. Future work will improve the prototype to improve the design based on user feedback and iteratively improve the functionalities and interfaces and conduct a longitudinal study to investigate the effect of the games towards improving cognitive among older adults with mild cognitive impairment.

**Keywords**—System usability scale; older adults; mild cognitive impairment

## I. INTRODUCTION

EmoGame is an emotional game application to help older adults with emotional and cognitive problems [16]. This game is developed with a reminiscence therapy approach. Reminiscence therapy is a memory therapy used for positive emotions in older adults who typically live with mild cognitive impairment (MCI) [21]. MCI could be a minor cognitive disability when someone has trouble recalling things or thinking clearly. Although the side effects are not sufficiently serious to lead to a diagnosis of Alzheimer's disease, MCI also interferes with emotions, causing negative emotions [31]. Based on this problem, the researchers developed EmoGame to help older adults living with MCI [20]. As a new game that has not yet been marketed, EmoGame requires a test to measure its quality. This test is needed to find the advantages and disadvantages of the game to help its development, facilitating decisions on whether this game is worth using [22]. One such test that can be used to determine the quality of the game is the system usability scale (SUS).

One approach is to ensure that EmoGame has a user-friendly interface. The interface can be measured from the end user's perspective [26]. Such measurement reveals how users evaluate EmoGame, determining whether improvements

should be made before publication [18]. To perform interface testing, different strategies can be utilized, including heuristic assessment (HE) and SUS. HE and SUS are part of usability testing [23]. The focus of the two testing methods is the same, namely, assessing the interaction of the software interface, but the two are distinguished by their examiners (evaluators) [28]. HE interfaces testing is carried out by specialists [12], whereas SUS interface testing is specifically done by end users [8]. Therefore, SUS is used to test EmoGame because it emphasizes the perspective of the end user, resulting in evaluation results in line with real situations [24]. The SUS test uses 10 questions, and SUS does not require many tests, minimizing testing costs [15]. However, to further clarify the intended target population, researchers focus on tablet users aged 50 years and above living with MCI [1]. Therefore, this project is expected to be used as an example of conducting quality assurance on EmoGame by measuring the level of usability, and helping researchers decide whether the game can be used or still needs improvement.

This paper is divided into several sections. Section II explains the background related to technology and older adults, including a focus on games. Section III explains the materials and methods used. Section IV provides results and discussions. Section V concludes and gives suggestions for future work.

## II. BACKGROUND WORK

### A. Games for Older Adults

In information technology, the term “game” is used for entertainment facilities that use electronic devices. A game is a system or program in which one or more players make decisions by controlling objects in the game for certain purposes [10]. In dealing with the ageing process, older adults must maintain physical and mental health to stay healthy and happy. To maintain their physical health, older adults are recommended to exercise regularly with the appropriate duration and type of exercise for their age group [29]. Maintaining mental health is as important as maintaining physical health for older adults [2]. They can do various activities to train the brain as part of efforts to prevent a decrease in brain function, which is a natural part of the ageing process. One such activity is games.

Although most older adults have good mental health conditions, some are at risk of developing brain and mental health problems, especially dementia, senile disease, or depression [3]. Playing video games benefits emotional well-

being and cognitive performance [21]. Playing video games has benefits for children and older adults. In older adults, playing video games is good for memory function and positive emotions. These activities can also keep older adults entertained [30].

### B. Technology for Older Adults

Gerontechnology is a field that combines gerontology and technology, and it involves research and development of techniques, technology products, services, and environments based on knowledge of the ageing process [4]. The use of various types of gerontechnology by the elderly can help them to lead healthier, more independent, and socially better lives [10]. Gerontechnology is concerned with researching the biological, psychological, social, and medical aspects of ageing and exploring the potential offered by technological advances [11]. Gerontechnology was developed to comprehensively improve the quality of life of older adults [13].

Technologies are defined as assistive devices or technology-based services that aim to help the elderly perform their activities. Such services can combine multiple devices at once [22]. Preventive home modifications, such as handrails, have been shown to reduce the risk of falls, especially in the bathroom. Assistive technologies enable independence and improve the quality of life in older adults who have just been discharged from the hospital, helping limit the need for personal assistance [5]. This technology is also useful for nurses, especially in lifting and carrying patients, thereby minimizing injuries in nurses [20].

Technologies also include assistive technologies and tools to facilitate physical rehabilitation and social inclusion. Examples include video or computer games designed to provide interactive rehabilitation programs for older adults and people with stroke, as well as touch screen monitors for people with dementia to access memorable objects or entertainment features [14]. Environmental and individual-centred design technologies are also included in this scope [27]. Here, the whole environment is considered to help older adults to live independently and reduce the burden of care on their families or others who provide support [25]. Examples include hidden doors to minimize the risk of older adults with dementia leaving the house without surveillance and getting lost [6]. Such gerontechnology is possible because the technology used is easy to source and apply.

### III. MATERIAL AND METHODS

To obtain true and accurate research results, the research methods used in evaluating EmoGame can be explained as follows:

Fig. 1 shows the steps used in this process.

We took survey data from the respondents and socialized the application we had made and distributed questionnaires. Then we collect data or analyze the data we have obtained from research surveys, Table I. So from that data, we processed using the SUS (System Usability Scale) formula in order to get results from user satisfaction using the application.

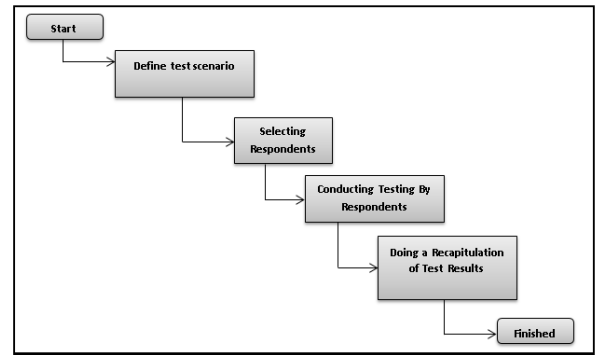


Fig. 1. Research Steps

TABLE I. SUS TESTING INSTRUMENT (SYSTEM USABILITY SCALE)

No	Question
1	I think that I would like to use this system frequently.
2	I found the system unnecessarily complex.
3	I thought the system was easy to use.
4	I think that I would need the support of a technical person to be able to use this system.
5	I found that the various functions in this system were well integrated.
6	I thought there was too much inconsistency in this system.
7	I imagine most people would learn to use this system very quickly.
8	I found the system very cumbersome to use.
9	I felt very confident using the system.
10	I needed to learn a lot of things before I could get going with this system.

Fig. 1 shows the steps of the research as follows: 1) determining the test scenario, 2) selecting respondents, 3) conducting testing with the respondents, and 4) summarizing the test results. In the first step, a test scenario is created, which begins with the software to be tested being explained and a questionnaire being developed [9]. In the second step, the respondents who will assess EmoGame are selected. In the third step, respondents are asked to evaluate EmoGame based on SUS. In the fourth step, test results are obtained according to SUS calculations.

The SUS uses a five-point scale, where 5 is “strongly agree” and 1 is “strongly disagree”. Table II provides further details.

TABLE II. RATING SCALE SCORE

Questions	Score
Strongly Disagree	1
Disagree	2
Neutral	3
Agree	4
Strongly agree	5

After the questionnaire data given to the respondents was collected, and then the results of the collected data were calculated responses by [10]:

1) Odd questions, namely, 1, 3, 5, 7, and 9 are reduced by 1 in the score given by the respondent. Odd SUS score =  $\sum Px - 1$ , Where Px is the number of odd questions.



2) Even questions, namely 2, 4, 6, 8, and 10 scores given to respondent are used to subtract 5. Even SUS score =  $\sum 5 - P_n$  where  $P_n$  is the number of even questions.

3) The conversion results are then added up for each respondent and then multiplied by 2.5 to get a range of values between 0 – 100. ( $\sum$  odd score –  $\sum$  even score) x 2,5.

4) After the score of each respondent has been known, the next step is to find the average score by adding up all the scores and dividing by the number of respondents. This calculation can be seen with the following formula [7]:

$$\bar{X} = \frac{\sum x}{n}$$

$\bar{X}$  = average score  
 $\sum x$  = total score SUS  
 n = number of respondents

where  $\bar{X}$  the average score,  $\sum x$  is the total score of the System Usability Scale and  $n$  number of respondents. From these results will obtain an average value of all assessments of respondents' scores. To determine, there are 2 (two) ways to grade the assessment results used [11].

The first determination is seen from the level of user acceptance, grade scale and rating adjective consisting of the level of user acceptance there are three categories, namely not acceptable, marginal, and acceptable. Meanwhile, in terms of grade level, there are six scales, namely A, B, C, D, E and F. From the adjective rating, consists of worst imaginable, poor, ok, good, excellent, and best imaginable [17].

The second determination is seen from the percentile side range (SUS score), which has a rating grade consisting of A, B, C, D and E [19]. Determination of results assessment based on SUS score percentile rank done in general based on the results user rating calculation. Second, this determination can be seen in Table III and Fig. 2.

TABLE III. SUS SCORE PERCENTILE RANK

Grade	Description
A	Score $\geq 80,3$
B	Score $\geq 74$ and $< 80,3$
C	Score $\geq 68$ and $< 74$
D	Score $\geq 51$ and $< 68$
E	Over score $< 51$

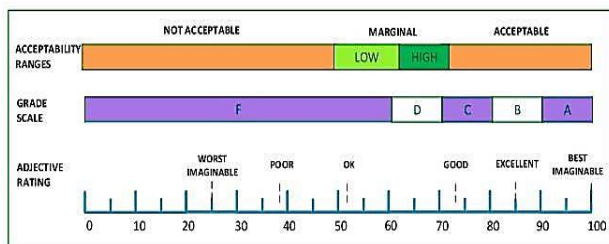


Fig. 2. Determination of assessment results (Bangor, Kortum, & Miller, 2009).

## IV. RESULTS AND DISCUSSION

### A. Emogame Application

Starting from the main menu, the user will enter the main page shown in Fig. 3. To start the game, the user clicks the start button.



Fig. 3. EmoGame prototype.

Memory Puzzle Game (Fig. 4): Players are presented with a set of face-down cards. They flip a card to see a picture and then look for a matching card with the same picture. If they find a match, they can look for the next pair. The player finishes the game when they find all pairs. This puzzle game is useful for training the cognitive abilities of older adults.



Fig. 4. Games puzzle memories.

Game of Memory Exploration (Fig. 5): In this game, players explore a village house and remember the pictures that are in the house. The images are of old and antique items commonly used in the past. The intent of this exploration is to train the brain with old images, encouraging good memories and positive emotions. Players explore the village house and recall the objects in the house, following the instructions given by the game. The player must complete the stages one by one. The goals of this game are to recall past objects with a reminiscence therapy approach and to increase positive emotions.



Fig. 5. Games exploration of memories.



Music of Memories (Fig. 6): If players do not want to play the other games, they can listen to music. These selections of old music were chosen to potentially help older adults recall memories of their pasts. Here, players can choose memorable songs, which are expected to help older adults gain positive and cognitive emotions. This development of this module's game followed feedback during a pilot study that suggested using music that was liked by older adults.



Fig. 6. Music memories.

Twenty respondents were invited for testing with the SUS instrument [3]. However, to obtain more accurate data, 20 respondents were invited to test EmoGame. The characteristics of the respondents were gender, education level, experience using smartphones, and age. For educational level, two of the respondents had undergraduate degrees. All respondents had more than five years' experience of using smartphones. Finally, all respondents were 50 years of age and over. The mini-mental state examination (MMSE) screening was used to find older adults with MCI, and 20 respondents were obtained from the SUS assessment.

Respondents who tested EmoGame can represent end users whom are older adults living with MCI. Thus, the representation of end users from the level of education, age, gender, and experience in using smartphones from the respondents' characteristics reflects reality [25].

**B. Assessment Results**

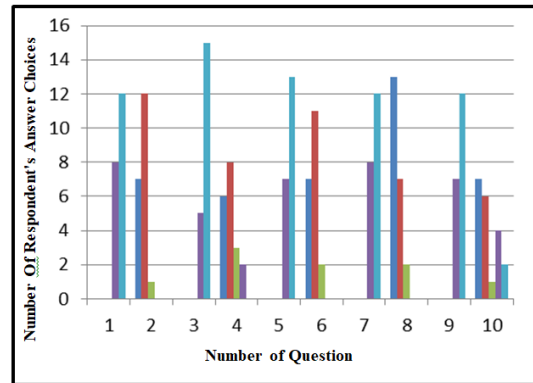
This study uses data from as many as 20 respondents consisting of older adults who use the EMOGAME application. Respondents will answer 10 questions given. The results of the answers from respondents will be calculated using equations (1), (2), and (3) so that it will produce an average score as shown in Table IV:

TABLE IV. ASSESSMENT

No	Results	Score
1	30 x 2.5	75
2	32 x 2.5	80
3	35 x 2.5	88
4	29 x 2.5	73
5	32 x 2.5	80
6	30 x 2.5	75
7	32 x 2.5	80
8	31 x 2.5	78
9	31 x 2.5	78
10	31 x 2.5	78
11	34 x 2.5	85

12	34 x 2.5	85
13	30 x 2.5	75
14	36 x 2.5	90
15	35 x 2.5	88
16	32 x 2.5	80
17	36 x 2.5	90
18	36 x 2.5	90
19	35 x 2.5	88
20	33 x 2.5	83
<b>Average</b>		1640/20= 82

Information from Table V shows *R* is the respondent and the *Qn* question. The results from the questionnaire –*n* can be obtained with an average score of 82. The following (Fig. 7) are the respondents' responses to some of the questions asked.



Description:  
 Strongly Disagree (orange), Disagree (green), Neutral (purple), Disagree (red), Strongly Agree (blue)

Fig. 7. Graph of SUS results.

In Fig. 7, it can be explained that there were 10 questions given to the respondents, and there were several results that stated negative and positive. For the results of negative statements, there are questions number 2, 4, 6, 8 and 10 where the respondents are quite understanding in using this EmoGame application. As for the results of the positive statements that respondents understand and like in playing the EmoGame application game, the positive statements are found in questions number 1, 3, 7.5 and 9. As for the percentage value generated from the SUS 82 value, it is in the range of 80% to 90%.

**V. CONCLUSION**

The EmoGame application was evaluated based on research conducted on 20 respondents. Results indicated that the average score obtained from a questionnaire was 82. EmoGame is considered satisfactory regarding adequacy, Grade A on the grade scale, and excellent in descriptive word rating. The assessment with a percentile rank of the average score (82) is in Grade A, where the value exceeds 80. A score of 82 means that EmoGame is suitable for end users as a game to help older adults living with MCI and to support the cognitive and emotional health of older adults.

Future work is to improve the design based on user feedback and iteratively improve the functionalities and interfaces. A longitudinal study with the sample respondents of older adults will be carried out and larger data collections will be analyzed to represent the older adult's user perception and experience.

#### ACKNOWLEDGMENT

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# Intelligent Recommendation of Open Educational Resources: Building a Recommendation Model Based on Deep Neural Networks

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**Abstract**—Information overload is a challenge for the development of online education. To address the problem of intelligent recommendation of educational resources, the study proposes an intelligent recommendation model of educational resources based on deep neural networks. First, a deep neural network-based custom recommendation model for educational resources is constructed after a multilayer perceptron-based prediction model is established. The results showed that the prediction model proposed in the study steadily reduced the average absolute error as the number of iterations increase, reaching an average of 0.704, with the loss value stabilising at around 0.6, which is lower than that of the deep neural network prediction model. Compared to the deep neural network prediction model, the normalised discounted cumulative gain is typically 0.01 higher and in terms of hit rate, 0.03 higher. The prediction time of the similarity algorithm is faster than that of the neural network. The mean squared error ranged from a high of 1.29 to a low of 1.19, both lower than other algorithms, and the mean absolute error ranged from a high of 0.56 to a low of 0.54, lower than all other algorithms except the support vector machine algorithm. The average absolute error of the deep neural network resource representation algorithm ranged from a high of 1.46 to a low of 1.45, lower than all other algorithms except the support vector machine algorithm, and the average squared error ranged from a high of 3.43 to a low of 3.24, better than all other algorithms. In conclusion, the model constructed by the study has a good application effect in recommending educational resources, and has a certain promoting effect on the development of online education.

**Keywords**—Intelligent recommendation; deep neural networks; multilayer perceptron; educational resources

## I. INTRODUCTION

The development of online education (OE) has provided more convenience for learners, but with the abundance of educational resources (ER) there has also been an increase in knowledge redundancy, so how to reduce the cost of time for users to access the target content has become a key issue, and resource recommendation (RR) technology should also make more accurate, fast, timely and personalised changes. Machine Learning (ML) is ubiquitous in everyday life. Deep Neural Networks (DNN), a technique in the field of ML, is popular for its complex and deep structure with powerful predictive power and has appeared in many applications, such as face intelligence perception techniques [1-3]. Given the abundance of resources and the constrained storage space of mobile devices, providing users with individualised and accurate

recommendations has become a crucial and urgent issue [4]. Intelligent recommendation of ER is an extremely complex process that focuses on both user and resource characteristics to personalise the recommended resources, as well as considering the accuracy and timeliness of the push. To date, there has been little research on personalised recommendations of learning resources combined with deep learning technology, and the models are relatively complex. In this context, this study constructs a DNN-based intelligent recommendation model for ER, consisting of a recommendation prediction model and a personalised recommendation model, and improves the recommendation prediction model using a Multilayer Perceptron (MLP). There are two main points of innovation in this study. The first point is to improve the scoring method of DNN prediction model using MLP. The second point is to optimize the recommendation effect by dividing the RR into three segments: resource filtering, RR and resource display. The core framework of the study is divided into four sections. The first section is a review of the current state of the art. The second is to construct a prediction model based on MLP-DNN and an intelligent recommendation model for ER based on DNN. The third part is an application effect analysis of the proposed model-based model. The last part concludes the whole study.

## II. RELATED WORKS

DNNs are multilayer unsupervised neural networks capable of representing complex functions with fewer parameters, and are used in ML with the aim of allowing computers to simulate human learning. Samek et al. argue that with the widespread and highly successful use of ML in industry and science, there is a growing need for interpretable artificial intelligence, and therefore the problem of better understanding nonlinear ML, and in particular DNNs, interpretable and explainable methods for solving capabilities and strategies are receiving increasing attention [5]. Deep learning, according to Geirhos et al, is the foundation of today's machine intelligence and is what started the current wave of artificial intelligence, although its limitations have only recently come to light [6]. Jiang et al. demonstrate how DNNs designed as discriminative networks can operate as quick agent EM solvers and learn from training data. Additionally, they looked into how deep generative networks may be set up as reliable global optimizers and even learn geometric aspects from device distributions [7]. In order to better understand these learned representations, Bau et al. proposed network anatomy for methodically identifying the

semantics of specific hidden units in image classification and image generation networks. They claimed that DNNs are effective at finding hierarchical representations for solving challenging tasks on large datasets [8]. Jeyakumar et al. compare the most cutting-edge explanation techniques to see which ones are best at explaining model decisions in their cross-analysis Amazon Mechanical Turkey study, which they use to support their claim that internal work on explaining DNN models has attracted a lot of interest recently [9]. Huang et al. argue that despite an initial understanding of adversarial DNN training, it remains unclear which configurations can lead to more robust DNNs, and propose to fill this gap by comprehensively investigating the effect of network width and depth on the robustness of adversarially trained DNNs [10]. In response to the problem that training DNNs typically requires large amounts of labelled data, Jing et al. introduced self-supervised learning methods as a subset of unsupervised learning methods to minimise the high cost of collecting and annotating large datasets [11]. According to the argument of Liang T et al., network compression and other optimisations can help DNNs overcome their complicated network design, which poses difficulties for effective real-time use and requires high computational and energy costs [12]. An xDNN has been proposed by Angelov et al. that solves the bottleneck of classical deep learning methods and provides an interpretable internal architecture that outperforms current approaches while consuming little CPU power and training time [13].

By evaluating users' historical activity to determine their preferences and selecting content that matches their tastes for recommendation from a large amount of information, intelligent recommendation helps solve the information overload problem. Zhou et al. proposed an intelligent recommendation method to facilitate patients' healthcare decision-making process by providing automatic clinical guidance and pre-diagnostic advice to patients [14]. Zhou et al. designed and applied an intelligent recommendation mechanism to support user collaboration in an academic big data environment [15]. Traditional recommendation algorithms struggle to provide customers with quick and reliable recommendations in the IoT context, thus Cui et al. addressed this issue and suggested a new recommendation based on a time correlation coefficient model and an improved cuckoo search K-means [16]. According to Zhang et al., a lot of interpretable recommendation methods, particularly model-based methods, have been developed recently and applied to real-world systems to give not only high-quality recommendations but also understandable explanations [17]. To increase user trust and improve recommendation acceptance, Sardianos et al. contend that recommendation systems should be interpretable. They have created a clear and convincing recommendation mechanism that tailors recommendations based on user preferences and habits [18]. Logesh et al. argue that recommender systems are widely used to solve the problem of users suffering due to information overload problems in the Internet [19]. In line with Yin et al. [20], a new matrix decomposition model with deep feature learning was proposed in order to address the problem that the majority of current service recommendation methods have some significant flaws and cannot be directly used in edge

computing contexts.

In conclusion, despite recent advances in ML and AI made possible by DNNs, the field of education has been slow to adopt these technologies, and there has been little research on how to integrate intelligent ER recommendations with deep learning technology. To address this shortcoming, the study constructs a DNN-based intelligent recommendation model (RM) for ER, which has important practical value and prospects for online education.

### III. CONSTRUCTION OF DNN-BASED INTELLIGENT RM FOR ER

Online education is growing quickly as a result of the expansion of information technology in the field of education. However, the vast volume of ER also causes information overload, making it difficult for OE to make sensible recommendations of knowledge. In order to more accurately recommend appropriate contents for users and decrease the time cost of acquiring ER, the study builds an intelligent RM for ER based on DNN, including a recommendation prediction model of MLP-DNN and a DNN education resources personalised RM.

#### A. MLP-DNN-based Educational RR Prediction Model

##### Construction

Developed from artificial neural networks, DNNs are the most fundamental model for deep learning techniques, allowing more efficient modelling of potential higher-order and non-linear interactions between multiple features through a multi-layer non-linear structure. DNNs add more hidden layers to artificial neural networks, with fully connected neurons between layers, and as the number of layers increases, DNNs have greater learning power. However, the more layers, the better. Fig. 1 shows the basic structure.

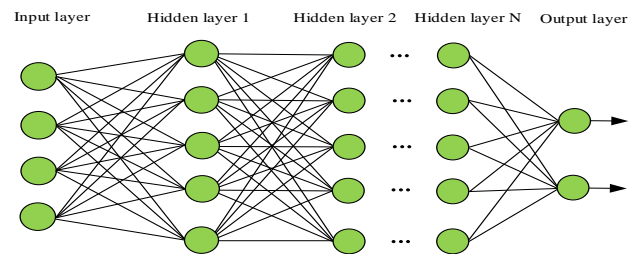


Fig. 1. Basic structure of deep neural networks.

Intelligent recommendation analyse the user's preferences and then recommend content for the user based on the preferences. Traditional RR methods mainly include hybrid recommendation methods, content-based recommendation, collaborative filtering recommendation methods and context-based recommendation methods. Intelligent recommendation of ER is not only about screening suitable content from a huge amount of ER and personalising it for users, but also about ensuring accuracy, efficiency, timeliness, diversity and initiative, in order to help users improve their learning efficiency. Fig. 2 revealed the system.

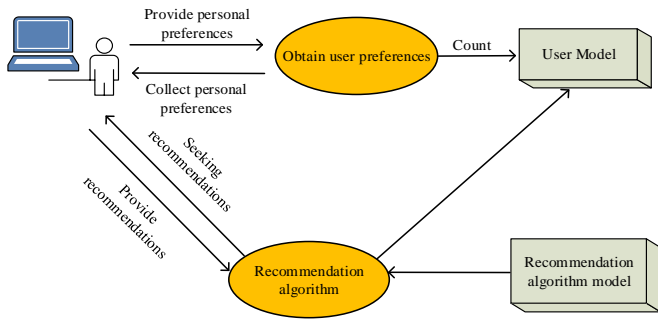


Fig. 2. General model for personalized recommendation systems.

To achieve personalised recommendations, the features of the user and ER need to be fully considered and the user's ratings need to be predicted. In order to obtain the attribute features of users and ER, the attributes of users and ER are first input into the DNN to obtain the vector of user and educational resource attribute features, as shown in Equation (1).

$$\begin{cases} \bar{x} = f(w_1x + b_1) \\ \bar{y} = f(w_2y + b_2) \end{cases} \quad (1)$$

In equation (1),  $x$  denotes the user attributes,  $y$  denotes the education resource attributes,  $w$  denotes the weights and  $b$  denotes the bias. The *concatenate(.)* function is then used to fuse the individual attributes of the user and the educational resource to obtain the attribute features, as shown in equation (2).

$$\begin{cases} u_i = \text{concatenate}(\bar{x}) \\ s_j = \text{concatenate}(\bar{y}) \end{cases} \quad (2)$$

DNN models are constructed using the obtained user and educational resource features, including a DNN model for predicting user ratings of ER and a DNN model for predicting user learning intervals. The first DNN prediction model is based on real user context and learning resource context data, which can effectively predict users' ratings of relevant learning resources and ensure the personalisation and accuracy of educational RR. The user context includes characteristics such as age, gender and interests, and the educational resource context includes resource learning time interval, resource difficulty and user rating. The second DNN prediction model is based on real user context, educational resource context, and learning environment context, which can effectively predict users' learning interval and ensure the timeliness and proactivity of educational RR. After the model is constructed, it is trained by the existing real data, and the specific process is shown in Fig. 3.

However, the vector multiplication scoring approach used in the aforementioned DNN prediction model is computationally demanding and tends to consume a lot of resources, making the model less efficient and having a negative impact on the recommendation effect. The presence of numerous layers of neurons is the key feature of the multi-layer perceptron. By switching from a vector multiplication approach to one where the user and resource

features obtained by the model are fed into the MLP and the final output is the predicted score, the DNN prediction model is improved by exploiting its processing of non-linear data. This is done by building a prediction model based on the MLP-DNN. Fig. 4 illustrates the MLP-based rating prediction technique.

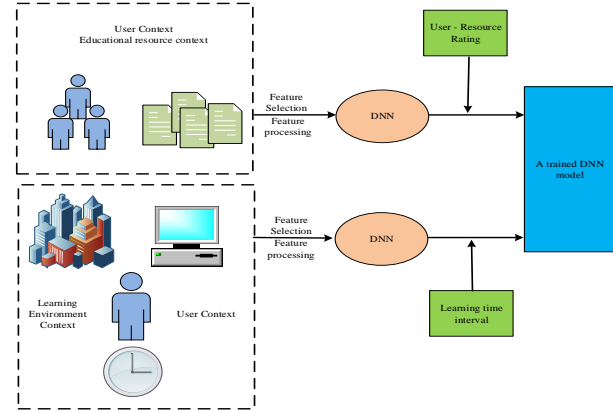


Fig. 3. DNN model training.

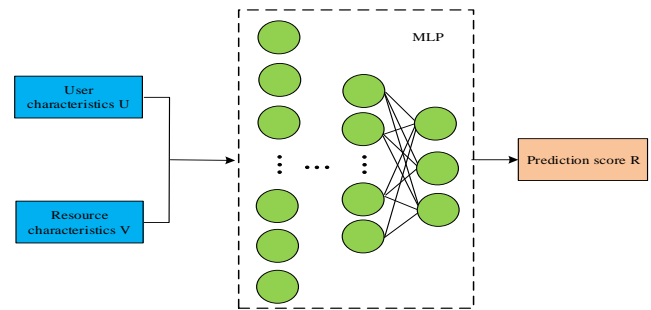


Fig. 4. MLP based scoring prediction method.

The input vector of the input layer of the MLP is a fusion of the features of the user and the educational resource, as shown in equation (3).

$$x_0 = \text{concatenate}(u_i, v_j) \quad (3)$$

The output value of  $x_0$  after the first layer is shown in equation (4).

$$x_1 = f(W_1x_0 + b_1') \quad (4)$$

In equation (4),  $W_1$  denotes the weight matrix, and  $b_1'$  denotes the bias vector. The final output layer is the prediction score, as shown in equation (5).

$$x_l = f(W_lx_{l-1} + b_l') \quad (5)$$

### B. Building a Customised RM for ER using DNN

The RR model is closely interlinked with the prediction model and is an application of the prediction model, with the aim of improving the timeliness and accuracy of educational RRs after learning through big data. The RR model contains three core modules: resource filtering, RR and resource display, and the three modules are interrelated, as shown in Fig. 5.



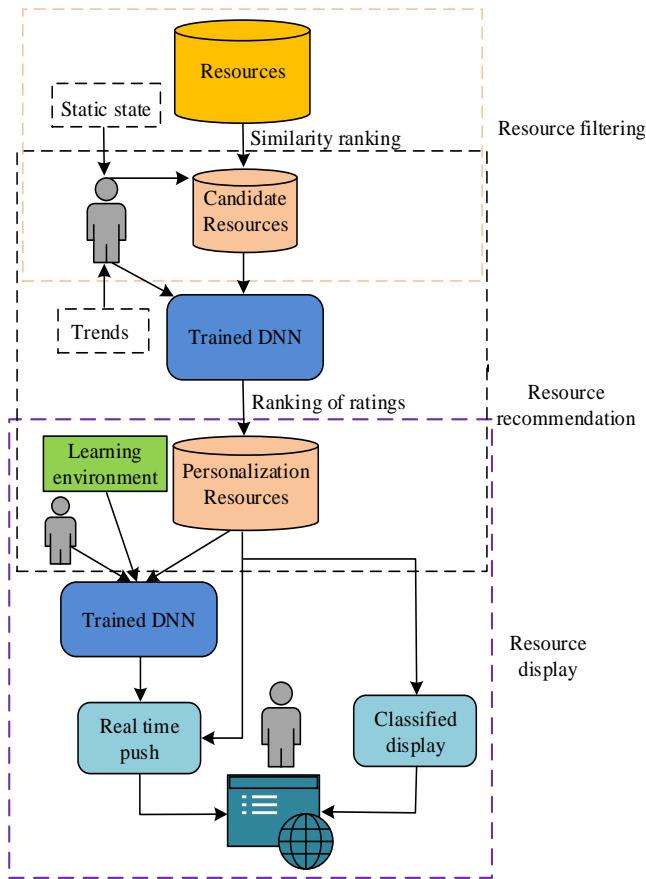


Fig. 5. A personalized RM for ER based on DNN.

In the resource filtering section, the research designs a similarity-based educational resource filtering algorithm. When ER are directly recommended by DNN intelligent RM, the large amount of information will increase the complexity of the model, increase the response time and reduce the recommendation efficiency, so ER should be filtered. The resource filtering method based on similarity ranking can filter out most of the ER that are not interesting or relevant to users before using the model to make recommendations. At the same time, in order to prioritise the latest resources, a similarity reduction method based on a time factor is designed to realise that the older the educational resource, the faster the similarity reduction. The similarity between ER and users' learning interests is calculated as shown in Equation (6).

$$S = \frac{A \times B}{\|A\| \times \|B\|} - at \quad (6)$$

In equation (6),  $t$  denotes the difference between the current time and the resource release time,  $A$  and  $B$  denote the learning interest vector and the educational resource vector respectively, and  $a$  denotes the acceleration of similarity decreasing with time, with the acceleration changing dynamically and calculated as shown in equation (7).

$$a = \frac{t}{\delta T^2} \quad (7)$$

In equation (7),  $T$  denotes the time duration of the educational resource desired by the user and  $\delta$  denotes the variable parameter. Thus the final similarity between the educational resource and the user's learning interest is shown in equation (8).

$$S = \frac{A \times B}{\|A\| \times \|B\|} - \frac{t^2}{\delta T^2} \quad (8)$$

In the RR section, the research designs a DNN-based RR algorithm. The algorithm focuses on building and training a DNN, which predicts the user's rating of ER. User features are used as input with educational resource features such as user ratings, resource difficulty and resource learning time, and the output is the user's rating of the educational resource for RR. The main performance evaluation metrics often used in recommendation systems are Mean Squared Error (MSE), Mean Absolute Error (MAE), Standard Mean Error (SME), Recall and Accuracy. MSE is used to measure the accuracy of scoring, as shown in Equation (9).

$$MSE = \frac{1}{|T|} \sum_{i,j} (R_{i,j} - \hat{R}_{i,j})^2 \quad (9)$$

In equation (9),  $T$  represents the test set,  $\hat{R}_{i,j}$  and  $R_{i,j}$  represent the predicted and actual ratings respectively, and the smaller the difference between their values, the better the recommendation. The MAE measures the absolute error between the predicted and actual user ratings, as shown in equation (10).

$$M = \frac{1}{n} \sum_{a=1}^n |p_{ia} - r_{ia}| \quad (10)$$

In equation (10),  $n$  denotes the number of user  $i$  rated products, and  $p_{ia}$  and  $r_{ia}$  denote the predicted user ratings and actual user ratings respectively. The SME is described in equation (11) as follows.

$$N = \frac{M}{r_{\max} - r_{\min}} \quad (11)$$

$r_{\max}$  and  $r_{\min}$  in equation (11), respectively, stand for the highest and lowest user rating numbers. In the equation (12), recall is the percentage of all products that the user is recommended by the system out of all items that the user likes, and accuracy is the percentage of items that the user is truly interested in.

$$\begin{cases} \text{Recall} = \frac{N_{rs}}{N_r} \\ \text{Precision} = \frac{N_{rs}}{N_s} \end{cases} \quad (12)$$

In equation (12),  $N_s$  denotes the number of all recommended items,  $N_r$  denotes the number of all products that the user likes, and  $N_{rs}$  denotes the number of items that the user likes in the recommendation list. The paper suggests a DNN-based timely pushing of resource presentation method



that can accurately forecast users' learning intervals and estimate the duration of their subsequent learning in order to carry out timely pushing of resources. The user's learning time on that day is shown in Equation (13).

$$T = \max(n_i) \rightarrow t_i (1 \leq i \leq 5) \quad (13)$$

#### IV. ANALYSIS OF THE EFFECTIVENESS OF DNN-BASED INTELLIGENT RM FOR ER

The study constructs a DNN-based intelligent RM for ER, however, the effectiveness of the model has to be further verified. The research is analysed in two main aspects. The first part is an analysis of the effectiveness of the MLP-DNN-based RR prediction model. The efficiency of the algorithms created for the DNN-based customised RM for ER is examined in the second half.

##### A. Analysis of the Effectiveness of MLP-DNN-based Educational RR Prediction Model

The study collected and collated data from 400 users, 650 ER and 32,000 rating records from an online learning platform. As these data were both structured and unstructured, the data were pre-processed and classified and numbered. In Fig. 6, as the number of iterations increases, the MAE value gradually decreases to 0.704, indicating that the MLP-DNN prediction model combining both user characteristics and educational resource characteristics has more complete data and the error tends to decrease, which has some validity.

The network was trained with the DNN prediction model

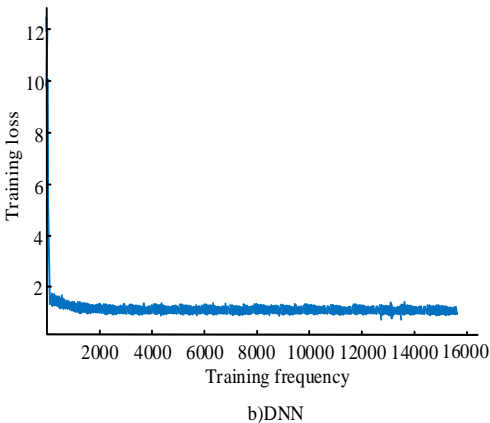
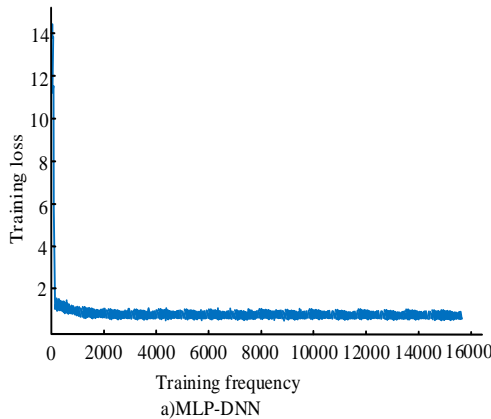


Fig. 7. Results of training networks using DNN model and MLP-DNN model.

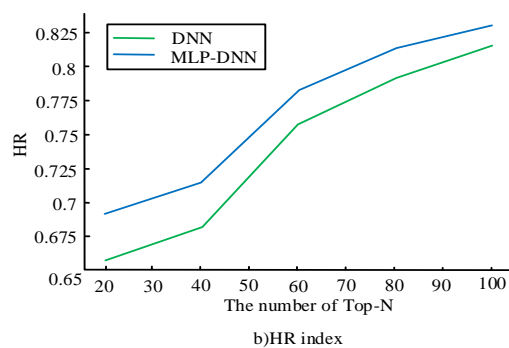
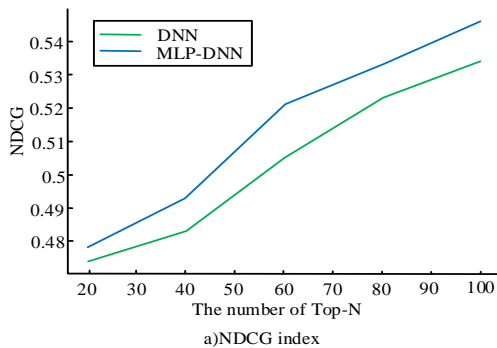


Fig. 8. The influence of top N number on recommendation performance.

and the MLP-DNN prediction model. Fig. 7 shows that the loss value of the MLP-DNN prediction model is stable at about 0.82, while the loss value of the MLP-DN prediction model is stable at about 0.63.

After the rating prediction is completed, the top N learning resources are finally recommended. Normalize Discount Cumulative Gain (NDCG) and Hit Radio (HR), are two evaluation metrics based on the Top-N recommendation algorithm. The MLP-DNN prediction model and the DNN prediction model were analysed in terms of both NDCG and HR metrics respectively. Fig. 8 shows that as the number of Top-N rises, both models' NDCG and HR metrics continue to rise. However, the DNCG metric of the MLP-DNN prediction model was on average 0.01 higher than that of the DNN prediction model, and on average 0.03 higher in the HR metric.

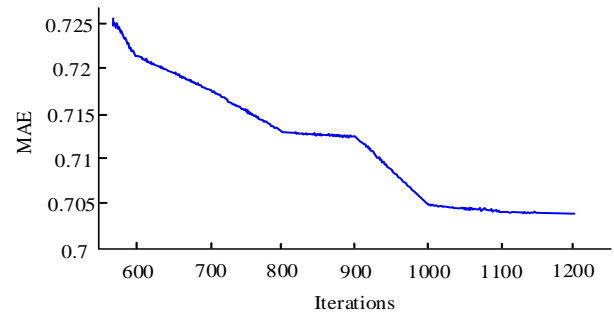


Fig. 6. The results of training MLP-DNN model using MAE function.

In summary, the MLP-DNN prediction model constructed in the study has some validity and is better for rating prediction, faster scoring, simpler methods and better recommendations than the DNN prediction model.

### B. Analysis of the Effectiveness of DNN-based Personalized RM Algorithm for ER

The study analyses the rationality and effectiveness of the three algorithms developed in the DNNER personalised RM. The first is the similarity-based ER filtering algorithm, where the most important step is to process the user's learning interests and the relevant text of the ER, convert the text into a vector, calculate the cosine similarity through the vector, and add a decrementing time factor to the final similarity calculation. To more accurately convert the text into vectors, the study uses a Chinese BERT pre-training model based on the full word coverage technique on top of BERT. The study briefly compares the resource filtering algorithm based on similarity ranking with the time required for neural network prediction. Fig. 9 shows that the time needed for prediction by the similarity algorithm is less than the time needed for prediction by the neural network, demonstrating that the resource filtering algorithm based on similarity ranking developed in this study can speed up the efficiency of recommendations and decrease response times, and its use can also speed up the feature processing process of resources.

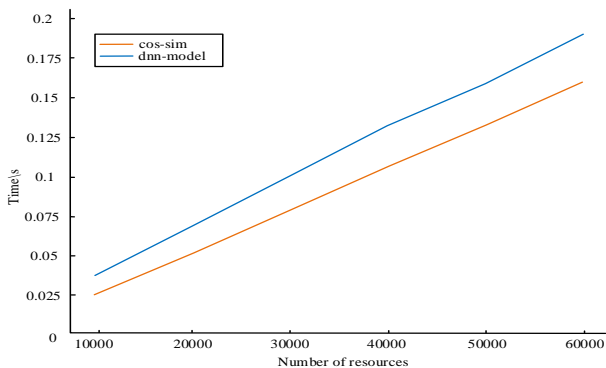


Fig. 9. Comparison of the time required for similarity algorithm and neural network prediction.

The effect of the DNN constructed and trained by the RR algorithm was then further validated. By using Python programming technology to process user data and course rating data collected from an online learning platform, we obtained 65783 rating records for 790 courses from 24244 users. The pre-processed dataset was split and 80% was classified as the training set for training the DNN, while the remaining dataset was used to test and validate the DNN. Select Adagrad optimiser, Huber loss function, relu activation function. Divide all the data into four samples of increasing quantity, 40%, 60%, 80% and 100% of the total quantity. The sample distribution is shown in Fig. 10, where the number of users in samples 1 to 4 is 12444, 16801, 20735, and 24244, respectively. The number of courses is 761, 777, 785, and 790, respectively. The evaluation scores are 26313, 39470, 52626, and 65783, respectively.

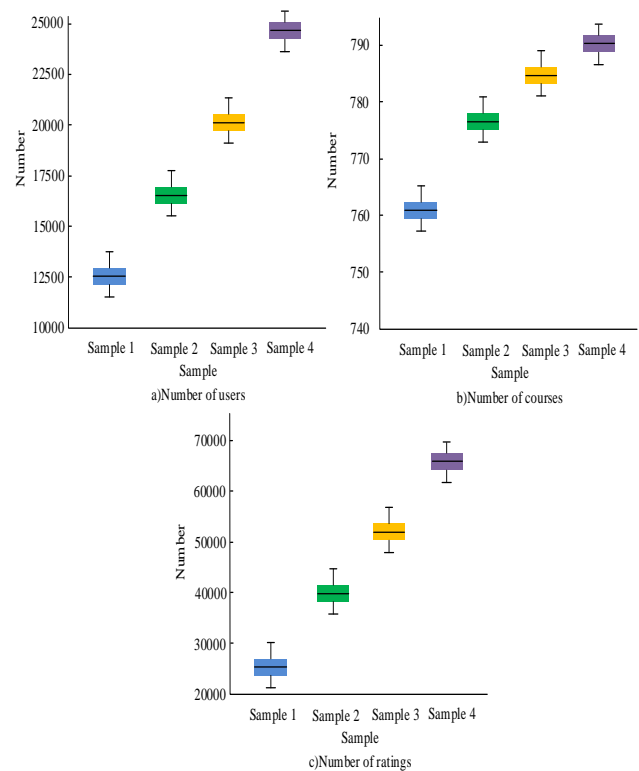


Fig. 10. Data distribution of resource recommendation algorithm experiments.

Decision Tree (DT), Support Vector Machine (SVM), k-Nearest Neighbor (KNN) and Convolutional Neural Networks (CNN) were selected to compare with the algorithm designed in this study. DNNRR algorithm designed in this study. In Fig. 11, in the comparative trials of the four samples, the MAE value of the DNNRR method designed in the study was the highest at 0.56 and the lowest at 0.54; it was lower than all the other algorithms except the SVM algorithm which was slightly higher; the MSE value was the highest at 1.29 and the lowest at 1.19, which were lower than the other algorithms. There is no difference between the MAE values of the CNN algorithm and the DNNRR algorithm, except for the obvious difference in the first sample, but the MSE values of the DNNRR algorithm are both lower than those of the CNN algorithm.

To verify the feasibility of the DNN-based resource display algorithm, using 70413 learning records from 13891 users collected and preprocessed on an online learning platform as experimental data. The Adam optimiser was chosen, the tanh activation function was picked,  $\delta$  was set to 2.5, and the initial learning rate was set to 0.001. Following the calculation of the time interval, 80% of the data set was divided into the training set and 20% into the test set. The data was divided into four samples in the same way as in the experiments to validate the DNNRR algorithm, as shown in Fig. 12.

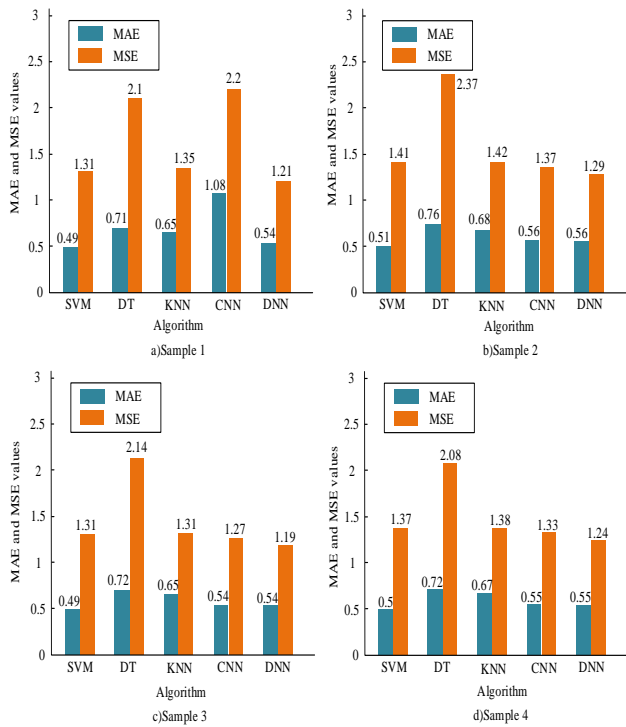


Fig. 11. Comparison results of MAE and MSE values for different recommendation algorithms.

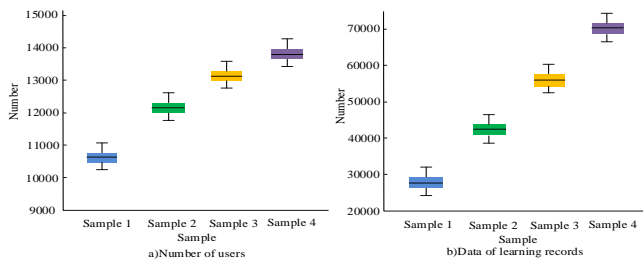


Fig. 12. Data distribution of resource display algorithm experiments.

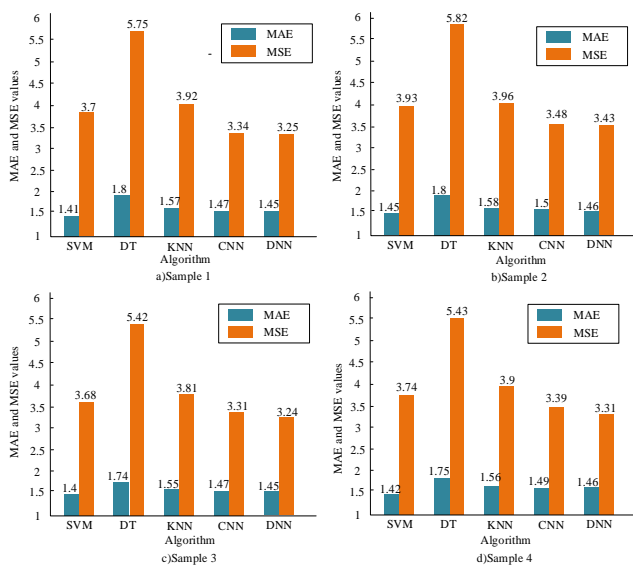


Fig. 13. Comparison of MAE and MSE values of 5 algorithms.

The same comparison was made with four classical algorithms, DT, SVM, KNN and CNN. In Fig. 13, in the comparison experiment for the four samples of different algorithms, the highest MAE value of the DNN resource display algorithm designed in this study is 1.46 and the lowest is 1.45, which are lower than the other algorithms except that it is higher than the SVM algorithm. The highest MSE value is 3.43 and the lowest is 3.24, which are better than the other algorithms. The study shows that the designed DNN-based resource presentation algorithm is reasonable and effective.

## V. CONCLUSION

Online learning platforms are steadily getting better thanks to the Internet's quick development. This convenience is accompanied with information overload, which adds to the time required for users to obtain knowledge. Intelligent recommendation technology can help solve this problem by providing personalised, intelligent, accurate and timely information recommendations. To address the problem of rational exploitation of OE resources, the study proposes a recommendation prediction model based on MLP-DNN and a personalised RM based on DNN. The outcomes revealed that the Loss value of the MLP-DNN prediction model was stable at about 0.6, which was about 0.2 lower than the Loss of the DNN prediction model. The DNCG metric was on average 0.01 higher than the DNN prediction model, and the HR metric was on average 0.03 higher than the DNN prediction model. The similarity algorithm took less time to predict than the neural network algorithm. The MAE value of the DNNRR algorithm was the highest at 0.56 and the lowest at 0.54, and the MSE value was the highest at 1.29 and the lowest at 1.19. The MAE values were lower than the other algorithms except for the SVM algorithm. The highest MAE value of the DNN resource display algorithm is 1.46 and the lowest is 1.45, and the highest MSE value is 3.43 and the lowest is 3.24. The MAE values are lower than other algorithms except for the higher than SVM algorithm, and the MSE values are lower than other algorithms. In conclusion, the model constructed by the research institute has a certain promoting effect on the development of the online education industry. However, the data collected in this study is still not rich enough for DNN learning, and the user evaluation experiments are not exhaustive enough. Therefore, in the future research work, it is necessary to further improve the system, collect more data, combine specific scenarios to collect more user evaluations, and establish corresponding answer banks to achieve automatic question answering function, so as to better apply to the intelligent recommendation of educational resources.

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# Role of Artificial Intelligence and Business Decision Making

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**Abstract**—Artificial Intelligence (AI) has emerged as a transformative technology with profound implications for various sectors, including business. In recent years, AI has revolutionized decision-making processes by providing organizations with advanced analytical capabilities, enabling them to extract valuable insights from vast amounts of data. The application of AI in businesses may force the sector to rely on quicker, less expensive, and more accurate marketing techniques. By utilizing the AI in marketing strategies, a business owner may increase audience reaction and build a strong online brand that can compete with others. In addition to marketing, it has the capacity to remodel a business with fresh concepts. Additionally, it provides solutions for challenging problems, aiding in the enormous business growth. The study's primary goal is to investigate how artificial intelligence and decision-making are deployed in business and tried to explore how AI is being used to enhance decision-making processes and how it is changing business models. The study reveals that the role of artificial intelligence in business decision making is transformative, offering significant advantages in terms of efficiency, accuracy, and innovation. AI-powered systems enable businesses to process and analyze vast amounts of data efficiently, leading to quicker and more informed decision making. Overall, the integration of AI in business decision making has the potential to drive organizational success and shape the future of business practices.

**Keywords**—Artificial intelligence; business decision making; efficiency; accuracy; innovation; marketing strategy; machine learning

## I. INTRODUCTION

AI is a disruptive technology advancement that, together with robots, is altering every single fundamental aspect of how businesses operate [1]. Artificial intelligence (AI) is defined as human-produced, machine-assisted, structured, organized information. AIs are created using human insight approaches including learning, reasoning, and self-healing. The future of marketing is artificial intelligence. Artificial intelligence makes it possible to make specific decisions while also saving tons of time and money. Data collection, forecasting, and trend analysis are all capabilities of AI systems. In terms of technology, artificial intelligence is the process of integrating cloud technology, network devices, robots, computers, and the creation of digital content as well as multiple business methods, systems, and day-to-day activities. In the past, present, and future, artificial intelligence computers will flourish. Future marketing initiatives must embrace artificial intelligence's growth and development. Artificial intelligence software is being used by businesses every day to streamline operations, cut costs, speed up turnaround, and increase productivity. Technology is developing at an unheard-of rate,

and businesses who have already switched to advertising AI software will have a unique edge when the next breakthrough rolls along.

Deep learning and machine learning are the two basic categories of AI learning. The learning method used by machines is analogous to human learning. By machine learning, AI-based experience, or gathering empirical data via expertise in existing in the environment, is building knowledge and storing it, and with each new cycle of learning, fixing the problem becomes more efficient and effective. One idea that appears frequently in search engine results is machine learning, which is regarded as a poor kind of artificial intelligence [2]. Hence, machine learning aims to identify the patterns on which algorithms are built. Deep learning is comparable to machine learning, with the exception that AI builds neural networks as it learns. Additionally, human participation is necessary for deep learning since humans provide as examples for AI to learn how to handle problems. This type of learning is employed in multi-layered learning and is frequently utilised in the development of intricate systems intended to address intricate problems [3].

However, as organizations embrace AI in their decision-making processes, it is crucial to address certain challenges. Data privacy and security concerns arise due to the reliance on large amounts of sensitive information. Ethical considerations, such as the responsible and transparent use of AI, must be carefully managed to ensure that decision making aligns with societal values. Additionally, the impact on the workforce needs to be considered, as AI systems automate certain tasks, potentially changing job roles and necessitating reskilling or upskilling initiatives.

The integration of artificial intelligence in business decision making has the potential to revolutionize how organizations operate and strategize. By enhancing efficiency, accuracy, and innovation, AI empowers businesses to harness the power of data and make informed decisions in a dynamic and competitive landscape. However, the responsible and ethical use of AI, along with considerations of data privacy, security, and workforce impact, must be carefully navigated. As businesses continue to embrace AI technologies, the landscape of decision making is set to undergo significant transformations, shaping the future of organizations across various industries.

## II. LITERATURE REVIEW

This technology has shown itself to be a strong ally for businesses in terms of supporting operational business



procedures as well as improving the efficiency of their core businesses. To support e-commerce [4], economic activities and information analysis procedures for trading operations [5], informed decision making [6], detecting fraud processes in financial operations [8], or text evaluation of financial information [9], AI is therefore a useful tool. Researchers have highlighted how AI technologies, such as machine learning and natural language processing, enable organizations to automate repetitive tasks and streamline decision-making processes and by leveraging AI algorithms [7], businesses can process vast quantities of data quickly, reducing the time required for analysis and enabling real-time decision making [11]. Organizations to explore new possibilities, identify untapped market opportunities, and develop innovative strategies [12], data privacy and security are critical concerns, as the use of AI involves the processing of sensitive information [13], additionally, ethical considerations arise in the use of AI, such as transparency, fairness, and accountability [14]. In addition, AI is crucial for operations including marketing [10], customer management [15], product launches, after-sales services [16], and stock management [17], as well as for industry 4.0 activities [18]. Due to the speed at which decisions can be made, the ability to analyse complicated circumstances quickly, and the drop in operational costs, the use of specialized algorithms in these jobs produces competitive advantages [19].

The availability of vast volumes of information important to business, or "Big Data," has increased the utility of AI in organisations. This word refers to those vast databases of data that is both structured and unstructured points that exhibit volume, diversity, velocity, as well as other traits including variability, truth, and value [20]. Managerial processes experienced a drastic transformation as a result of business use of big-data as a vital tool [21]. Studies have given conceptual frameworks for the use of big data in business [22], considering the information, technologies, methods, and impacts they have. The phrases "Artificial Intelligence" and its associated terms "Big Data," "Business Intelligence," and "Machine Learning" have shown a rise in queries over the past decade (2010–2019). Business intelligence utilized to be the most prevalent term, but as shown by Fig. 1, its use has steadily declined as analytics and other descriptive analytic solutions have grown more commonplace in businesses.

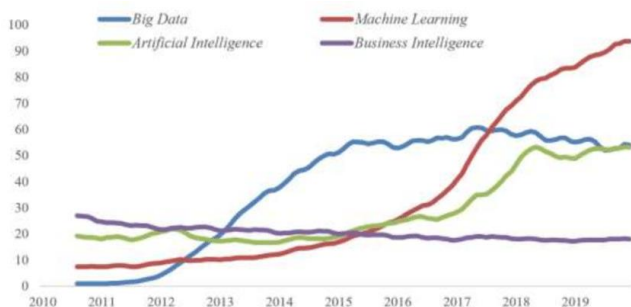


Fig. 1. Popularity of terms among online users between 2010 and 2019: AI, big data, business intelligence, and machine learning.

Business analytics (BA) was described by Davenport and Harris [23] as the "extensive use of data, quantitative and statistical analyses, predictive and explanation models, and

fact-based management" that eventually influences choices and actions. Vidgen, Shaw, and Grant [24] point out how BA may be viewed as a mediator between the data that the organisation has access to and the real economic value that can be obtained by using it to take better actions and make more informed decisions.

To examine the relationship between AI and strategies to create commercial value, Borges et al. [25] conducted a literature study. According to this point of view, this article aimed to close this gap by conducting a thorough literature review focused on the integration of business strategy and AI; incorporating the current approaches and models, featuring the anticipated advantages, difficulties, and opportunities; and starting a dialogue about potential new research directions. In order to present research gaps, they selected papers from conference proceedings and peer-reviewed publications and constructed a framework.

### III. ROLE OF ARTIFICIAL INTELLIGENCE IN BUSINESS

The role of AI in modern digital life is quickly expanding, and the advertising and marketing industries are no exception. Artificial intelligence is transforming industries one by one, from the witty and intelligent Siri to Tessa's self-driving car to Google AI that could really learn video games in only a few hours. Artificial intelligence can be used for a variety of purposes, such as identifying data trends to reduce market risks, improving customer service with virtual assistants, or even analyze millions of documents stored on various servers within an organization to identify compliance failures. But businesses have only lately been able to foresee and anticipate the opportunities that robots and artificial intelligence (AI) might offer to the future of business. Businesses can reduce their faults thanks to AI's consistency and rule-based programming. Its endurance, together with ongoing upgrades and the capacity to record procedures, leads to fruitful economic prospects. Artificial intelligence applications make use of robotics, computer vision, voice recognition, machine learning, and natural language processing technology. There are several commercial prospects offered by these technologies.

#### A. AI in Decision Making

Making decisions is a crucial component of managing a business. Data mining, big data, and enormous files are all significant components of commercial decision-making. Data security is yet another crucial duty. The criteria on which the theory is based are these terms and the replacement of executives. Human and AI are very close to one another. One makes decisions using historical facts, whereas the other utilises experience. Data is a value to AI since without it, AI would not be able to make decisions, Fig. 2.



Fig. 2. An AI-based model for decision-making.



Artificial intelligence modeling has the ability to overcome the gap and meet client demands. AI opens the way for specific decision-making and also saves a tonne of time and money. AI systems are capable of data collection, forecasting, and trend analysis. The lifetime value of a customer may also be predicted by AI. Humans can sum it up by stating that AI lowers the system's bounce rate. AI peruses the data in a process known as data mining, also known as opinion mining. Web searches for views and sentiment are made possible through opinion mining. Marketers may learn more about their target markets and particular products in this way. AI makes use of particular websites, online pages, and search engines. AI enables us to make decisions more quickly and simply.

To examine the relationship among AI and decision-making in dynamic corporate situations, Trunk et al. [26] conducted a literature study. In order to provide an overview of the prospects of existing research outlining for linking AI with business decision-making in changing contexts, the authors looked for peer-reviewed publications and did a content analysis. The findings are given in a conceptual framework that first outlines how humans might use AI in decision-making in dynamic situations before outlining the challenges, prerequisites, and implications that should be considered.

The goal of Duan's study [27] was to illustrate how AI may be used to make decisions. According to the study, AI makes broad judgments to support or replace humans on topics like AI's participation and integration. The usage and impact of resurrected AI-based dynamic frameworks are discussed in this research. Also, it offers a number of advices for those that deal with data frameworks. Beginning with publications published in international journals, the research gives a brief overview of AI's historical past (IJIM). The article discusses AI in broad and the primary issues concerning AI. The cooperation and coordination required to supplement or completely replace human representatives were also covered. The study offers research into the usage of AI for dynamics in the age of big data by offering twelve recommendations for were experts and hypothesized turns of occurrences like AI invention and implementation with human association.

#### IV. METHODOLOGY

With more data, AI gets better. Businesses produce more data every day, so it can learn from it, adapt as it is collected, and use it to get the desired results for the organization or goal. A business may gain a lot from AI data collection that uses previous data to anticipate future results. Real-time processing allows businesses to access data to assist in solving any unresolved problems or making innovations.

In the commercial sector, AI and decision-making are becoming increasingly important. AI solutions may give companies a competitive edge by enhancing customers' perceptions of and interaction with digital strategy-based applications. Innovative aspects geared towards the social cognitive capacities of the AI age will be provided through entrepreneurial intention through the production of new goods. The final result is frequently that fighting and mental training should prioritise safeguarding the advent of AI to create

innovative products and suppliers. Businesses can profit from integrating next-generation AI technology if they have a clear electronic Internet business plan that includes their goals, efficiency, and legal framework. The conceptual framework used in this investigation is shown in Fig. 3.

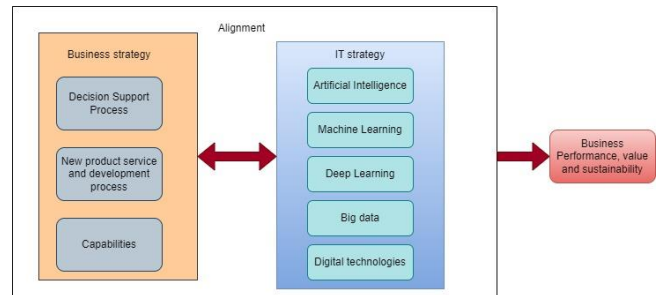


Fig. 3. Conceptual framework.

Our comparison of traditional and AI-based strategic planning suggests a framework that illustrates how the modalities may be used to enhance the value of strategic planning. As depicted in Fig. 4, our strategy's three key organizations are aggregated human AI choice-generating, full human AI delegation, and crossbreed human AI and AI human sequential choice creating.

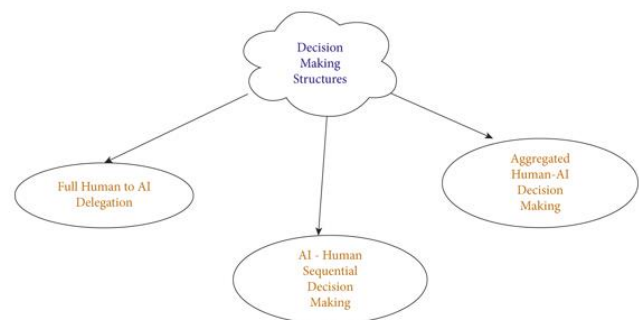


Fig. 4. Building blocks for AI.

Organizational competency and, more importantly, technological and technical competence are used to identify the potential applications of AI. Also, the enterprise using AI must implement business digital transformation. The goal of digital transformation is to alter the business model, or to change the conventional manner of conducting business and move a company online. In addition to altering the business perspective, the organisation greatly improved process efficiency and effectiveness.

#### V. RESULTS AND DISCUSSIONS

The modern business paradigm is altered by artificial intelligence. Many businesses can improve their efficacy and efficiency by using AI, but doing so comes at a cost of spending a large sum of money to ensure that all of the infrastructure required for such a system to operate normally is in place. Each organisation must also undergo a digital transformation that affects how some organisational departments work in order to use AI. Moreover, digital transformation refers to the conversion of the conventional business model to a virtual system, such as the cloud. Because AI systems may be used for a variety of analyses as well as

decision support, they can have a substantial influence on how well organisations function. The organization's quality management is built on a decision-making process relying on the facts that are documented. The efficiency of AI decision-making tools is shown in Fig. 5, 6, and Table I.

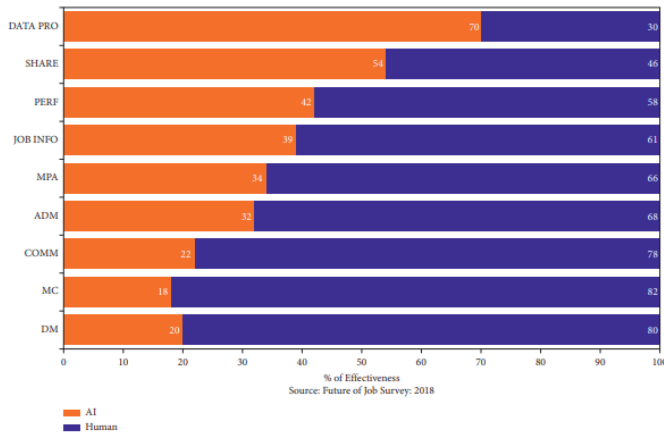


Fig. 5. Using AI technologies effectively in business decision-making (2018).

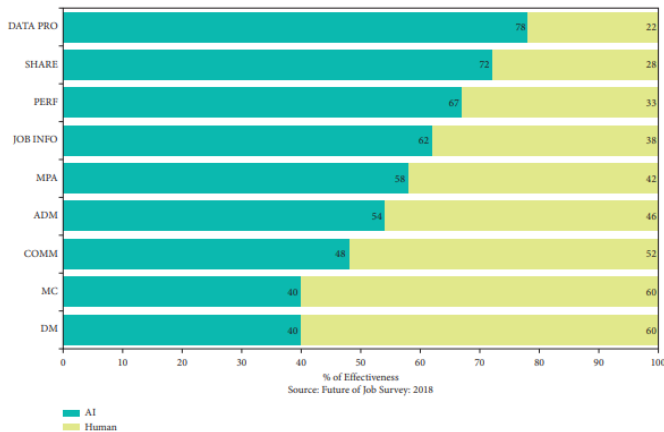


Fig. 6. Using AI Technologies in business decision-making (2022).

TABLE I. USING AI TECHNOLOGIES EFFECTIVELY IN BUSINESS DECISION MAKING

Factors	Human proportionate hours		AI proportionate hours	
	2018	2022	2018	2022
Reasoning and decision-making	80	60	20	40
Managing and coordinating	82	60	18	40
Communication	78	52	22	48
Administration	68	46	32	54
Mental and physical activities	66	42	34	58
Identifying job-related information	61	38	39	62
Complex activities performance	58	33	42	67
Job-related data sharing	46	28	54	72
Data processing	30	22	70	78

The results demonstrate that AI may assist, replace for, or enhance human decision-making when formulating marketing plans. It specifically serves to highlight the prospect of a successful collaboration among management and machines. Moreover, organisational management may model how a potential action would affect various organisational segments due to the predictive modeling that AI is capable of performing. AI can be applied to risk management as well as risk assessment, which also falls under the needs of the system for quality management, when it comes to quality management.

Customer relations are among the most crucial capabilities an AI can have. Customer focus is one of the guiding principles of ISO 9001:2015, therefore AI may be utilised in sales and marketing to gather various types of customer-related data. Such information may be analysed, and the results of that analysis can be applied to better the goods and service that the business provides and in which it participates. As a result of the AI system's ability to respond to nearly all client inquiries soon after they are asked, employing AI in sales and marketing can boost customers' satisfaction. The AI system's most significant capability is its ability to compile all customer inquiries and do analysis, enabling the company to build organisational knowledge that can be used to future problem-solving or product and service enhancement. Apart from that, AI may be applied to nonconformities to solve certain issues based on the information that has been accumulated about how to do so. AI is able to apply several learning methods, like deep learning, machine learning, etc., making this feasible.

The integration of artificial intelligence in business decision making has the potential to revolutionize how organizations operate and strategize. By enhancing efficiency, accuracy, and innovation, AI empowers businesses to harness the power of data and make informed decisions in a dynamic and competitive landscape. However, the responsible and ethical use of AI, along with considerations of data privacy, security, and workforce impact, must be carefully navigated. As businesses continue to embrace AI technologies, the landscape of decision making is set to undergo significant transformations, shaping the future of organizations across various industries.

## VI. CONCLUSION

The approach of businesses to make decisions is revolutionised by artificial intelligence. Businesses may make better decisions by utilising AI systems' ability to analyse vast volumes of data and generate predictions and suggestions based on that data. Ultimately, AI has the power to revolutionise corporate decision-making by delivering quicker and more precise insights that can guide both operational and strategic choices. To minimise unforeseen repercussions and preserve consumer confidence, organisations must make sure AI is utilised responsibly and openly. The use of AI in decision-making by organisations and consumers is without a doubt the future. Technology offers many options and a simple means for making business decisions. AI is an extremely clever gadget. Data mining and big data are used to assist it make decisions. The study denies the idea that AI would replace humans and instead says that it is a very dynamic tool that is helpful for making decisions.

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# Unusual Human Behavior Detection System in Real-Time Video Systems

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**Abstract**—Abnormal behavior detection, in terms of importance, has become a necessity in real-time visual systems. The main problem is the ambiguity in the difference between the characteristics of abnormal and normal behavior, which its definition is usually different according to the previous context of images. In this research, three approaches are used. In the first approach, a standard Convolutional Automatic Encoder (CAE) is used. After evaluation, it was found that the standard CAE problem is that it does not take into account the temporal aspect of the image frames sequence. The second method involves automatic encoding to learn the dataset's spatio-temporal structures. In the third approach, the complex LSTM cells are used for further improvement. The outcomes of the test display that the proposed methods have better performance compared to many of the previous conventional methods, and their efficiency in identifying abnormal behavior is very competitive compared to previous methods.

**Keywords**—Anomaly detection; video sequence; standard Convolutional Automatic Encoder (CAE); spatio-temporal structures; LSTM

## I. INTRODUCTION

Over the past decade, real-time video analytics has grown rapidly and made tremendous progress. The primary goal of video analysis is to identify possible occurrences with minimal (or no) human intervention. Studies in the popular field of video control involve recognizing human operations as well as classifying these operations as usual and unusual or suspicious operations. The main role in this area is to identify abnormal events in the videos using a monitoring system (which is fully automatic, manual, and semi-automatic). The manual monitoring system is completely human-dependent. Manual activity is required to analyze human behavior or to distinguish between abnormal and natural behaviors. The semi-automatic system requires less human interposition, while the fully automated surveillance system is the intelligent video surveillance system that is fully automatic and does not require human intervention to make decisions.

According to the current observations in the market [1], the public and private sectors invest a lot of money to protect the offices, buildings, centers, houses, infrastructure, etc.; these trends in the coming years will improve the automated security industry. As terrorist activities are on the rise today, it is important to identify the suspicious or abnormal operations that could affect the usual human operations. The unusual events are the disorders or behavioral deviations of an object (relative to the usual behavior of that object) that include placing the object in an abnormal location, unusual movement pattern (such as moving in the mistake direction, unusual rotation,

violence or conflict between people or different movements as opposed to general movements such as walking all people but crawling some people) or any the abnormal event. Each event can be normalized in one scenario and abnormal in another [2].

The recognition of unusual events can be done in two techniques: The first is to train the system with usual events and unusual events and then to identify future occurrences using the previous information. The second method is to follow the dominant ownership according to which the dominant behavior of the individual (behavior that occurs frequently) is considered normal behavior, and the behavior that occurs less often is considered unusual and unusual. An anomaly is detected by taking and analyzing the motion and physical signs of the objects in the video [3]. The method of detecting motion anomaly includes the speed, direction, location and path of the moving object. The method of detecting outward anomalies includes the condition of the object, the identification or color of the object, and so on [4].

In this article, various systems are presented that detect anomalies in video frames. In this research, three approaches are used, and the results of each are presented. In each approach, by adding more aspects, it is possible to improve the previous approach. Therefore, the main contributions of the current article can be stated as follows:

- Improving the performance of this system by providing different methods and considering the temporal and spatial sequence of the frames.
- Increasing the speed of this system to detect abnormal behaviors
- Designing the appropriate methods to identify the various abnormal behaviors according to the selected dataset.

The remaining article: Related research in this field is described in the second section. The suggested methods is explained in the third section. The dataset's elements as well as the implementation results are provided in the fourth part. This paper's conclusions and future research directions are also stated in the fifth part.

## II. RELATED WORKS

In this part, previous work or existing research background in the area of automatic detection of unusual human activities is discussed. Various frameworks can be used to recognize abnormal behaviors in surveillance video (without human interposition) [5]. Researchists have used different methods depending on the application or events under study. In previous

research on recognizing abnormal events, Young et al. [6] suggested a new approach to detecting unusual behaviors and identifying dominant behaviors. The dominant set theory proposed by Alvar et al. [7] is used to recognize the abnormal behavior of the object in the image frames sequence. In this regard, Wang et al. [8] suggested using the covariance matrix as a feature descriptor. The SVM classification of an online nonlinear is used to classify the usual and unusual events.

Chung et al. [9] have presented a review article that describes how to solve the problem of showing abnormal event videos. The concept of the conditioned finite Boltzmann machine and the independent component analysis has been used to extract better features (as a common easy method). It was discussed to learn fully learned feature representations and the concept of in-depth feature analysis. In identifying the activity, the most important and vital task is understanding the behavior that Jiang et al. [10] tested and evaluated in a review article. In this work, the author describes (in detail) the characteristics of the behaviors in the videos to detect the anomaly. Different parts of the body are used to recognize human gestures and emotions. Chen et al. [11] introduced a common time filter approach in which the head and the other parts of the body are used to extract features as well as to analyze human behavior. The research in this field has faced the problem of using related examples in multi-factor scenarios. Zhou et al. [12] have proposed the concept of feature labeling with multi-level correlation in videos to identify the different events.

A multi-feature-based method proposed by Hong et al. is used to detect and track different objects [13]. Daphner and Garcia [14] proposed a method that uses pixel-based descriptors to detect very small objects in the image. Also, Ning et al. [15] presented a common recording approach and a smart contour segmentation method for object tracking. Zhang et al. [16] presented the heavy obstruction in object tracking using the outward model. The spatio-temporal model is used to track object videos with obstruction. Several methods have been proposed to detect abnormal behavior. Depending on whether the sample videos require initial determination or training before detecting any unusual operation [16], the supervised approach, the semi-supervised approach, and the unsupervised approach are the three categories into which these techniques fall.

In the supervised approaches, the anomaly recognition input samples are labeled the usual and unusual [17]. The technique is prepared for activities with predetermined features, and path, movement, speed, or appearance is utilized as indicators for classifying them into normal and abnormal categories. The second method is a semi-supervised approach that requires only natural information to train the system. The following categories are used for categorizing this technique: model-based classification and rule-based classification. In the rule-based approach, the rules are set, which help classify the sample into two categories: normal and abnormal. Samples that comply with the rules are classified as normal behaviors, and samples that do not comply with the rules are classified as abnormal. Online dictionary update and flexible encryption [9, 18, 19] are two techniques primarily used in the rule-based approach. The third strategy is unsupervised, which does not

require both usual and unusual cases as training data. In these approaches, the classification is based on the hypotheses that state that abnormal behaviors occur less frequently (compared to normal behaviors).

#### *A. Limitations of Related Works and Solutions*

During the past two decades, the recognition and the tracking of the humans in the consecutive video frames, representing and analyzing their activities, and finally identifying their intrusive behavior has been one of the most challenging topics in the field of machine vision, and the attention of the research groups has attracted many reputable universities. On the other hand, the detection of abnormal behavior in video frames faces many limitations. According to the background of the presented research, some of these limitations (that the related works are faced) is briefly listed. The presented method in [28,38], which focuses on the detected paths of objects, assigns the normal labels and the abnormal labels based on which conventional path is ahead. These methods noticeably lose their effectiveness when there is an obstruction or when there is a change in the brightness of the images, and also when there are crowded scenes in the images, these methods have a high computational complexity. Therefore, researchers have proposed the methods that use low-level features such as hinges and gradients to learn the spatial-temporal dimensions and relationships in such features. On the other hand, in some researches such as [12], the one-class SVM classifier was used in the upper layer, which is also a challenge because the detection of the anomalies in video frames that related data have not class label, is not possible. Therefore, methods that are compatible with the non-labeling data class should be considered. Also, the most important challenge in some of the works done in this field such as [43,36] is that the proposed methods are applied to specific data and video frames, which have limitations. There are some of them, the most important of which is not covering a large number of the abnormalities. For example, the UMN dataset [32] and Hockey Fight [33] only include the fight anomaly. For this purpose, it is necessary to consider a dataset that includes a wider range of anomalies. In addition, some works such as [5,35] work on the basis of extracting features from the detected paths of the objects that do not consider the aspect of temporal and spatial sequence of the video frames. This leads to not identifying the certain abnormalities. Therefore, in order to further improve the anomaly detection systems, it is felt necessary to use the aspect of temporal and spatial sequence of the frames. It makes the frames share their learning between the adjacent frames and then reduce the processing cost.

According to the mentioned limitations, the points that are considered to solve these limitations in this article are as follows. The first point is that due to the fact that the data does not have a class label, in this research, the auto-encoders were used to encode and decode the video frames to overcome this limitation. The second point is that in the selection of the dataset, the current article has considered a dataset that includes a wider range of anomalies. This dataset includes three movement abnormalities of cyclists, skaters, motorbikes, small carts, people in wheelchairs, etc. The third point is that the different methods have been tried to provide more

improvement, and also the aspect of temporal and spatial sequence has been considered.

### III. PROPOSED METHODS

The methods used in this study are according to the point that when an unusual event happens, the newest video frames differ from the old frames. An end-to-end model is trained with a feature descriptor as well as a decoder-encoder that trains the frame input volume patterns in a manner that is inspired by [20]. This model is trained with the input video, so these video volumes consist only of frames with normal behavior. This work aims to reduce renovation error, which is the difference between the input video volume. After proper model training, the usual video is awaited to have a low renovation error. However, the video frames are expected to consist of frames with abnormal behaviors also high renovation errors. By limiting the error generated by each input value, the system can recognize when an unusual event happens [21, 22]. In general, the presented method includes three main steps: pre-processing, feature learning (which, in this study, three learning approaches is used), and regularity score.

#### A. Pre-processing

At this stage, the conversion of raw data into balanced and acceptable input for the model is done. To assure that the input frames are the same scale, each is extracted from the input video and resized to 100×100. Next, the pixel values are scaled between zero and one; for normalization, each frame is subtracted from its global average image. The average image is computed in the training dataset by averaging the pixel values in each position in each frame. The photographs are then made into grayscale versions to make them smaller. In order to have a single mean and variance, the photos are then standardized [23].

The input of the model in some of the approaches used in this research is the volume of the video, in which each volume contains 10 continuous frames with different steps. A lot of training data is needed because this method has a lot of parameters. Therefore, to increment the amount of the training dataset, the data in the time dimension is reinforced. To produce these volumes, the frames with step-1, step-2 and step-3 is connected. For instance, the first sequence of step-1 consists of frames (1,...,10), while the sequence of the first sequence of step-2 contains a numbered frame (1, 3, 5, 7, 9, 11, 13, 15, 17, 19) and the first sequence of step-3 includes frames (1, 4, 7, 10, 13, 16, 19, 22, 25,28). The input is now ready to train the model [23].

#### B. Feature Learning

As mentioned earlier, three approaches are used to creating regular patterns in the training videos. In the first approach, a standard convolutional automatic encoder (CAE) is used. After using CAE, it became clear that the problem with standard CAE is that it does not take into account the temporal aspect of the image sequence. Thus, it is not easy to identify certain abnormalities, such as a person moving faster than average. Therefore, in the second approach, an automatic encoder is used to learn spatio-temporal structures in the dataset. That is, instead of considering only one image at a time,  $n$  images are considered simultaneously. In the third approach, complex

LSTM cells are used for further improvement. LSTMs can be used to predict the next video frames. Below, each of the approaches and their details is described:

1) *Standard convolution automatic encoder*: According to its name, the automatic encoder contains two stages: encoding and decoding. By adjusting the numeral of encoder output modules to be less than the input, an automatic encoder has been employed for the first time to reduce dimensions. This model is trained using error replication in an unsupervised method and minimizing the renovation error of decoding outcomes from the original inputs. An automatic encoder can extract more advantageous information by choosing the nonlinear activation function over traditional linear conversion techniques like PCA. Here, these automatic encoders in the unsupervised method are used to detect the anomalies because a supervised learning method suffers from an imbalance [24].

However, automatic encoders are great for this status because these encoders can be trained on usual components and do not require marginal data. After the training, a feature view is provided for a section and compares the output of the automatic encoder with the input. If there is more difference, the more likely it is that the input contains anomalies. As mentioned, the automatic encoders consist of two sections: 1) an encoder that encodes the input data using a reduced representation and 2) a decoder that attempts to renovate the original input data from the reduced representation. The network is subject to restrictions that force the automatic encoder to learn a concise representation of the training dataset. It does this in an unsupervised manner and is, therefore, the most appropriate case for abnormalities [25].

Here, the used network structure is defined. The encoder includes two layers of convolution and two layers of MaxPooling. The decoder and encoder are connected by a fully connected layer. The bottleneck larger can be reconstructed the more information. The decoder includes two upsampling layers and two deconvolutions' layers. Fig. 1 shows the presented network structure. So, with using CAE, it becomes clear that the problem with standard CAE is that it does not take into account the temporal aspect of the image sequence. Thus, it is not easy to identify certain abnormalities, such as a person moving faster than average. Therefore, in the second approach, an automated encoder is used that can learn spatio-temporal structures in the dataset. That is, instead of considering just one image at a time,  $n$  images are considered simultaneously, which is explained in the next section.

2) *Spatio-temporal stacked frame encoder*: The proposed architecture presented in this approach includes two sections: 1) the automatic spatial encoder for learning the spatial structures of each frame and 2) the temporal encoder-decoder for learning the temporal samples of encoded spatial structures. The spatial encoder and decoder, as seen in Fig. 2, have two layers of convolution and deconvolution, respectively. Convolution layers are renowned for their superior object detection performance. Convolution in a convolution network primarily extracts the necessary features from the input image. By understanding image attributes,



convolution preserves the spatial link among pixels (employing tiny input data squares) [20].

Convolution operations are point multiplications between the local input areas and the filters mathematically. Suppose the several square input layers  $n \times n$  be available, followed by the convolution layer. If the  $m \times m$  filter is used, then the output of the convolution layer will be  $(n - m + 1) \times (n - m + 1)$ . During training, a convolutional network discovers the filters' values independently. However, before training, the parameters like the numeral of filters, the size of the filters, and the numeral of layers should be defined. More filters enable us to extract more image features, and the resulting network is better at spotting patterns in previously unseen images. A balance should be struck by not altering the number of very large filters because more filters need more computation time and use memory faster [26].

It is presumed that all inputs (and outputs) in a traditional feed-forward neural network are independent. However, learning the temporal dependencies between the inputs (in sequence tasks) is important. A word prediction model, for instance, should be able to gather data from previous inputs. The RNN functions identically like a feed-forward network, except that the input vector and the complete input history impact the output vector values [20].

Theoretically, RNNs could use arbitrary long sequences of information, and however, in reality, RNNs are constrained to a few steps because slopes have disappeared. On the other hand, as mentioned earlier, a problem with the standard CAE is that it does not take into account the temporal aspect of the image sequence. Thus, identifying specific abnormalities, such as a person moving faster than average, is not easily detectable [20]. Therefore, in this approach, an automatic encoder is described that can also learn the spatio-temporal structures in a dataset. In this approach, instead of considering just one image at a time,  $n$  images are simultaneously considered. The standard CAE considers input as [packet size, 1, width, height], and the spatio-temporal encoder considers input as [packet size, size, width, height]. In the third approach, the complex LSTM cells are used for further recovery. LSTMs can be used to predict the next frames of a video, and their details are given in the next section.

This architecture receives a trail of length  $T$  as an input sample as well as generates a renovation of the input sample trail. Each layer's outcome size is indicated by the numbers on the right. Every time, the location encoder collects one frame as input. It processes 10 frames, delivers the attributes encoded in 10 frames, and gives the encoder time to complete the encoding. Decoders mimic encoders in the reverse direction to reconstruct the volume of the video.

3) *Spatio-temporal auto-encoder with convolutional LSTMs*: In this section, the short memory model is used and add it to the third approach for further improvement. In other words, the second approach is developed by using LSTM. As mentioned in the second approach, the spatio-temporal encoder and decoder both include two layers of convolution and deconvolution. In contrast, the temporal encoder (in the third technique) adds three-layer long short-term memory

(LSTM) convolution. The LSTM model is popular for sequence learning and time series modeling and has demonstrated its performance in applications like speech translation and handwriting identification. Convolution layers are known for their high performance in object recognition [23]. The general architecture of the third approach's proposed method is depicted in Fig. 3.

In the previous section, a brief description of RNN was given. In this approach, as stated, a type of RNN is used: the forgetfulness gate, which is a return gate in the long short-term memory model (LSTM). With this suggested structure, LSTMs are prevented from dissipating or exploding post-propagation errors, allowing them to act on lengthy trails and be combined to gain higher-level information. Equations 1 to 6 and Fig. 4 provide the tabloid formulation of a common LSTM [23]:

$$f_t = \sigma(W_f \otimes [h_{t-1}, x_t] + b_f) \quad (1)$$

$$i_t = \sigma(W_i \otimes [h_{t-1}, x_t] + b_i) \quad (2)$$

$$\hat{C}_t = \tanh(W_c \otimes [h_{t-1}, x_t] + b_c) \quad (3)$$

$$C_t = f_t \otimes C_{t-1} + i_t \otimes \hat{C}_t \quad (4)$$

$$o_t = \sigma(W_o \otimes [h_{t-1}, x_t] + b_o) \quad (5)$$

$$h_t = o_t \otimes \tanh(C_t) \quad (6)$$

Equation 1 displays the layer of forgetfulness. Equations 2 and 3 are where new data is subjoined, and Equation 4 merges new and old data, while Equations 5 and 6 are moved from the current LSTM unit and apply what has been previously trained in the upcoming time step. The variable  $h_t$  indicates the latent state,  $x_t$  indicates the input sample, also  $C_t$  indicates the cellular state at time  $t$ .  $b$  is a bias vector, and  $W$  is a teachable matrix, and the symbol  $\otimes$  represents the product of Hadamard [23].

The convolutional long short-term memory model (ConvLSTM), a type of LSTM architecture, was first presented by Shi et al. [27] and more recently used by Patraikin et al., which presented in [28] and is used to predict the video frames. In comparison to conventional fully connected LSTM, ConvLSTM replaces its matrix operation with convolution. ConvLSTM requires less weight and provides a map with better spatial features by employing convolution for hidden-to-hidden and input-to-hidden connections. Equations 7 to 12 can be used to summarize the ConvLSTM unit's formulation [23].

$$f_t = \sigma(W_f * [h_{t-1}, x_t, C_{t-1}] + b_f) \quad (7)$$

$$i_t = \sigma(W_i * [h_{t-1}, x_t, C_{t-1}] + b_i) \quad (8)$$

$$\hat{C}_t = \tanh(W_c * [h_{t-1}, x_t] + b_c) \quad (9)$$

$$C_t = f_t \otimes C_{t-1} + i_t \otimes \hat{C}_t \quad (10)$$

$$o_t = \sigma(W_o * [h_{t-1}, x_t, C_{t-1}] + b_o) \quad (11)$$

$$h_t = o_t \otimes \tanh(C_t) \quad (12)$$

While these equations are similar to Equations 1 to 6, their input is in the form of an image. At the same time, the weight set for each connection is replaced by convolution filters

(symbol \* indicates a torsional action). This allows ConvLSTM to work with better images than FC-LSTM because it can propagate the spatial features (per unit time) through any ConvLSTM mode. Note that this convolution type also adds the optional hole connections to allow a unit to receive the previous information better. So, the previous model is developed by using complex LSTM cells. This proves that ConvLSTM is more efficient in video processing, and ConvLSTM can also be used to predict the next video frames [23]. In this study, 10 input frames are stacked in a cube. These frames placed on the cube are processed by 2 layers of convolution (encoder). Then, these are given to a temporal encoder/decoder consisting of 3 layers of LSTM convolution and 2 layers of deconvolution and the output frames are reconstructed. When initializing the model, the initial state vector for LSTMs should be created.

### C. Regularity Score

After model training, the input of experimental data into the trained model can be used to analyze the efficiency of presented models and examine whether these models can reduce the detection of false abnormal behaviors. Also, it examines whether these models can detect abnormal events correctly or not. For better comparison, the regularity score is calculated using the same procedure for all image frames; the only variation is in the model that was learned. The Euclidean distance between the input frame and the renovated frame is calculated using the renovation error of all values of pixels in the frame  $t$  of the video trail [23]:

$$e(t) = \|x(t) - fW(x(t))\|_2 \quad (13)$$

where,  $fW$  is the weight training by the spatio-temporal model. Then, the anomaly score  $s_a(t)$  is calculated by scaling

between zero and one. The regularity score  $s_r(t)$  can thus be readily calculated by subtracting the anomaly score by one [23]:

$$s_a(t) = \frac{e(t) - e(t)_{min}}{e(t)_{max}} \quad (14)$$

$$s_r(t) = 1 - s_a(t) \quad (15)$$

### D. Anomalies Detection

1) *Thresholding*: It's easy to tell whether a video frame is common or exceptional. Each frame's renovation error indicates whether it may be considered an abnormal frame. This threshold specifies how much of the sensitivity of behavior recognition system. Setting a low threshold, for example, makes the system more sensitive to scene events, which causes more alerts to be generated. Setting various error thresholds allows us to obtain the false positive and true positive values, which are then used to compute the area under the receiver operating characteristic (ROC) curve. Additionally, when the false positive rate is the same as the false negative rate, the equal error rate (EER) is gained [29].

2) *Events count*: As described in [20], the PersistenceID algorithm is utilized to simultaneously group the local minimums with a fixed temporal frame of 50 frames to reduce noise and meaningless minimums in the regularity score. Therefore, it is presumed the local minimum of 50 frames refers to the same unusual event. This is an advisable temporal window size because an unusual event must take at least 2-3s to make sense (videos are recorded at a speed of 24-25 frames per second).

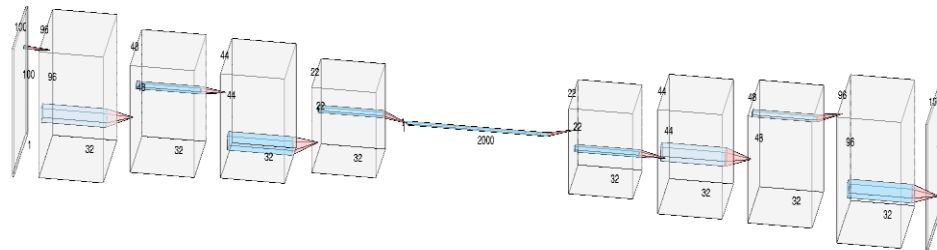


Fig. 1. Proposed network structure.

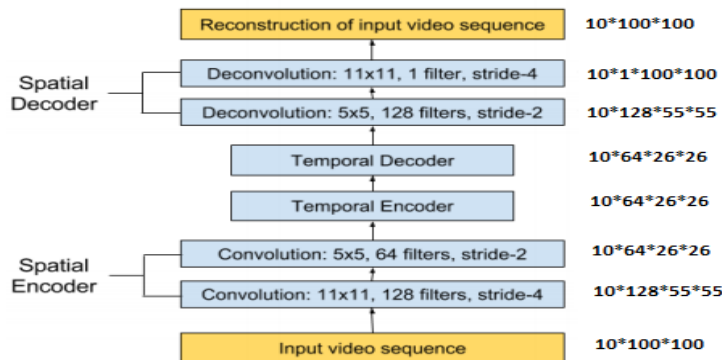


Fig. 2. Proposed network architecture for the second approach.

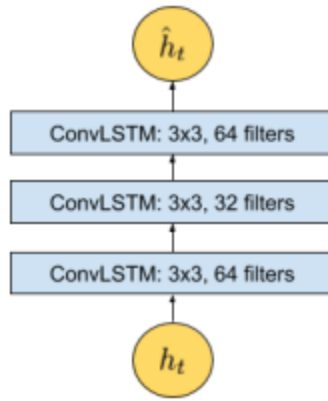


Fig. 3. Magnified architecture at Time  $t$  for the third approach where  $t$  is the input sample at this Time point. There are three layers of convlstm in the temporal encoder-decoder pattern.

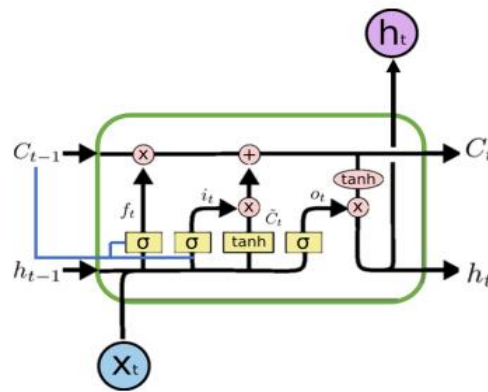


Fig. 4. A generic LSTM's architectural structure. The blue line displays an optional hole structure that allows the inner state to see the state of the prior cell  $C_{t-1}$  for better decision-making (best seen in color).

#### IV. DATASET AND IMPLEMENTATION RESULTS

In this part, the implementation's details and its outcomes is described. The presented methods in this study have been compared with previous conventional methods on the UCSD dataset, which will be described below. This comparison has been evaluated and concluded using ROC curve criteria and EER rate. A scatter plot of sensitivity for a binary classifier model with a variable threshold is the ROC curve. In order to specify the abnormal frames, the levels of frame pixels are used. These two measurement values are defined below:

- Measurement at the frame level: If a single pixel of each frame is considered unusual, then this frame is considered abnormal.
- Pixel-level measurement: if the algorithm detects that at least 40% of the correct background pixels are covered by unusual pixels, and then the corresponding frame is considered as abnormal.

##### A. Dataset

In order to train the model and evaluate the presented method, the UCSD dataset is used, which has been used in almost all the articles presented in this field. Two separate open spaces were used to collect the two subsets of this dataset, Peds1 and Peds2, respectively. A fixed camera recorded both

subsets at 10 frames per second at a resolution of 158×234 and 240×360. The right background files in it allow evaluating the levels of the frame and pixel. Thirty-six videos were used for testing in the Peds1 subset, 34 videos for training in the Peds2 subset, 16 videos for testing and 12 videos for training. Fig. 5 displays an instance of frames that existed in this dataset.

In the proposed method, a pre-processing step is presented in which the conversion of raw data into a smooth as well as acceptable input for the model is performed. Every frame is taken out of the raw video and resized to 100×100 to verify that the input frames have the same scale. Next, the pixels' value is scaled between zero and one; for normalization, each frame is subtracted from its global average image. The average image is computed in the training dataset by averaging the value of pixels at each position in each frame. To lower the size, the images are then changed to grayscale versions. In order to have a single mean and variance, the output images are then normalized. Then, the input of the model in some of the approaches used in this research is the volume of the video, in which each volume contains 10 successive frames with different steps. Large amounts of training data are needed because this model has a lot of parameters. Therefore, to augment the length of the training dataset, the data in the time dimension is reinforced. To create this volume, the frames with step-1, step-2 and step-3 is connected [23].

### B. Evaluation Criteria

The presented methods in this research have been evaluated with some of the common methods that have been presented so far [30-38]. In order to evaluate the methods presented in the UCSD dataset, two criteria have been used to evaluate the accuracy of detecting the unusual behaviors: the pixel-level paragon also the frame-level paragon. The frame level paragon centralizes only on changes that predict which frame contains the unusual behavior without specifying where it occurs. A frame is regarded as abnormal by the frame-level paragon if it has at least one abnormal result and is not sensitive to the frame's location of the abnormal behavior. Also, the pixel level paragon is a measure that determines the temporal-spatial position of the frame. As mentioned, if at least 40% of the background pixels are correctly covered by pixels that the algorithm recognizes as unusual behavior, it will recognize that frame as unusual.

Then, by calculating the TP and FP rates, the ROC criterion can be obtained to analyze the algorithm's efficiency.

1) *Implementation Results:* As stated in the prior section, the images are selected at 100×100. Since none of the training videos in the Peds1 and Peds2 sets contains anomalies, half of the testing videos related to the Peds1 and Peds2 are randomly assigned for use in the training model. The remaining videos are used to test the samples. Each of the Peds1 and Peds2 are taught separately. 140248 normal samples and 35215 abnormal samples were extracted from the Peds1 set, and 63579 normal and 20638 abnormal samples were extracted from the Peds2 set.

Because abnormal samples are substantially fewer in number than normal samples, there may be an imbalance

problem in the class. To solve this problem by re-sampling, the number of the usual and unusual instances was tried to be in equilibrium. The presented method in this research is supported by a software interface called Keras [39], which supports the neural networks and convolutional using the Theano [40, 41] and TensorFlow software libraries [42]. This software interface is written in Python and can be run on CPU and GPU.

GHz Intel (R) Core (TM) i7 CPU and 8G RAM were used in the proposed approach. The convolutional network is implemented in GPU, and the graphic card used in this method is NVIDIA GEFORCE 840M. The results of the method are presented, as well as previous research, on Peds1 and Peds2 of the UCSD dataset in the following sections. The results obtained from the other methods are adapted from the relevant references in which these methods are introduced.

On the other hand, the system is trained by minimizing input volume renovation errors. The mini-batch with size 64 is used and every training session lasts up to 50 epochs or until the data validation loss stops after 10 successive epochs. The spatial encoder and decoder's activation function is chosen to be the hyperbolic tangent. Despite its ability to adjust, the re-modified linear unit (ReLU) is not used to verify the polarity of the encoding and decoding function since the activation values from ReLU are not very high. An example of the output and abnormal behaviors detected in the UCSD dataset is depicted in Fig. 6. This figure shows the output of identifying abnormal behaviors for the various methods presented in this study. Below, the results related to the error as well as the accuracy of the suggested methods are displayed. The methods presented in this research have been evaluated with some common methods presented so far [30-38, 43]The results related to the presented methods as well as previous studies, are displayed in Tables I and II of the UCSD dataset in Peds1 and Peds2, respectively.



Fig. 5. Examples of images in the UCSD dataset: The first row is Peds1, and the second is Peds2.

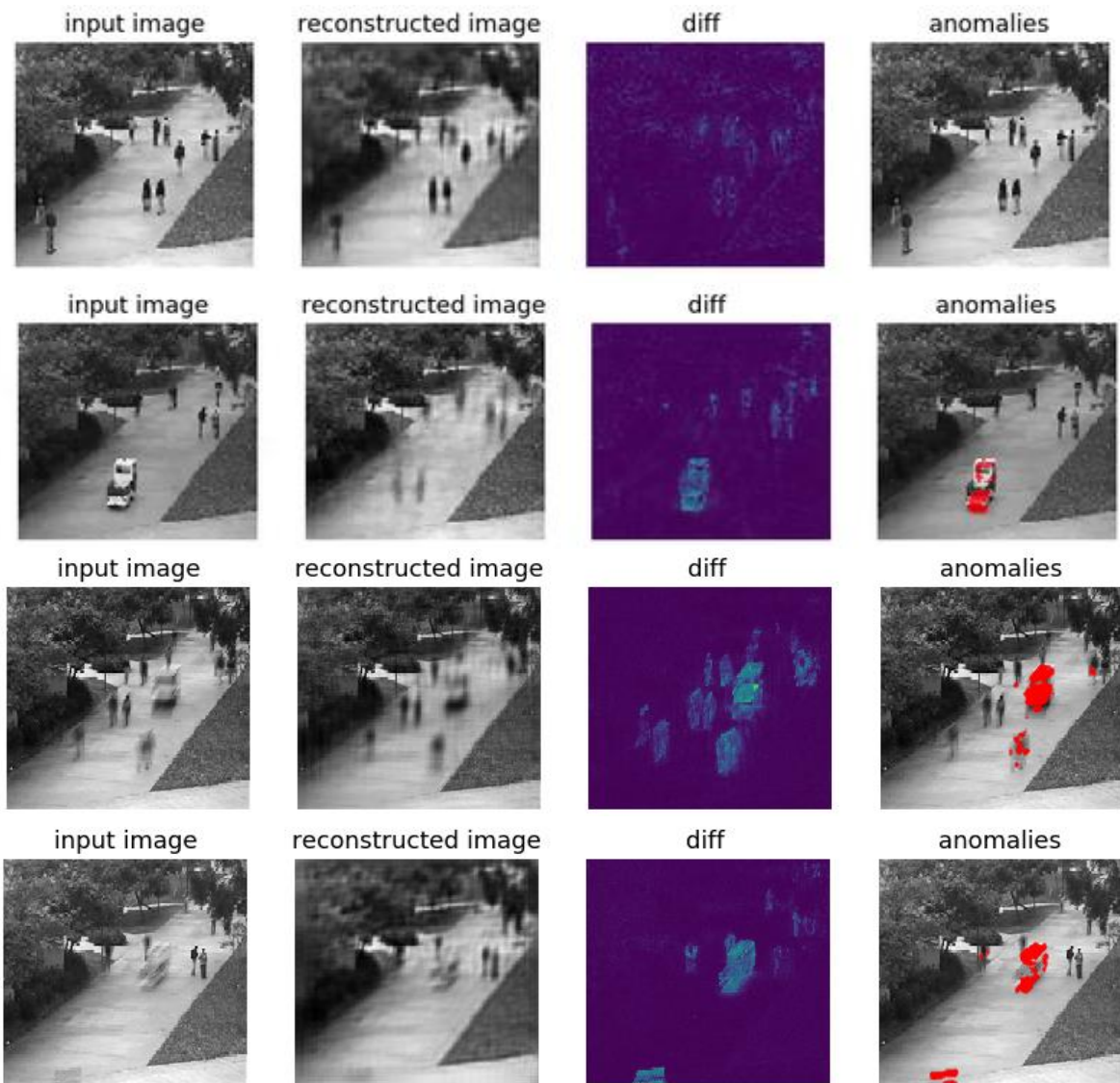


Fig. 6. Output of identifying abnormal behaviors for different methods.

TABLE I. ERR RATE IN THE PEDS1 SUBSET OF THE UCSD DATASET

Name of the author of the article	ERR rate at the pixel level	ERR rate at the frame level
Cheng et al. [31]	38.8	19.9
Cong et al. [32]	51.2	23
Adam [30]	38.9	23.6
Kim [35]	39.6	19.6
Kaltsa [34]	27	21.1
The first proposed method	49.7	33.1
The second proposed method	28.5	21.9
The third proposed method	27.5	21.1

TABLE II. ERR RATES IN THE PEDS2 SUBSET OF THE UCSD DATASET

Name of the author of the article	ERR rate at the pixel level	ERR rate at the frame level
Adam [30]	43.8	22.4
Kim [35]	31.1	22.4
Kaltsa [34]	26.9	25.1
The first proposed method	48.8	35.4
The second proposed method	27.9	20.2
The third proposed method	26.8	19.1



The first row is the output for standard automatic convolutional without the dense layer; the second row is the output for standard automatic convolutional with the dense layer; the third row is the output of temporal-spatial automatic convolutional; fourth row is the output for temporal-spatial automatic convolutional with LSTM.

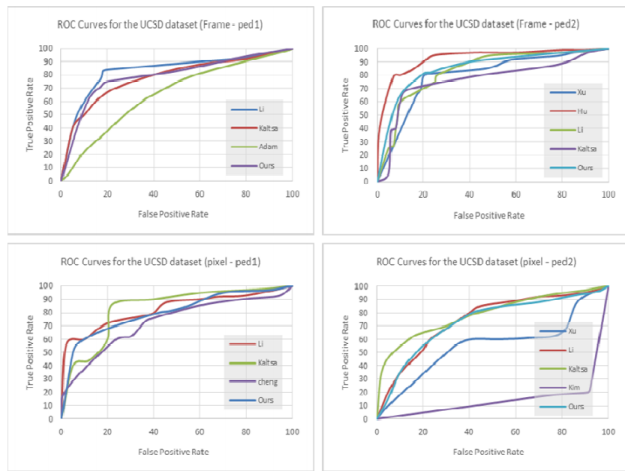


Fig. 7. UCSD dataset ROC curves at the pixel and frame levels.

The obtained results from the other methods are adapted from the relevant references in which these methods are introduced. The results of detecting abnormal behaviors are given in the figures presented above. The ROC curves in this dataset are reported in Fig. 7 for best presented method versus other methods. According to the image below, it can be seen that the presented methods have shown competitive performance in comparison with the previous methods presented in this field. In particular, the results obtained at the frame level in the proposed methods are very similar to the results of the best approaches introduced in this field. Compared to other methods, the suggested methods have a competitive efficiency at the pixel level. In general, it can be said that the methods presented in this study have a very competitive efficiency in the UCSD dataset with the results of other methods.

## V. CONCLUSIONS AND SUGGESTIONS

This study addresses the challenging issue of video anomaly recognition using deep learning. In this study, three approaches are presented. The anomaly detection is formulated as a distance detection problem in the spatio-temporal sequence. The best approach to solve this problem is to compound the ConvLSTM and the spatial feature extractor. In this approach, which works best, the ConvLSTM layer retains the benefits of FC-LSTM and is also appropriate for spatio-temporal data due to its inherent convolution structure. By using a spatial and temporal convolution feature extractor in the encoder-decoder structure, a trainable model has developed for detecting video anomalies. The presented models have the benefit of being semi-supervised; all that is required is a lengthy movie with just typical events in a still view. Notwithstanding the models' ability to detect unusual events and their power against existing noise, these methods might

produce more erroneous alarms than other techniques depending on how complicated the scene's activities are.

In the future, researchers can examine ways to improve the results of video anomaly recognition with active training; another direction is to consider using human feedback to update the trained model for better recognition and fewer false alarms. One solution is to add a monitored module to this system that will only work on the video segments that have been filtered by using the way which have described. After gathering enough video data, it trains a differential model for classifying the anomalies.

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# A Comprehensive Study of DCNN Algorithms-based Transfer Learning for Human Eye Cataract Detection

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**Abstract**—This study presents a comparative analysis of different deep convolutional neural network (DCNN) architectures, including VGG19, NASNet, ResNet50, and MobileNetV2, with and without data augmentation, for the automatic detection of cataracts in fundus images. Utilizing hybrid architecture models, namely ResNet50-NASNet and ResNet50-MobileNetV2, which combine two state-of-the-art DCNNs, this research demonstrates their superior performance. Specifically, MobileNetV2 and the combined ResNet50+MobileNetV2 outperform other models, achieving an impressive accuracy of 99.00%. By emphasizing the efficacy of diverse datasets and pre-processing techniques, as well as the potential of pretrained DCNN models, this study contributes to accurate cataract diagnosis. Furthermore, the proposed system has the potential to reduce reliance on ophthalmologists, decrease the cost of eye check-ups, and improve accessibility to eye care for a wider population. These findings showcase the successful application of deep learning and image processing techniques in the early detection and treatment of various medical conditions, including cataracts, addressing the needs of individuals with diminished vision through ocular images and innovative hybrid architectures.

**Keywords**—Cataract detection; eye disease; ocular images; deep convolutional neural network (DCNN); hybrid architecture

## I. INTRODUCTION

The eye is a crucial component of the human body, but conditions such as cataracts can impede its function. Cataracts are characterized by the formation of a cloudy, impenetrable layer on the eye, typically as a result of aging. This can lead to a variety of vision issues, including difficulties with tasks such as reading, driving, and recognizing people. According to a report by the World Health Organization (WHO), a staggering 2.2 billion individuals will be affected by blindness or visual impairments by the year 2025, with 1 billion of these cases predicted to be preventable. Cataracts are a significant contributor to this trend, with an estimated 40 million people expected to lose their sight due to this condition.

In Bangladesh, cataracts account for 80% of eye problems affecting individuals over 30 years old, with approximately 120,000 new cases reported each year. This issue is particularly prevalent in rural areas where access to medical services and ophthalmologists is limited, resulting in a high number of cases of blindness. Early detection of cataracts can prevent complete blindness, but current detection methods are costly and require an ophthalmologist. Therefore, there is a need to develop an automated cataract diagnosis system to reduce the burden on

medical professionals, lower costs, and make eye care more accessible to a wider population.

Automated systems for identifying and assessing cataracts have been a subject of research for many years. Despite previous studies analysing fundus images for cataract detection and classification, their suboptimal performance was attributed to limitations in feature extraction and pre-processing methods. To enhance the precision of deep learning models, an extensive literature review was conducted, evaluating various aspects including datasets, pre-processing techniques, feature extraction methods, feature selection criteria, classifiers, and models. Our findings revealed the potential of deep CNN architecture-based models using image processing methods for detecting cataracts on fundus images. Surprisingly, few studies have utilized DCNN architecture-based models with transfer learning for cataract detection. Many researchers have investigated the use of deep convolutional neural network-based architectures, including VGG19 [1-2] and ResNet [3], for the purpose of detecting cataracts. These architectures, which fall under the category of deep neural network-based architectures [4], have gained widespread recognition in the fields of computer vision and imaging due to their ability to efficiently tackle tasks such as segmentation, detection, classification, and image analysis [5]. They comprise multiple layers of information processing stages. To identify cataracts from fundus images, researchers have utilized pre-trained deep neural network models via transfer learning techniques [6]. Moreover, other models such as MobileNetV2 and NASNet can be employed for image classification tasks, and are also suitable for the purpose of cataract classification.

This study aims to bridge a research gap in the field of AI-assisted medical diagnosis by focusing on the application of deep learning and image processing techniques for the automatic detection of cataracts in ocular images. Unlike previous studies, this research provides a comparative analysis of model performance, specifically examining the impact of data augmentation on various Deep Convolutional Neural Networks (DCNNs). By employing the ResNet50-NASNet and ResNet50+ MobileNetV2 ensemble model, which combines two state-of-the-art DCNNs, this study achieves a higher accuracy rate in detecting cataracts while maintaining efficient image recognition and classification. Furthermore, the proposed system has the potential to reduce the dependence on ophthalmologists, decrease the cost of eye check-ups, and enhance accessibility to eye care for a wider population. These significant contributions shed light on the successful application of deep learning and image processing techniques

for the early detection and treatment of not only cataracts but also various other medical conditions.

The key contribution of this study can be summarized as follows:

- 1) Demonstrated the effectiveness of diverse datasets and pre-processing techniques in improving the accuracy of deep learning models in medical image analysis and classification.
- 2) Highlighted the potential of pre-trained DCNN models in accurately identifying cataracts in fundus images.
- 3) Showcased the benefits of hybrid architectures in enhancing the accuracy of medical image analysis and classification.
- 4) Provided insights into the impact of data augmentation on the performance of deep learning models in medical image analysis and classification.

The structure of this paper consists of four sections. Section I serves as an introduction, while Section II includes a review of related work and a literature review of the challenges. Section III provides an outline of the methodology and materials utilized in the research. In Section IV, the results and discussion of the study are presented. Section V lists the limitations and future work. Finally, Section VI contains the conclusion along with a list of references.

## II. LITERATURE REVIEW

The following section provides a comprehensive literature review on the subject matter, examining relevant studies and scholarly works. Weni et al. [7] proposed a CNN-based system for cataract classification achieving an accuracy of 97% in 50 epochs using a basic CNN architecture with ReLU and SoftMax activation. Hossain et al. [8] developed a ResNet50-based method for cataract detection in fundus images. Zhou et al. [9] used the DST method with residual network to minimize overfitting and memory shortage problems and employed the ResNet architecture for cataract detection and grading. Zhang et al. [10] provided a multi-model ensemble method for automatic cataract detection using ultrasound images and achieved the highest accuracy of 97.5%. Nihal et al. [11] addressed the issue of overfitting in large datasets by utilizing residual network architecture. VGG19, ResNet50, and Resnet101 models were employed in [12] and [13]. Neha et al. [14] proposed a multi-class, multi-label cataract detection system utilizing fundus images from publicly available and private datasets. Similarly, Lakshmi et al. [15] and Nadim et al. [16] utilized VGG16 for cataract detection. Conversely, Khan et al. [17] utilized transfer learning approach based on a VGG19-based CNN achieving an accuracy of 97.47%.

Table I provides a comprehensive overview of relevant studies, their methods, models and datasets utilized in the context of eye disease. Several studies have recently explored cutting-edge technologies aimed at improving accuracy and efficiency in different fields. Among them, four papers [28-31] stand out for their innovative approaches showcase the latest technologies, such as saliency detection networks, EMG signals, ant colony optimization, and graph-based extreme learning machines. In recent years, there has been a growing interest in combining machine learning algorithms with optimization techniques to enhance the accuracy and efficiency

of models. Several recent studies [32-37] have investigated the potential of such combinations, as highlighted in the literature.

TABLE I. LITERATURE REVIEW OF RELEVANT STUDIES

Paper	Objectives	Method	Dataset Type	Source
[18]	Detect Cataract and Identify the Severity	DCNN	Fundus Image	ODIR, Kaggle
[19]	Detect Cataract and Non-Cataract	ResNet50	Fundus Image	ODIR, Kaggle
[20]	Detect Cataract and Non-Cataract	Resnet with DST	Fundus Image	Private
[21]	Detect Cataract and Identify the Severity	DCNN	Fundus Image	Private
[22]	Eye Disease Detection	VGGNet	Fundus Image	ODIR, Kaggle
[23]	Detect Cataract and Non-Cataract	CNN, VGGNet	Fundus Image	Private
[24]	Eye Disease Detection	VGGNet, ResNet, AlexNet	Fundus Image	Private
[25]	Detect Cataract and Identify the Severity	VGGNet, ResNet, AlexNet	Fundus Image	Private
[26]	Eye Disease Detection	VGGNet	Fundus Image	ODIR, Kaggle
[27]	Eye Disease Detection	VGG16, EfficientNet, ResNet, MobileNetV2	Fundus Image	ODIR, Kaggle

## III. METHODOLOGY

This section describes the tools utilized in the data collection process, data analysis, and the proposed deep learning method for classifying cataracts, specifically a multi-layer neural network architecture. The model is capable of distinguishing cataracts from fundus images. The architecture of the proposed system is illustrated in Fig. 1. The framework of the cataract detection system comprises several steps, including image acquisition, preprocessing, model implementation, and performance analysis. These steps are thoroughly described in the subsequent sections.

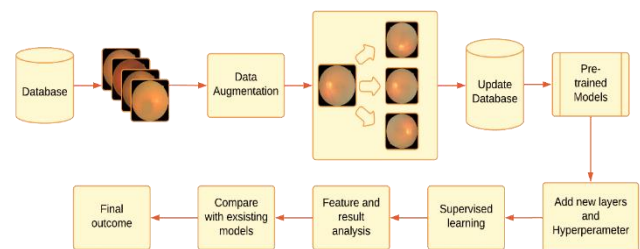


Fig. 1. Workflow of eye cataract detection.

### A. Dataset Properties

The present study utilized data collected from publicly available datasets, namely, the Ocular Disease Recognition [43] and Eye Diseases Classification [44], as well as datasets from Kaggle. Fig. 2 provides an overview of the dataset images used in the study. The figure presents a visual representation of the dataset, showcasing examples of fundus images included in the research. The aforementioned datasets comprised images of

normal and cataract eye conditions that were labeled by qualified authorities. The combined dataset utilized in this study included two classes, cataract and normal, and a total of 2000 images. The cataract class comprised 1000 images, while the normal class contained 1000 images that were appropriately labeled and split in a suitable ratio. In order to increase the amount of data in the dataset, image augmentation was applied. After augmentation, the total number of images in the dataset was increased to 5000. During the training phase, 80% of the data was utilized, with the remaining 20% reserved for the testing session. The combination of datasets and augmentation techniques utilized in this study provided a diverse and extensive dataset, which was utilized for the development and evaluation of an automated system for the recognition of cataracts in eye images.

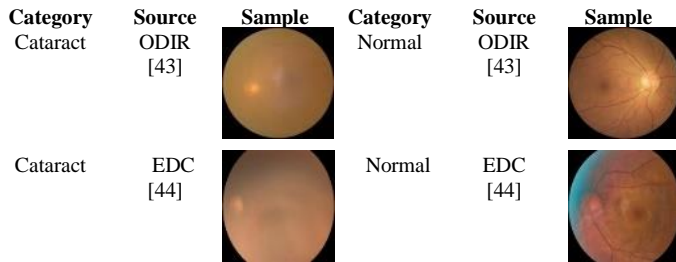


Fig. 2. Dataset image overview.

**B. Data Pre-Processing**

Multiple fundus image datasets were acquired, and a pre-processing pipeline was implemented to ensure consistency and enhance the quality of the data. Fig. 3 presents a step-by-step visualization of the data pre-processing methods used in the study. The images were selectively filtered to include only cataract and normal images, while excluding others such as diabetic retinopathy, hypertension, pathological myopia, glaucoma, age-related macular degeneration, among others.

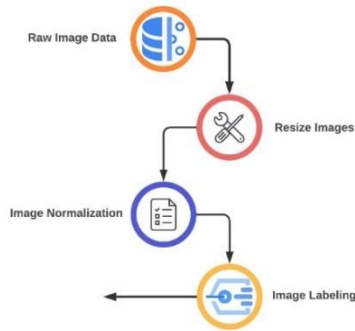


Fig. 3. Data pre-processing methods step by step.

To standardize the image sizes, the OpenCV library was utilized for resizing and normalization, involving subtracting the mean value from all pixels. Each image was appropriately labelled as either cataract or normal, and the dataset was then converted into an array format using NumPy, facilitating the subsequent training process.

To enhance the model's capacity to generalize to new images, augmentation techniques were applied, including

rotation and flipping. These techniques were implemented using the Keras framework [38]. Fig. 4 depicts the dataset splitting process employed in the study. The random augmentation process was applied to both the training and testing data to enhance the model's ability to learn with a larger dataset. The arguments used in the augmentation process are provided in Table II.

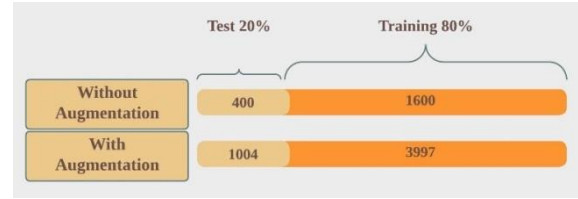


Fig. 4. Dataset splitting.

TABLE II. ARGUMENTATION FUNCTIONAL VALUE

Augmentation	Value
Rescale	1/0.255
Rotation	20
Flip	True

**Rescale:** Rescaling is a method of adjusting the range of values of a dataset by multiplying or dividing each value by a constant factor. It is commonly used in image processing, to standardize the data where pixel values are often represented as integers between 0 and 255, and rescaling the data can help to prevent overfitting and improve model's performance. Data augmentation rescaling by a factor of 1/.255 can be mathematically represented as:

Suppose, a 2D matrix

$$A = [[1, 0, 0], [0, 1, 0], [0, 0, 1]]$$

$$A\_scaled = A * (1/.255) \tag{1}$$

**Rotation:** Data augmentation rotation by 20 degrees can be mathematically represented as a matrix multiplication of the 2D matrix with the rotation value. Here,  $\theta$  is the data point after rotation.

Rotation value,

$$R = [[\cos(20), -\sin(20)], [\sin(20), \cos(20)]]$$

$$\theta = A * R \tag{2}$$

**Flipping:** Data augmentation with flip horizontal and flip vertical can mathematically be represented as a transformation matrix applied to each point in the image.

For flip horizontal, the transformation matrix value,

$$Fh = [[-1, 0, 0], [0, 1, 0], [0, 0, 1]]$$

$$A = A * Fh \tag{3}$$

For flip vertical, the transformation matrix value,

$$Fv = [[1, 0, 0], [0, -1, 0], [0, 0, 1]]$$

$$A = A * Fv \tag{4}$$

However, the testing data will also be used in conjunction with the first augmentation strategy. Fig. 4 illustrates the distribution of images in the test and train sets both before and after applying the augmentation techniques.

### C. Model Selection

In order to detect cataracts in fundus eye images obtained from ocular datasets, various model architectures were employed, namely VGG19, NASNet, ResNet50, and MobileNetV2. These architectures were selected to enhance the accuracy of cataract detection and improve the overall performance of the models. A detailed analysis of the method architecture is presented below for a better understanding.

1) *Visual geometry group architecture*: The Visual Geometry Group at the University of Oxford developed a CNN model called VGG19, known for its depth and use of small convolutional filters and max pooling layers [39]. In VGG19, feature maps are down-sampled by small 3x3 convolutional filters that focus on the most important features. To enhance the overall effectiveness of the model and address overfitting, we implemented several techniques, such as adding a dense layer with 512 neurons and a ReLU activation function, a dropout layer with a rate of 0.5, and a dense layer with 49 neurons and a sigmoid activation function. The model also includes a global average pooling layer, which reduces the spatial dimensions of the input by taking the average of the values in each channel, allowing the model to focus on the most important features and improve performance. Finally, we added a 1-unit dense layer with a sigmoid activation function [shown in Fig. 5(a)] to make the final prediction.

2) *Neural architecture search*: Neural Architecture Search (NAS) is a type of convolutional neural network developed by the Google Brain team [40]. The goal is to design an architecture with minimal human intervention and limited resources. In our study, we used a pre-trained NASNet model with ImageNet weights and added some additional layers. We introduced a fully connected layer architecture of 512 neurons with ReLU activation, followed by dropout with a rate of 0.5. Next, we added another fully connected layer of 49 neurons with sigmoid activation. We down-sampled the output using a 2D global max pooling layer and then extracted all-combinational features using a dense layer to make the final prediction [Fig. 5(b)].

3) *Residual network architecture*: The author in [41] is a convolutional neural network (CNN) developed by Microsoft Research, which has gained widespread popularity for image classification tasks. It is a deep neural network comprising 50 layers and is designed with a residual architecture. This model has produced outstanding results on various image classification tasks. It is referred to as a "residual" network due to its residual functions related to the input rather than learning the desired functions directly. This property enables the network to learn complex, highly non-linear functions more efficiently, resulting in much higher accuracy than traditional feedforward networks. In this study, we utilized the pre-trained ResNet50 model on ImageNet and added additional layers,

such as dropout with a rate of 0.5, a dense layer with 512 neurons, Global average pooling layers, and a single-node dense layer, as shown in Fig. 5(c).

4) *MobileNetV2*: [42] is an advanced neural network architecture designed to efficiently classify images on mobile and embedded devices. Developed by Google and introduced in their 2018 publication "MobileNetV2: Inverted Residuals and Linear Bottlenecks," this architecture represents an improved version of its predecessor, MobileNetV1. MobileNetV2 utilizes a combination of linear bottlenecks, inverted residual blocks, and short connection paths to reduce the number of computations required by the network. This results in a faster and more efficient model while maintaining a similar level of accuracy. Additionally, MobileNetV2 is highly versatile and can perform well on a variety of devices. It can easily be integrated with existing neural network architectures to build larger, more complex models. To further improve accuracy, we added some additional layers to the pretrained MobileNetV2 and fine-tuned it for cataract detection [Fig. 5(d)].

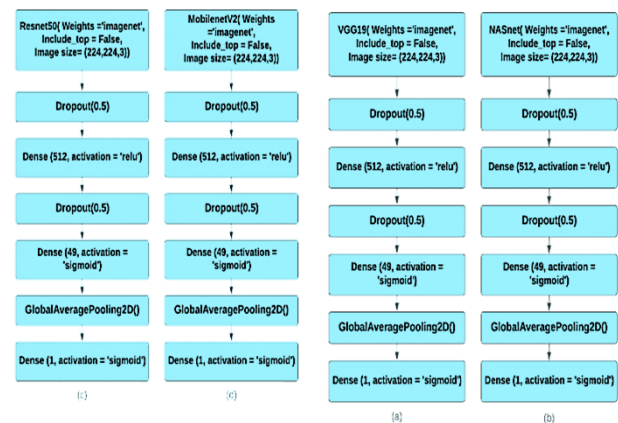


Fig. 5. Layer visualization of four different DCNN models.

5) *Ensemble learning with combined ResNet50+NASNet and ResNet50+MobileNetV2*: Ensemble learning is a popular technique in machine learning that combines multiple models to improve accuracy and reduce overfitting. Fig. 6 showcases the layer visualization of the ResNet50+NASNet hybrid deep convolutional neural network (DCNN). In this case, two powerful models, ResNet50+NASNet and ResNet50+MobileNetV2, are combined to create a hybrid model. By combining these models, the resulting hybrid model benefits from the strengths of each individual model, resulting in higher accuracy and robustness. Additionally, the non-trainable parameters in both models contribute to the overall performance by improving the generalization ability of the model. It is worth noting that the trainable parameters in both ResNet50+MobileNetV2 and ResNet50+NASNet are significantly lower than the total parameters, which is due to the use of transfer learning. It utilizes the strengths of each individual model and benefits from the non-trainable parameters to achieve state-of-the-art performance.



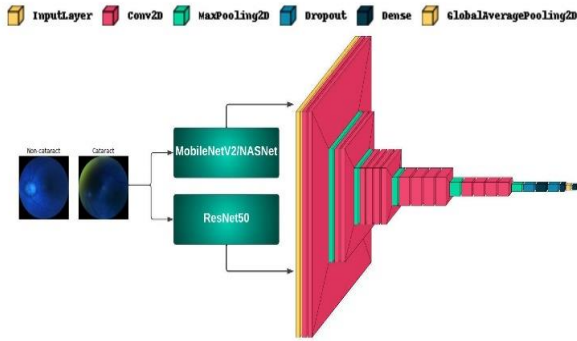


Fig. 6. Layer visualization ResNet50+NASNet hybrid DCNN.

#### D. Evaluation Metrics

This subsection elucidates the confusion metrics employed to gauge the efficiency of the models. The matrix provides insight into the number of true positives, true negatives, false positives, and false negatives, allowing for a more in-depth analysis of the model's strengths and weaknesses. Confusion matrix is widely used in various fields, such as medical diagnosis, fraud detection, and image classification, where the accuracy of the predictions is critical. By analyzing the confusion matrix, data scientists can identify the areas where the model is performing well and areas where it needs improvement, enabling them to fine-tune the model to achieve better results.

**Accuracy:** This is one of the evaluation metrics, represented by the ratio of correct prediction and the total predictions made.

$$\text{Accuracy} = (\text{TP} + \text{TN}) / (\text{TP} + \text{TN} + \text{FP} + \text{FN}) \quad (5)$$

**Sensitivity:** This metric is used to evaluate model performance by measuring its ability to detect positive prediction. It also called true positive rate (TPR) or recall.

$$\text{Sensitivity/Recall} = \text{TP} / (\text{TP} + \text{FN}) \quad (6)$$

**Specificity:** This metric calculate the percentage of true negatives which are actually negative. It can also be referred to as the True Negative Rate (TNR).

$$\text{Specificity} = \text{TN} / (\text{TN} + \text{FP}) \quad (7)$$

**Precision:** Precision is another evaluation element that calculates a model's performance by finding the ratio of Positives predictions and total number of Positives predictions. It measures the accuracy of positive predictions made by the model, particularly in the case of minority class predictions.

$$\text{Precision} = \text{TP} / (\text{TP} + \text{FP}) \quad (8)$$

**F1 score:** F1 score is an alternative evaluation metric that combines precision and recall scores to determine a model's accuracy. It is reliable when the classes in the dataset are balanced and have a similar number of data points.

$$\text{F1 score} = (2 \times \text{Precision} \times \text{Recall}) / (\text{Precision} + \text{Recall}) \quad (9)$$

#### E. Experimental Setting

During the experimental phase, the binary cross-entropy loss function and Adam optimizer were employed to train the

models. The batch size was set to 49, and the models underwent training for a duration of 15 epochs. The loss between the true and predicted labels was calculated throughout the training process to assess the model's performance. The execution environment for this experiment was Google Colab, which provided 25 GB of RAM but no GPU acceleration. The compiling parameters used in this experiment are summarized in Table III.

TABLE III. COMPILING EXPERIMENTAL SETUP PARAMETERS

Parameters	Value
Initial learning rate	1e-3
Optimizer	Adam
Loss	Binary cross-entropy
Epochs	15
Batch size	49
Executable Environment	Colab

#### IV. RESULT AND DISCUSSION

In this section, a comprehensive analysis and interpretation of the results obtained from the different models performed will be presented. The analysis will provide insights into the effectiveness of the models in the given task, and highlight the strengths and weaknesses of each approach. Additionally, the results will be evaluated using appropriate statistical methods to determine the level of significance and confidence in the findings.

The Tables IV and V represents the performance of Six different deep learning algorithms with and without data augmentation, namely VGG19, ResNet50, NASNet, MobileNetV2, and two combinations of ResNet50 with either NASNet or MobileNetV2, in terms of accuracy, specificity, sensitivity, F1 score, and precision. It can be observed from Table IV that MobileNetV2 achieved the highest accuracy score of 99.00%, followed closely by Combine ResNet50+MobileNetV2 with an accuracy of 98.75%. NASNet also performed well, achieving an accuracy of 98.50%. On the other hand, ResNet50 had the lowest accuracy among the algorithms, achieving only 72.50%. This indicates that ResNet50 may not be the most appropriate algorithm for the given task. However, it is important to note that accuracy alone may not be sufficient to evaluate the performance of these algorithms. Other metrics such as sensitivity, specificity, F1 score, and precision should also be considered for a more comprehensive understanding of their performance. Additionally, the choice of algorithm should be based on the specific requirements and constraints of the task at hand, such as computational cost, training time, and resource availability. Overall, based on the analysis of the provided table, it can be concluded that MobileNetV2 achieved the best performance in terms of accuracy, specificity, sensitivity, F1 score, and precision without data augmentation.



TABLE IV. PERFORMANCE OF THE DL ALGORITHMS WITHOUT DATA AUGMENTATION

Model	Accuracy	Specificity	Sensitivity	F1 score	Precision
VGG19	96.25%	95.48%	97.01%	96.30%	95.59%
ResNet50	72.50%	72.86%	72.14%	72.50%	72.86%
NASNet	98.50%	99.50%	97.51%	98.49%	99.49%
MobileNetV2	99.00%	99.50%	98.51%	99.00%	99.50%
Combine ResNet50+NASNet	97.75%	98.49%	97.01%	97.74%	98.48%
Combine ResNet50+MobileNetV2	98.75%	99.50%	98.01%	98.75%	99.49%

TABLE V. PERFORMANCE OF THE DL ALGORITHMS WITH DATA AUGMENTATION

Model	Accuracy	Specificity	Sensitivity	F1 score	Precision
VGG19	97.41%	98.01%	96.81%	97.39%	97.98%
ResNet50	88.65%	93.44%	83.83%	88.05%	92.72%
NASNet	98.51%	100.00%	97.01%	98.48%	100.00%
MobileNetV2	98.61%	99.80%	97.41%	98.59%	99.80%
Combine ResNet50+NASNet	97.81%	100.00%	95.61%	97.76%	100.00%
Combine ResNet50+MobileNetV2	99.00%	99.60%	98.40%	99.00%	99.60%

From the accuracy metric, it can be seen in Table V that MobileNetV2 performed with an accuracy score of 98.61%, followed by NASNet with an accuracy of 98.51% and Combine ResNet50+MobileNetV2 performed best with an accuracy of 99.00% with data augmentations. ResNet50 performed poorly with an accuracy of only 88.65%. The specificity metric shows how well the models can identify true negatives. It can be observed that all models except ResNet50 achieved high specificity scores, with NASNet and the combined models achieving a perfect score of 100%. The sensitivity metric shows how well the models can identify true positives. MobileNetV2 had sensitivity score of 97.41%, followed by Combine ResNet50+MobileNetV2 had the highest with a score of 98.40%. ResNet50 had the lowest sensitivity score of 83.83%. The F1 score, which is the harmonic mean of precision and recall, provides a balance between the two metrics. It can be seen that all models except ResNet50 achieved high F1 scores, the combined ResNet50+MobileNetV2 model achieving a perfect score 99.00%. Finally, the precision metric shows how well the models can avoid false positives. All models except ResNet50 achieved high precision scores, with NASNet and the combined ResNet50+NASNet model achieving a perfect score of 100%.

The provided Fig. 7(a-f) displays plots that depict the relationship between the training and validation accuracy of each deep learning model without data augmentation. The

graphs illustrate how the accuracy of each model changes as the number of epochs increase during the training process. It can be observed that for some models, such as MobileNetV2 and NASNet, the validation accuracy increases in a consistent and linear manner with the training accuracy. However, for other models such as ResNet50, the validation accuracy starts to plateau while the training accuracy continues to increase. These plots provide valuable insights into how each model performs during training and can be useful for further model optimization.

Fig. 8(a-f) displays plots that exhibit the relationship between the training and validation loss of each deep learning model without data augmentation. The plots demonstrate varying behaviors of the models during training, where some models exhibit a consistent and linear decrease in both training and validation loss, while others experience a plateau in validation loss and a continued decrease in training loss. These plots provide valuable information on the convergence properties of each model and can be used for optimizing the models' performance. Furthermore, analyzing the loss function during the training phase is a common technique used in evaluating the effectiveness of deep learning models, and these plots can provide insights into the models' learning dynamics.

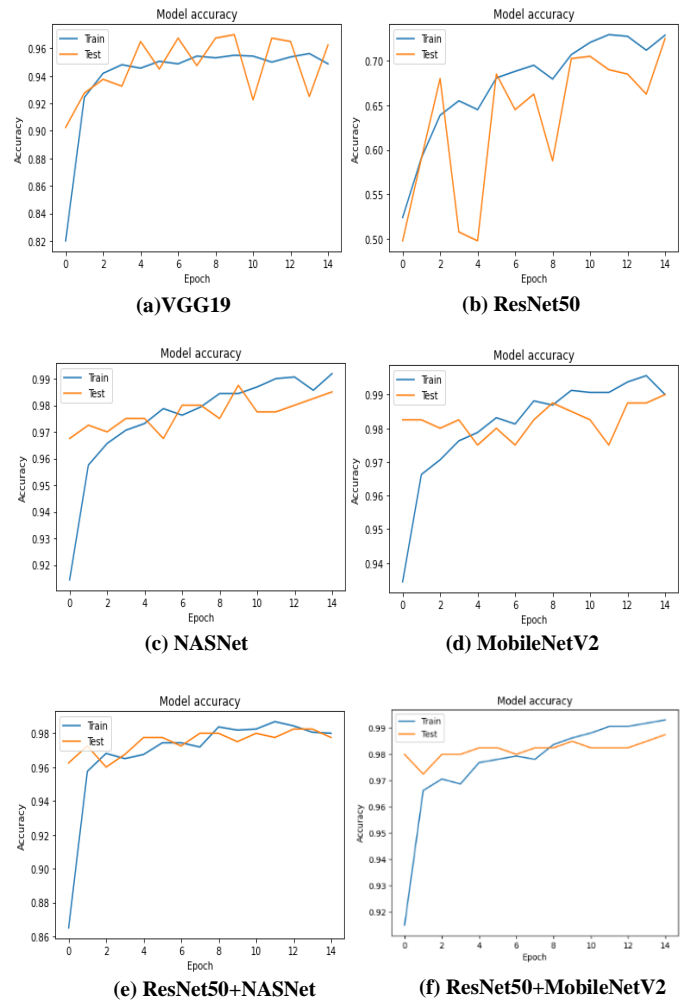


Fig. 7. (a-f) Plot showing the relationship between each deep learning model's training & validation accuracy without data augmentation.

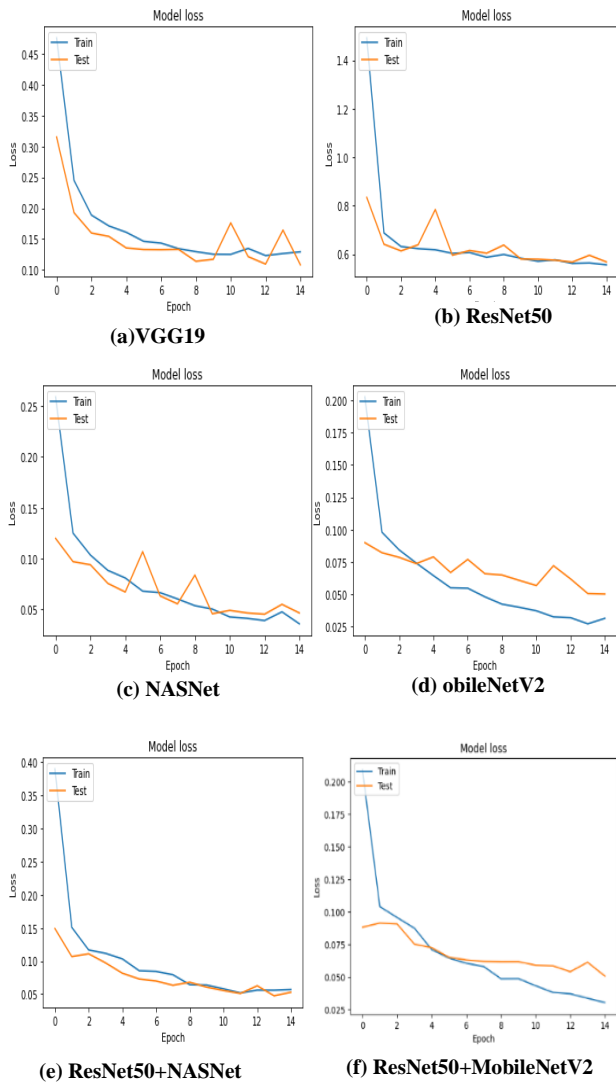


Fig. 8. (a-f) Plot showing the relationship between each deep learning model's training & validation loss without data augmentation.

Fig. 9 and 10 present plots that illustrate the relationship between the training and validation accuracy (Fig. 9) and training and validation loss (Fig. 10) of each deep learning model with data augmentation. Comparing the results of the two Fig. with those without data augmentation (Fig. 7 and 8) provides insights into the impact of data augmentation on model performance. The graphs in Fig. 9 show an overall improvement in the training and validation accuracy of all models with data augmentation, where the gap between the two accuracies is smaller compared to the previous figure. Moreover, the models' accuracy tends to increase faster during the initial epochs of training. In Fig. 10, the behaviors of the models' training and validation loss is similar to that without data augmentation, although the loss values are slightly higher. This observation suggests that data augmentation can help to improve model accuracy without increasing overfitting.

Overall, the comparative analysis of Fig. 7 and 8 with Fig. 9 and 10 suggests that data augmentation can help to enhance the performance of deep learning models in image

classification tasks. By introducing variations in the training data, data augmentation can help models to generalize better to new data and improve their accuracy. Furthermore, analyzing the changes in the loss function and accuracy during the training process with and without data augmentation can provide useful insights into the learning dynamics of deep learning models and can guide model selection and optimization.

The comparison of accuracy between deep learning architectures with and without data augmentation highlights a significant improvement in performance when augmentation techniques are applied. The combined ResNet50+MobileNetV2 model achieved the highest accuracy of 99.00% with augmentation, while without augmentation; the accuracy was slightly lower at 98.75%. Notably, ResNet50 demonstrated a substantial increase in accuracy with augmentation, scoring 88.65% compared to 72.50% without augmentation. Fig. 11 visually represents this comparative performance, emphasizing the positive impact of data augmentation techniques on the accuracy and effectiveness of deep learning architectures. These findings affirm the benefits of employing augmentation techniques for improved model performance in image classification tasks.

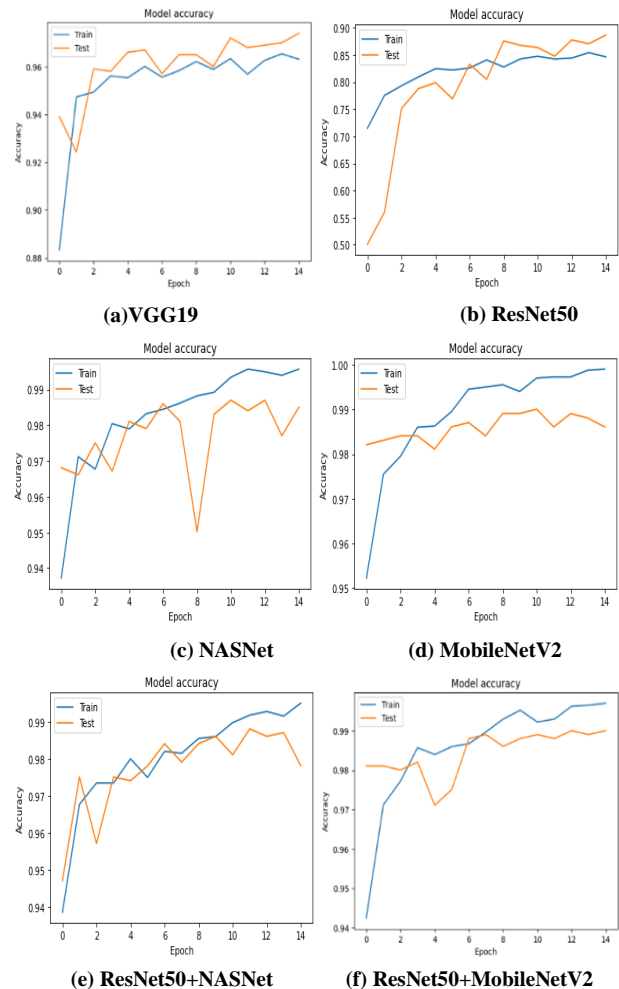


Fig. 9. (a-f) Plot showing the relationship between each deep learning model's training & validation accuracy with data augmentation.

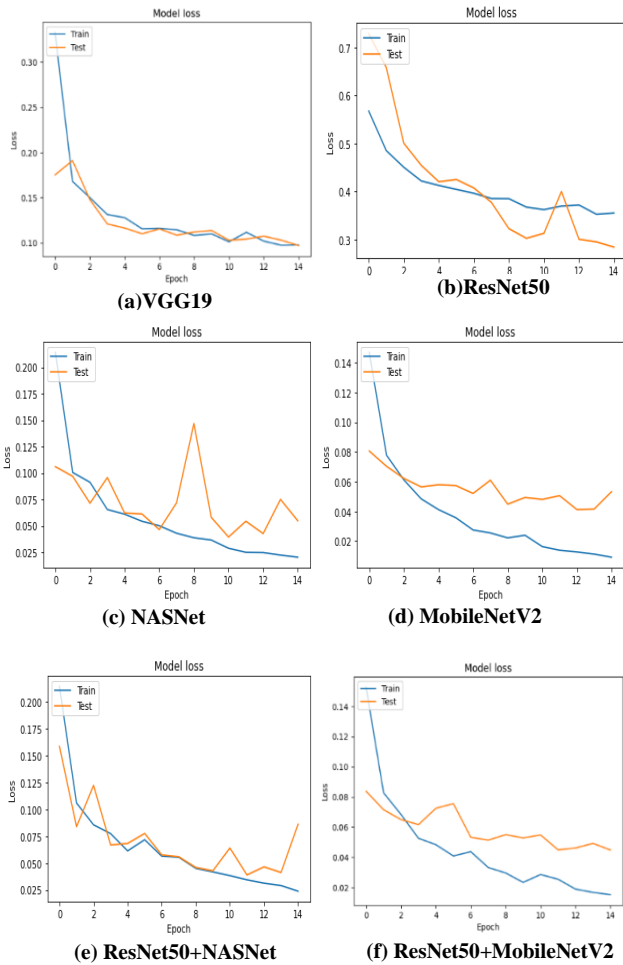


Fig. 10. (a-f) Plot showing the relationship between each deep learning models training & validation loss with data augmentation.

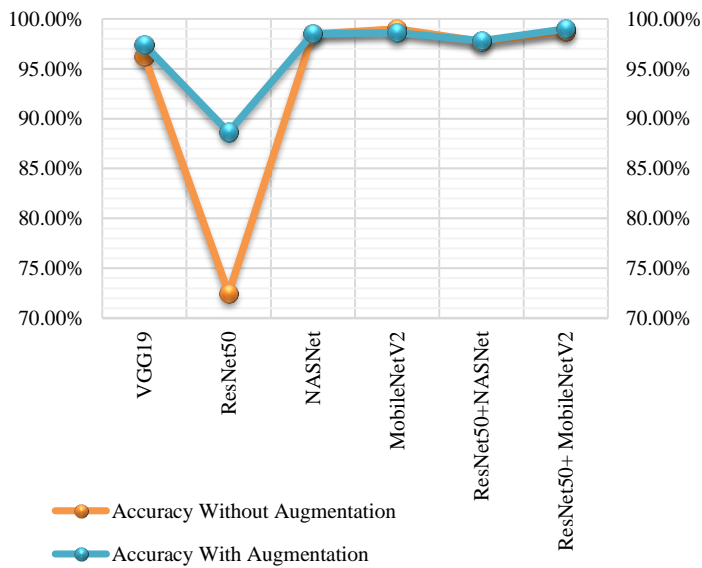


Fig. 11. Comparative performance of DL architectures with and without data augmentation.

## V. STUDY LIMITATIONS AND SCOPE FOR FUTURE RESEARCH

Despite our efforts to conduct a comprehensive study, it is important to acknowledge certain limitations that should be taken into consideration when interpreting the results. First, the sample size in our study was relatively small, which may limit the generalizability of the findings. Additionally, the study was conducted within a specific geographic region, and the results may not be applicable to other populations or settings. Moreover, the data collection process relied on self-report measures, which may introduce response biases or inaccuracies. Lastly, the study design was cross-sectional, which limits our ability to establish causal relationships between variables.

Our study has opened up several avenues for future research in this field. Firstly, future studies could consider employing a larger and more diverse sample to enhance the external validity of the findings. Longitudinal studies could be conducted to explore the causal relationships between the variables of interest. Additionally, conducting similar research in different geographic regions or cultural contexts could provide valuable insights into the generalizability of the results. Furthermore, incorporating objective measures or alternative data collection methods would enhance the reliability and validity of the findings. Lastly, exploring the effectiveness of intervention programs or strategies targeting the identified variables could be an important area for future research.

## VI. CONCLUSION

Various deep convolutional neural network architectures were compared with transfer learning for the accurate classification of fundus images for cataract diagnosis. This study demonstrates the efficacy of deep convolutional neural network (DCNN) architectures for automatic cataract detection in fundus images. Specifically, MobileNetV2 and the combined ResNet50+MobileNetV2 models exhibit superior performance, achieving an impressive accuracy of 99.00%. The utilization of diverse datasets, data augmentation, and hybrid architecture models, such as ResNet50-NASNet and ResNet50+MobileNetV2, contributes to accurate cataract diagnosis. The findings highlight the potential of deep learning and image processing techniques in early detection and treatment of medical conditions, particularly cataracts. Furthermore, the proposed system shows promise in reducing the reliance on ophthalmologists, decreasing the cost of eye check-ups, and improving access to eye care for a wider population. This research underscores the successful application of innovative hybrid architectures and emphasizes the importance of leveraging pretrained DCNN models for accurate and efficient cataract diagnosis.

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# System Dynamics Approach in Supporting The Achievement of The Sustainable Development on MSMEs: A Collection of Case Studies

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**Abstract**—Sustainable development in MSMEs is very important to encourage economic growth, improve the welfare of people, and ensure environmental sustainability. However, achieving sustainability in the MSME sector faces many challenges due to the complex interdependencies and dynamic interactions among various factors. The system dynamics approach makes it possible to model and simulate dynamic feedback loops, time delays, and nonlinear relationships between these factors. This paper provides an overview of the system dynamics approach and its suitability to address the complexities inherent in the MSME sector in its application to sustainable development. It explores the issues faced by MSMEs in achieving sustainable development and how the system dynamics approach models and analyzes the behavior of these MSMEs. These issues cover the dimensions of product development, technology and ICT inclusion, supply chain, business development, financial resources, and organizational support. This study was conducted on several case studies from various industries, namely the steel industry, agro-industry, craft industry, tourism industry, plastic molding, manufacturing, cosmetics, and digital companies; who come from various countries. From this study it was concluded that the system dynamics approach has significant potential to support the achievement of sustainable development in MSMEs, because it allows MSMEs to be able to effectively model and simulate the behavior of various factors that affect their operations, such as resource allocation, environmental impacts, and social considerations; proactively addressing sustainability challenges, adapting to changing market conditions, and contributing to broader socio-economic and environmental objectives.

**Keywords**—System dynamics; sustainable development; Micro Small and Medium Enterprises (MSMEs)

## I. INTRODUCTION

The agreement of the agenda on Sustainable Development Goals (SDGs) 2030 which aims to end poverty, social inequality, and protect the environment represented by three pillars namely economic growth, social inclusion, and environmental protection is still being pursued and implemented. One of the SDGs adopted by the United Nations which is goal 8 relating to decent work and economic growth, aims to promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. This goal aims to promote development-oriented policies that support productive activities, decent job creation,

entrepreneurship, creativity, and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services.

Micro-, small- and medium-sized enterprises (MSMEs) are drivers of economic growth in many countries [1]. MSMEs have a very important role in economic development as a significant contributor to gross domestic production (GDP) and job creation [2]. Because the existence of MSMEs has a positive influence on development, the sustainability of MSMEs needs to be maintained, especially by the government. The factors that influence the sustainability of MSMEs are different, depending on the point of view of each institution.

The concept of sustainability is interpreted as a socio-ecological process that takes place dynamically and continuously, resulting in a system that works and can be applied for the long term; where the underlying thing is the concern of all parties about efforts to improve the quality of human life, to efforts to change behavior to meet sustainable living needs not only for the present but also for the future, especially related to the problem of worsening natural damage.

Sustainable development is an abstract idea with complex and involving goals in various aspects. Because MSMEs and their sustainable development are complex systems and involve many stakeholders and perspectives in seeing how MSMEs are affected and what variables influence them, it is necessary to map the complexity of the system comprehensively from a macro perspective. Knowing this complexity requires a tool and understanding of sustainable development. One tool that can be used to formulate and model sustainable development is a system dynamics approach. This approach is widely used because it can provide an overview of real-world phenomena and the interrelationships of various elements of the dynamic variable. By understanding the complex dynamics of MSMEs that are influenced by various interrelated factors such as market conditions, economic policies, and social dynamics; the system dynamics approach provides a structured framework for understanding and modeling these complex dynamics, helping stakeholders gain insight into MSME behavior and sustainability challenges. Sustainable development in MSMEs often involves handling feedback loops which can lead to a strengthening or balancing effect. System Dynamics can help identify and mitigate reinforcement loops that perpetuate unsustainable practices or amplify negative impacts. On the



other hand, System dynamics can also identify counterbalance loops that promote sustainable behavior and ensure long-term viability. The System Dynamics model can highlight points of influence where interventions can be strategically implemented to achieve sustainable development in MSMEs. By simulating various scenarios and analyzing the impact of interventions on system behavior, decision-makers can prioritize and design effective policies, practices, and interventions that lead to positive results. In addition to providing an analysis of long-term effects, System Dynamics can also provide an analysis of delays in achieving sustainable results. This capability helps MSMEs and policymakers evaluate the potential consequences of decisions and policies taken so that new scenario analyses and simulations can be carried out to identify strategies that can balance short-term and long-term goals.

Based on the complexity that exists in MSMEs and the capabilities that can be provided by system dynamics, the authors conducted a review of the existing literature related to the application of system dynamics in the MSME sector. This study is expected to provide insights to support sustainable development in MSMEs by focusing on understanding complex interactions, identifying points of influence for positive change, analyzing long-term effects, assessing policy interventions, promoting learning and capacity building, and increasing collaboration between stakeholders. In this paper, two terms are used in mentioning the object of study, namely Micro, Small, and Medium Enterprises (MSMEs) and Small and Medium Enterprises (SMEs) with the same purpose. The use of each term will be based on the literature studied.

## II. SUSTAINABLE DEVELOPMENT AND SDGs OVERVIEW

### A. Sustainable Development

Sustainable development is a concept that refers to meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. It is based on the idea of balancing economic growth, social well-being, and environmental protection, to create a better future for all. Sustainable development involves a long-term approach to decision-making that takes into account the social, economic, and environmental impacts of policies and practices. It recognizes that economic growth is necessary for human development, but that it must be pursued in a way that is socially inclusive and environmentally sustainable.

Achieving sustainable development requires collaboration between governments, civil society, and the private sector. It involves making choices that promote economic, social, and environmental sustainability, and that are based on an understanding of the interconnectedness of these three areas.

### B. Sustainable Development Goals (SDGs)

The United Nations has played a key role in promoting sustainable development through the adoption of the Sustainable Development Goals (SDGs) in 2015. The SDGs are a set of 17 goals and 169 targets that aim to end poverty, protect the planet, and ensure prosperity for all. The 17 SDGs cover a range of economic, social, and environmental issues, including poverty; hunger; health; education; gender equality; clean water and sanitation; affordable and clean energy; decent work and economic growth; industry, innovation, and

infrastructure; reduced inequalities; sustainable cities and communities; responsible consumption and production; climate action; life below water; life on land; peace, justice, and strong institutions; and partnerships for the goals.

The SDGs are designed to be universal and apply to all countries, regardless of their level of development or income. They are also intended to be integrated and interconnected, recognizing that progress in one area can have positive or negative impacts on other areas.

Achieving the SDGs requires action at all levels, from local to global, and involves a range of stakeholders, including governments, civil society, the private sector, and individuals. The SDGs provide a shared vision, roadmap, and comprehensive framework for achieving sustainable development, and represent an important opportunity to address the most pressing of world challenges, including poverty, inequality, and climate change.

## III. SYSTEM DYNAMICS OVERVIEW

System dynamics models typically use stocks and flow to represent the accumulation and flow of resources or information within a system. They also incorporate feedback loops, which are the interactions between different components of the system that influence each other's behavior over time.

System dynamics refers to the study of the behavior of complex systems over time. System dynamics was first built by Forrester in 1969 with the aim of building models that can understand complex systems and states [3]. With system dynamics, we can analyze complex systems in a simpler way to get a complete system understanding, based on boundaries and scope discussion. Systems dynamics has been applied to various fields, including business management, engineering, environmental science, and public policy.

System dynamics involves building a computer model of a system that incorporates key components (i.e. stock and flow), relationships, and feedback loops. This model can be used to simulate system behavior over time and test various scenarios and policies. Data in system dynamics is not only in quantitative form but can also be in qualitative form, because some of the variables considered in the model may not be in quantitative form. System dynamics can facilitate qualitative forms by using dummies (quantifying qualitative data).

One of the key strengths of system dynamics is its ability to capture the nonlinear and dynamic nature of many real-world systems and to identify the underlying causes of persistent problems or unexpected outcomes. System dynamics models can help decision-makers to better understand the complexities of the systems they are dealing with and to make more informed and effective decisions based on data-driven insights.

## IV. MICRO, SMALL, AND MEDIUM ENTERPRISES OVERVIEW

Micro, Small, and Medium Enterprises (MSMEs) are important drivers of innovation and economic growth, and they can be a source of employment and income for low-skilled workers and marginalized groups. In recent years, there has been increasing recognition of the importance of supporting the development of MSMEs, particularly in developing countries

where they can play a critical role in poverty reduction and sustainable development. Governments, development agencies, and other stakeholders are working to provide MSMEs with access to finance, technical assistance, and other resources to support their growth and development.

Small and Medium Enterprises (SMEs) are entities that can support the economic development of a country [4], [5]. Meanwhile, specifically for developing countries, the context of Micro, Small, and Medium Enterprises (MSMEs) is more widely used because micro-enterprises continue to increase from time to time [1]. Based on EU recommendation, the European Commission defines micro, small, and medium enterprises based on several main factors namely the number of employees (staff headcount), sales (turnover), and profit (balance sheet total). A micro business is a company that has less than 10 employees, sales, and profit of at most EUR 2 million. While small business is a company that has employees less than 50 people, sales and profit of at most EUR 10 million per year. Finally, medium-sized businesses have fewer than 250 employees, and sales of at most EUR 50 million or EUR 43 million of profit per year. If the company has a larger amount than this provision, it can be categorized as a large company.

MSMEs have a critical role to play in achieving the SDGs, as they are a major source of employment and economic growth in many countries. However, they also face significant challenges in adopting sustainable business practices and contributing to the achievement of the SDGs. Efforts to support MSMEs in achieving sustainable development can help to accelerate progress towards the SDGs and promote a more inclusive and sustainable global economy.

### V. DISCUSSION ON SYSTEM DYNAMICS AND MSMEs

In the context of MSMEs (Micro, Small, and Medium Enterprises), system dynamics can help business owners and managers to understand the interdependencies between various components of their organization and how they interact over time. System dynamics can be used in MSMEs to model the behavior of the business and identify potential problems or opportunities. By analyzing the behavior of the business over time, system dynamics can also help MSMEs to identify areas where they can improve efficiency and performance.

Table I provides an overview of system dynamics applications in MSMEs/SMEs. The industries included are the steel industry, agro-industry, manufacturing, cosmetics, craft, plastic molding, and other non-categorized industries. The year represents the date of publication, so it may differ from the year the study was conducted. It shows that using system dynamics for sustainable development started many years ago and is still relevant today. The column 'Main Goals' shows the main purpose of using system dynamics for each study. The sections that follow are summaries of each of the studies and their implementation of the system dynamics approach.

#### A. Product Development

Improve product development planning is recommended as one of the strategies to support company performance. Based on that, research [6] identifies and analyzes the factors that influence the advantages and product development success in

the steel industry in Iran. The steel industry has a dynamic development structure because there are dynamics in the interrelationships between the elements that influence the quality and success of SMEs in this sector. Therefore, companies need to adopt an all-encompassing strategy related to creating and maintaining collaboration rather than concentrating on a single issue. Using system dynamics techniques in this study, it was found that the factors which influence the success and excellence of SMEs in the steel industry are organizational, managerial, human, marketing, and environmental factors. The interrelationships between variables commitment, mutual trust, and satisfaction in collaboration play an important role in the success and excellence of small and medium enterprises in the steel industry. The consequence is companies must be able to choose the right and compatible partners in terms of sales markets and work activities within the company structure to minimize non-functional conflicts.

TABLE I. APPLICATIONS OF SYSTEM DYNAMICS ON MSMEs/SMEs

Sector	Case	Paper	Year	Main Goals
Product development	Steel industry	[6]	In press	Product development
Technology - ICT	South African SMEs	[7]	2021	Digitalization
	Indonesian MSMEs	[1]	2019	Digitalization
	SMEs	[8]	2022	Digitalization
	SMEs	[9]	2019	Building Information Modeling (BIM) adoption
	SMEs	[11]	2019	Mobile analytics adoption
Supply chain	Malaysian agroindustry	[12]	2018	Performance measurement
	Indonesian agroindustry	[13]	2019	Performance measurement
	Agri-food SMEs in Kunming, China	[14]	2020	Home delivery agri-food supply chain
Business development	Manufacturing companies	[15]	2019	Crisis management
	Cosmetic company	[16]	2021	Sustainable strategy
	WoC-owned SMEs in the US	[17]	2022	Business sustainability
	Indonesian craft industry	[18]	2019	Business sustainability
	Plastic molding industry	[19]	2020	Risk management
	Digital companies	[20]	2021	Business model innovation
	Iranian SMEs	[21]	2019	Increased ROI
	Iranian SMEs	[22]	2021	Business management
Finance	Indonesian SMEs	[23]	2022	Bankability
	Malaysian SMEs	[24]	2018	Financial risk
Organizational	Mexican tourism industry	[25]	2023	Organizational resilience
	Developing country SMEs	[26]	2018	Industrial clustering

## B. Technology – ICT

In this era, digitalization is becoming increasingly important for micro, small, and medium enterprises (MSMEs) to remain competitive and relevant in a fast-paced business environment. Process transformation involves many interrelated variables, and digitalization is no different. To make it easier for SMEs to navigate, a model was developed using the case of SMEs in South Africa to understand the complexity and management of digitization [7]. This model uses a system dynamics approach by considering the dynamic interactions between the determining variables which are productivity, finance, and skill of the workforce. Productivity is shown by the Labor Productivity Factor which refers to the percentage of the number of skilled workers, skill of the workforce is divided into skilled workers and unskilled workers, and finance is represented by the flow variable, namely the expenditure variable which is the result of calculations from sales, marketing costs, digitization costs, and wastage contingency. The developed model provides knowledge that digitalization has an impact on increasing sustainability performance; this condition demands the need for digital empowerment. Besides that, efficient process control with the right technology, especially for a large enough scale of operation, requires automation to avoid unexpected things.

The process of digitizing MSMEs is complex and requires a holistic approach that considers various factors, one of which is the adoption of technology such as ICT inclusion. Reference [1] conducted research using a system dynamics approach in building MSMEs models with the involvement of ICT to increase MSMEs income, based on case studies in Indonesia. Because this is a macroscopic model, aspects other than ICT are also included, namely aspects of the market, MSMEs business stocks, government, and financing, which are considered to affect the increase in MSMEs income. From the causal loop diagram they developed, it is known that the ICT aspect is seen from the type of MSMEs whether it is micro, small, or medium level. For all levels, ICT capabilities are influenced by three components, namely digital operations, internet users, and e-banking services. Because ICT is an investment and is a long-term commitment, ICT inclusion requires adequate financial support from various parties, it can be personal, the government, or other parties funding. This means that the ICT capability at each level of MSME is influenced by these funding sources; as previously stated that ICT inclusion is aimed at increasing MSMEs income. Income is represented by the number of orders which is one of the variables in the market aspect. This linkage means that the more orders, the income of MSMEs business will be higher. Where each type of MSMEs business has its level of ICT capability, the number of orders will also be influenced by the MSMEs ICT capability itself. Meanwhile, the MSMEs business stocks and government aspects do not have a direct relationship with ICT aspects but are connected with market and funding aspects. From this model, the recommendation given is the need to increase the level of ICT capability in each type of MSME to increase their income.

ICT forms the foundation for digital transformation by providing the infrastructure and capabilities an organization needs to digitize its operations while facilitating social

interaction, content sharing, and networking among users can be done using social media platforms. For businesses, social media in general can provide an avenue for companies to engage with customers, build communities, conduct market research, and promote their products and services, in other words increasing market share. To identify the interrelationships of variables to increase SME market share due to the involvement of social media platforms, [8] utilizes one of the social media that is Instagram to study it using a system dynamics approach. From the developed model it is known that to increase market share, it is also necessary to increase engagement. The scenario model shows that engagement increases after including Instagram (social media) features in the simulation model. The increasing trend is found in the number of new customers, total business sales, and profit value. In other words, the use of social media in this case Instagram, helps SMEs in increasing their market share. The Instagram features considered in the simulation model are the number of comments, saves, views, likes, followers, and posts. This means that engagement can be increased by increasing the number of posts and interactive activities and maximizing the usage of Instagram (social media) features.

In the construction industry, system dynamics is used to explore BIM adoption in SMEs in developing countries [9]. Building Information Modeling (BIM) is a digital technology that has revolutionized the construction industry by enabling the efficient planning, design, construction, and management of building and infrastructure projects. The main benefit of BIM for SMEs is in facilitating information management, communication, and collaboration between supply chain actors [10]. System dynamics in this study is used to understand the dynamics and challenges faced in BIM adoption. The two conceptual causal models developed show a causal relationship between BIM adoption behavior at the organizational/project level and the industry level. Awareness, management support, benefits, and costs of investing in BIM are variables influencing at the organizational level while awareness, organizations, benefits, and government are influencing variables at the industrial level. From system dynamics modeling, policy insights are obtained for better BIM adoption to be executed in practice in SMEs.

The development of new digital technology that continues to move increasingly has an impact on SMEs. Research methods carried out by SMEs have also begun to utilize information technology, one of which is mobile analytics. Mobile analytics uses data from mobile apps, mobile websites, and other mobile platforms to gain insight into user behavior, preferences, and trends. Research [11] conducted a study on the impact of mobile analytics for SMEs using system dynamics simulations. From the model simulation carried out, insight was obtained that mobile analytics is the main key to competitive advantage in SMEs. With mobile analytics, companies can survive data vulnerabilities and can access real data for better organizational decision-making, which will ultimately build an agile organization, because organizations already understand how users interact with their business, identify areas for improvement, and make data-driven decisions to optimize and drive their business.

### C. Supply Chain

Being in a dynamic and competitive business environment, small and medium enterprises (SMEs) need to measure their supply chain performance to evaluate their business activities. While it is known that most SMEs do not have an effective performance measurement system because they do not identify their internal strengths and weaknesses but instead focus on external opportunities and threats. Related to this interest, [12] proposes a system dynamics approach to identify the main drivers of supply chain performance, develop strategies for performance improvement, and measure the impact of strategies on overall supply chain performance; by using case studies on companies engaged in agro-based industries in Malaysia. By using a system dynamics approach to model how information, actions, and consequences interact to produce a dynamic behavior strategy, it is known that lead time, product quality, and availability are the three main sequences of a company's strategy in winning customers. Purchasing domestic raw materials and production quality will help reduce lead time by providing products at any time to meet customer demand. It is the main focus of a responsive supply chain because it will improve company performance. Therefore companies need to have good collaboration with their supply partners so that they can integrate well to improve on-time delivery. The use of IT in planning delivery activities from suppliers and deliveries to customers is also important in a responsive supply chain. IT will act as a driving force for collaboration, process integration, and delivery speed. To achieve this goal, it is necessary to build a good information technology structure to support corporate responsiveness so that it can identify changes in the needs and desires of customers and other parties.

The development of other supply chain performance measurement models was also carried out using the case of the passion fruit agroindustry in North Sumatra Province, Indonesia. Study [13] identifies the factors that influence the performance of the passion fruit agroindustry supply chain for the sustainability of MSMEs and designed a supply chain performance measurement model using a system dynamics approach. Behavior on supply chain performance in building the sustainability of passion fruit agroindustry MSMEs is expressed as an increase in farmer production and income; and manufacture of essences and syrups. The key variables of the model are proven to affect the performance of the passion fruit agro-industry supply chain used to design sustainable MSME supply chain development scenarios, namely farmer skill and availability of land. Passion fruit production rate is influenced by the skills of farmers. The higher the level of passion fruit production, the more is passion fruit collector. Increasing collector passion fruit will increase extract industry production. This condition will increase waste products that can be composted and sold to farmers. The higher the compost production, the higher the efficiency of using the compost turn will produce environmentally friendly products. The consequence is an increase in the carrying capacity of the environment will have an impact on the availability of passion fruit land. With increasing availability of passion fruit land then it will increase fruit production rates. In the end, this condition will increase the income of SMEs and build the sustainability of the industry.

The agri-food supply chain is a multifaceted system that involves the production, processing, distribution, and consumption of agricultural products. To navigate these complexities effectively, stakeholders within the industry recognize the need for collaboration and cooperation. This prompted the formation of an agri-food supply chain alliance. Related to this problem, [14] developed a system dynamics model to investigate the stability of the cooperation of a "home-delivery-oriented agri-food supply chain" (HASC) alliance using a case study of an alliance built by an agri-food company in Kunming. HASC is a concept defined as an agri-food supply chain based on an alliance structure and collaborative strategy, which organizes agri-food SMEs with various competencies in the agri-food e-commerce (AE) market to provide services in meeting the daily needs of customers through home delivery. The results of this study indicate that the performance of the HASC alliance concerning time showed significant variation initially, but gained stability with the implementation of an appropriate control strategy. There was a decrease in the stability of the alliance in the early stages due to the running-in process between members and the process of adaptation of the alliance system to its internal environment. The model simulation shows that the stability of the HASC alliance cooperation is very sensitive to performance regarding strategies that control customer and environmental variations. Trust and market fluctuations have a great effect on the stability of membership and relationships. It is necessary to pay attention and focus on increasing mutual trust among members and controlling market fluctuations to minimize the risk of local markets. The model simulation results also show that for the HASC alliance, higher control strategy costs do not guarantee better stability. Therefore, it is necessary to control costs within a certain range that can help the HASC alliance to maintain stability and performance.

### D. Business Development

Within the scope of MSMEs business development, a system dynamics perspective can be included in the enterprise life cycle, crisis management, resilience, and business continuity management. Research [15] presents an analysis of the factors that lead to crises in small and medium enterprises (SMEs) and proposes a system dynamics model to explain the phenomenon. The model provides knowledge by explaining the mechanism of how during the crisis in SMEs, system dynamics help to predict the impact of various possible managerial decisions. This study was conducted in the Czech Republic and the model developed for the case of manufacturing companies. In this study, the crisis is categorized into 19 aspects, namely employees; customers/demand; inputs and supplies; regulations–bureaucracy–taxes; collecting bills; competition; owners; financial capital; capacity; natural disasters; technical breakdown; selling prices; quality of production; entrepreneur–personal crisis; thefts; placement of business; processes; outdated product; and legal entity. These aspects were analyzed through three stages using descriptive statistics, cross-tabulation, and association rules mining. The results of the analysis show several patterns underlying the crisis. Crisis classification is divided into two, namely crises in the internal environment and the external environment. Crises in the internal environment are related to employees, capacity, and

quality of production, while those in the external environment are related to input and supply, customers, and competition. By using a system dynamics approach, they develop a model explaining the relationship between the variables of the number of production employees and labor market; production capacity; production; outsourced product; stock of finished products; product quality and claims; inputs and supplies (including limitations, purchasing prices); demand (related to the price offered, competition and quality of previous investments, delivery delays, R&D and marketing); orders and their fulfillment; and revenues, costs, and profits. By testing and analyzing crisis scenarios, managers will gain knowledge and insight into the variables that affect aspects of a crisis, can predict the impact, and be able to determine actions to anticipate or resolve the crisis. This indirectly encourages sustainable development for the company and its business activities.

The system dynamics approach is also used in the Cosmetics Small and Medium Industries to develop a sustainable industrial strategy model that uses a case study of a personal care cosmetic company in Indonesia [16]. This strategy model is built from the integration of the system dynamics method and the open innovation approach. In this case, system dynamics is used to explore the complexity of SME problems that involve factors, actors, and dynamic relationships that affect output performance. While the open innovation approach is used to provide effective strategic choices in increasing output performance, both in terms of manufacturing operations; and economic, environmental, and social indicators. There are three strategic scenarios considered, namely self-lean improvement, limited collaboration, and comprehensive collaboration. From the simulation, it is known that in the self-lean improvement strategy, the productivity and profitability ratio shows a downward trend, including a decrease in demand, as well as an insignificant increase in improvement to environmental damage and human health. While limited and comprehensive collaborations demonstrated improvements in general depreciation and costs; cost savings; increased productivity and profitability; and reduced environmental and human health impacts. Limited collaboration shows a flatter slope of improvement compared to comprehensive collaboration which gives the best results. Comprehensive stakeholder involvement in an open innovation community effectively supports the achievement of the sustainability goals of SMEs. This support includes technical assistance from research and academic institutions, engagement of suppliers and distributors in lean and green improvement, assistance from cosmetics associations, and financial support from the government. Without such support, it is difficult for SMEs to grow and achieve sustainability, because there is a portion that is difficult to fulfill by the company itself. This collaboration is one strategy suitable for dealing with complex and dynamic sustainability challenges, with the takeover of resource support by external parties.

Studies on women concerning SMEs have also been carried out using a system dynamics approach. Study [17] conducted research to uncover the challenges faced by women of color (WoC)-owned SMEs in the United States. This research is

based on the finding that the majority of SMEs belonging to WoC failed in the first years of its establishment. This research focuses on the success of entrepreneurs (number of people) not on business success (number of entities) because people's (entrepreneurs) success is defined as business sustainability or profitable monetization events. This study's findings from the developed model suggest that access to capital (financing), social networks, and education and training are crucial factors that impact the success of women of color-owned SMEs. The variables that play a role in this model are opportunity rate, necessity factor, and desired financing rate. The opportunity rate is the number of WoC candidates, and the necessity factor is the number of WoC that startups out of need rather than an opportunity; which of these two variables will have an impact on the stock of aspiring WoC entrepreneurs. Meanwhile, the desired financing rate is the target as a goal gap modeling archetype which will affect the flow rate, namely the financing rate variable. The emphasis on these interventions as early as possible is intended so that WoC SMEs can survive in the early years of their establishment which is ultimately the sustainability of their business can be maintained.

The importance of the craft industry and its contribution to economic development and job creation prompted [18] to research the dynamics of budget allocation competition in this sector. This study uses the case of the craft industry in Indonesia and the system dynamics (SD) approach supported by the Balanced Scoreboard (BSC) framework and the ARCH-type model Success to Successful (StoS) approach. At the SD model development stage, the BSC framework is used as the basic development framework and the StoS approach of the ARCH-type model is used as a problem-solving concept. The system dynamics approach is used to model the interaction of the variables from the craft industry system, with budget allocations. From the model simulation, it is known that the budget allocation is not too significant in increasing SME revenue growth, so it is necessary to innovate budget allocation policies so that they have a significant impact on the development of SMEs. In those models, the exogenous variables are demand, price, and carrying capacity. Demand is related to changes in price as a form of response and carrying capacity affects the supply of raw materials. Ultimately the three variables have an impact on the production rates.

In another scope, [19] has studied the process of risk analysis and assessment using the integration of system dynamics techniques and Layers of Protection Analysis (LOPA) to improve risk management results. This research was conducted in the plastic molding industry in the case of fire risk assessment. The methodological approach integrated with this study is a structured risk assessment technique to obtain failure scenarios that may occur and assess the probability of an accident occurring, and system dynamics models are used to measure the interaction effects of various scenarios. From the developed SD model, it is known that the probability of events is associated with the risk of explosion in the supply system and the risk of spreading fire due to some engine malfunctions (engine aging effect). Scenario analysis in more detail considers the possibility of failure by using the time function. It turns out that if the period is longer, the possibility of damaged components becomes higher. As a

result, the system may fail to fulfill its security function. The probability value of the possibility of an explosion and its relationship to the possibility of spreading fire is a function of the values of several control variables, namely the frequency of maintenance and safety procedures. Through this study, it can be understood that the dynamics and uncertainties inherent in risk assessment and management in complex systems can be identified using a systems dynamics approach.

In the context of digital companies, which operate in technology-driven and rapidly evolving environments, business model innovation is essential for staying competitive and achieving sustainable growth. For that purpose, [20] developed a system dynamics model to increase evolutionary and innovative business models using an open innovation (OI) approach. In this study, the major influential factors of OI are identified as IP-sharing and key partners. These factors are concrete variables that exhibit positive feedback loops in the context of business model innovation (BMI). Positive feedback loops indicate that the company experiences growth and expansion when implementing OI. When more parties are involved, the amount of capital investment needed decreases. The company engages in collaboration with customers and suppliers. Extensive cooperation with partners will help companies identify more technologies and opportunities. This will encourage the achievement of sustainable growth. The simulation outcomes indicate that the implementation of OI has a substantial impact on company performance. This is based on the revenue-boosting effect resulting from accelerated product development and expanded market access facilitated by partnerships and IP sharing.

Iranian SMEs face many problems related to management. These problems often take root in strategic decision-making by managers. One such decision is related to the production department. Many of these companies provide production infrastructure at a high cost; however, they were unable to gain their share of the market, and eventually, they suffered losses. Related to these problems, [21] developed a model using the Schmid model as a basic model and a system dynamics approach aimed at evaluating existing policies to prevent capital loss. The developed model investigates whether customer networks in businesses without prior production have a role in increasing the return on investment (ROI). The model consists of 10 main elements, namely balance sheet, profit loss, machinery, production, customer, network, reputation, employee, innovation, and qualification. From the developed model, it proves that if the production unit is involved in selling the product to be produced, determines a network of loyal customers, and increases its production capacity, then the rate of return on investment under the same conditions will be five times higher than the original production plan. With this condition, the problem of return on investment (ROI) and capital losses can be overcome.

In addition to facing problems on the management side, SMEs in Iran also experience problems of uncertainty in their operating environment. Understanding their behavior patterns can help identify factors that contribute to success or failure. Reference [22] conducted a study focused on the development and application of a qualitative system dynamics model to analyze the behavior patterns of SMEs in Iran. The identified

behavior patterns are changes in the concept of technology due to a lack of market interest, an imbalance in the allocation of resources on the development of the technical and management side, and market development concerning the utilization of technology. From the simulation, it is known that the government needs to establish regulations that protect the flexibility and freedom of SME managers; provide marketing services and market research; and facilitate connections to the industry. It is also necessary to use a mentoring mechanism for coaching and leadership at all levels of SMEs, such as managing financial allocations, market planning, and improving the management structure and style. Facilitating administrative consulting provides a role to increase business area and workforce participation; reasonable control and can build a balance between the development of technological ideas and the capabilities of SMEs, especially in terms of human resources.

#### *E. Finance*

In the field of finance, a study was conducted to identify the driving factors and constraints faced in efforts of MSMEs upgrading. Using system dynamics modeling [23] reveals and shows how the dynamics of the transition of Indonesia MSMEs towards bankability during the COVID-19 pandemic. The focus of this analysis is MSMEs that initially have limited or no access to bank loans. From the developed model, it is known that several critical variables accelerate the status of MSME bankability from un-bankable to bankable, namely time to bankability (for entrepreneurial/micro enterprises), channel business, and the non-performing loan (NPL) of MSMEs. Extending the projected timeframe for entrepreneurial MSMEs to achieve bankability can expedite the process of transitioning un-bankable MSMEs into bankable ones more rapidly than the current circumstances. Building strong business channels or networks plays an important role in enabling MSMEs to recognize the benefits of financial services and foster closer relationships with stakeholders. This, in turn, accelerates the process of transitioning un-bankable MSMEs into bankable entities. Reducing the non-performing loans (NPL) of MSMEs can expedite the transition of un-bankable MSMEs into bankable entities compared to the present situation.

Investment decision-making is a critical process that involves assessing various financial risks associated with investment opportunities. In the current dynamic and complex financial environment, investors must have a comprehensive understanding of the potential risks and their impact on investment outcomes. Using the investment case on solar thermal heating installation in Malaysian SMEs, [24] undertook system dynamics modeling of financial risk as a valuable approach. The simulation results of the model show that government support (guarantee) and financial funding (soft loan) mechanisms have a major influence on investment decisions that lead to increased solar thermal installation capacity by Malaysian SMEs. Increasing the percentage of government support reduces the risk of Net Present Value (NPV). This means that government support plays a role in financial risk trends, and this should help increase installed capacity; because indirectly, it helps increase industry awareness to invest in solar thermal technology. With this model, policymakers can tailor appropriate policies for SMEs.



The right policies can contribute to risk analysis for other categories such as construction and operations.

#### F. Organizational

In the context of SMEs, which often have limited resources and capabilities compared to larger organizations, building resilience is critical to their long-term sustainability and success. Resilience refers to the capacity of an organization to effectively respond to and recover from disruptive events or shocks, such as economic downturns, natural disasters, or market fluctuations, and to adapt and thrive in the face of adversity. Research [25] studies the resilience and sustainability of SMEs by taking the case of the tourism industry in Mexico, through identifying the factors that need to be addressed to secure and promote their business. This study begins with conducting social network analysis (SNA) to obtain the latest understanding of organizational resilience in the SME literature. The results of SNA were then used to develop a conceptual model and simulate scenarios using system dynamics. The model simulation shows that organizational resilience is related to feedforward, buffering, and feedback control as critical factors that demand continuous coordination on the mechanisms between core operations and management. The need to stabilize organizational cycles by providing a buffer against fluctuations and weakening variations in existing capacity. These results can help managers rethink corporate resilience related to restructuring relations in operational and strategic units, improving autonomy, and strengthening strategic planning as well as feedback means.

Creating sustainable economic growth requires a synergistic and supportive ecosystem where companies, institutions, and stakeholders can collaborate, innovate and thrive. By clustering related industries and resources, it can stimulate economic development, increase competitiveness, and encourage innovation and entrepreneurship. In addition, within an industrial cluster, companies can collaborate and share resources, including energy-related infrastructure and technology. This can lead to optimizing energy systems and adopting energy-efficient practices. To gain insight into new economic dynamics related to industrial cluster growth and demand for energy intensity, [26] developed a model and simulated it using a system dynamics approach. The simulation results show the factors that affect growth cluster activities and productivity transaction cost barriers are energy intensity, energy efficiency, and energy conservation. Energy consumption patterns based on energy needs are stimulated by government policies through the development of cluster dynamics that utilize the innovations of energy intensity and efficiency. SMEs share a leading role in the development of innovative energy intensity. Which, the greater the energy efficiency, the smaller the calculated energy savings based on energy requirements. Therefore, cluster growth indirectly promotes technology spillover and higher GDP, and ultimately promotes economic growth. This will also provide macro benefits in the form of reduced energy demand and energy conservation.

System Dynamics, as previously discussed regarding its application to MSME sectors, offers valuable applications in various sectors. In product development, it enables modeling and optimization of product life cycles, demand patterns, and

decision-making for design and market entry strategies. In the technology and ICT domain, it helps in analyzing technology adoption, market dynamics, and risk management. In supply chain management, it facilitates an understanding of the complex dynamics and optimization of inventory, production, and distribution processes; optimizes performance and responsiveness. For business development, System Dynamics provides insight into market demand, competition, and growth strategies. In finance, it helps with financial forecasting, risk analysis, and policy evaluation. Lastly, in the organizational sector, it supports the modeling of decision-making, workforce dynamics, and organizational culture, assisting in organizational improvement and performance enhancement. Overall, System Dynamics offers versatile tools for understanding and optimizing the complex systems in the sector, enabling informed decision-making and sustainable growth.

## VI. CONCLUSION

From the review and description in the discussion section, it can be stated that the System Dynamics approach has the potential to make a significant contribution to achieving sustainable development in Micro, Small, and Medium Enterprises (MSMEs). Through the System Dynamics approach, MSMEs can effectively model and simulate the behavior of various factors that affect their operations, such as resource allocation, environmental impact, and social considerations; proactively address sustainability challenges, adapt to changing market conditions, and contribute to broader socio-economic and environmental objectives. This allows for a comprehensive understanding of the long-term consequences and feedback loops associated with different decisions and strategies.

The System Dynamics approach also enables MSMEs to identify points of influence and potential unintended consequences, facilitating informed decision-making toward sustainable development goals. By analyzing the causal relationships between different variables, MSMEs can develop effective strategies and promote a holistic perspective, keeping in mind the interrelationships of MSMEs in larger systems such as supply chains, technology adoption, local economy, and society. This perspective encourages collaboration, stakeholder engagement, and the identification of common goals and strategies for innovation, sustainable development, and resilience in the face of an evolving business landscape.

Despite the progress made in implementing system dynamics in various sectors, there are still important issues that need further study. In product development, research can explore integrating customer feedback and preferences into models to enhance product design and innovation. Regarding technology and ICT, further investigation is needed to understand the dynamics of emerging technologies, such as artificial intelligence and blockchain, and their implications for organizations. In supply chain management, research can focus on the integration of new technologies in supply chain networks. In business development, further studies are needed to incorporate competitive behavior. In the field of finance, research can study modeling the impact of changing regulations and global economic factors on the financial

system. Finally, in the organizational sector, research can explore the dynamics of organizational culture, leadership, and change management, and their impact on organizational performance and adaptability. Addressing these issues will contribute to a deeper understanding of System Dynamics applications and increase their effectiveness in addressing the complex challenges of achieving sustainable development in MSMEs.

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# A Precise Survey on Multi-agent in Medical Domains

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**Abstract**—Agent technology has provided many opportunities to improve the human standard of life in recent decades, starting from social life and moving on to business intelligence and tackling complicated communication, integration, and analysis challenges. These agents play an important role in human health from diagnosis to treatment. Every day, sophisticated agents and expert systems are being developed for human beings. These agents have made it easier to deal with common diseases and provide high accuracy with less processing time. However, they also have some challenges in their domain, especially when dealing with complex issues. To handle these challenges, the domain has become characterized by distinctive and creative methodologies and architectures. This survey provides a review of medical multi-agent systems, including the typical intelligent agents, their main characteristics and applications, multi-agent systems, and challenges. A classification of multi-agent system applications and challenges is presented, along with references for additional studies. For researchers and practitioners in the field, we intend this paper to be an informative and complete resource on the medical multi-agent system.

**Keywords**—Artificial intelligence; agent systems; multi-agent systems

## I. INTRODUCTION

Agent-based systems are one of the most exciting and essential fields of research that appeared in information technology in the 1990s [1]. Multi-agent systems (MAS) are significant and active research areas in artificial intelligence (AI). They combine several agents that collaborate, cooperate, negotiate, and communicate in a shared environment to pursue specific high-level objectives.

MAS research contains a broad scope of technical issues, including how to develop MAS to help encourage actions in agents, design algorithms that enable agents to accomplish a set of objectives, knowledge exchange and communications between agents. Their various approaches can be used to handle a multitude of applications, including industrial applications, commercial applications, entertainment, and medical applications [2][3].

In recent years, the world population has grown significantly, increasing the requirements of people and organizations in many sectors. One of the most critical sectors is healthcare, which plays a vital role in our society. However, medical centers, such as hospitals and medical laboratories, need help with dealing with this expansion and organizing the tasks between their departments. Collaborative and integrated systems such as MAS can be considered flexible solutions to these kinds of issues. Different health areas have used these systems for many purposes, such as home health care, eHealth

services, patient monitoring, disease diagnosis, and other issues that can be managed using multiple agents.

Our motivation in this paper is to provide an overview of multi, single, and sophisticated intelligent agent technologies in the medical domain, allowing the reader to fully grasp this large field. To do so, we first provide a comprehensive view of the agent's systems by defining the agents and outlining some of their main features and applications. Second, we discuss AI and MAS for the medical sector and review various recent studies in this area. The main contributions of this paper are:

- A detailed survey was conducted on agent-based technology.
- The MAS applications in the healthcare field were covered in five different domains. These are management and organization, decision-making support, data management, remote care, and disease diagnoses.
- The most recent studies (published from 2015 to 2022) were reviewed and presented.

Overall, the MAS background, achievements, and research challenges have been discussed in detail in each corresponding section. The rest of this paper is organized as follows. The second section introduces artificial agents and their various applications. Sections III and IV provide a general discussion of MAS and their key characteristics and of AI in healthcare. Section V is a comprehensive discussion of recent studies in medical MAS in different subfields. Moreover, the reviewed papers have been summarized and are presented in tabular form. Section VI discusses the challenges of using MAS in this field, and finally, Section VII concludes the review.

## II. ARTIFICIAL AGENTS

The agents, their main characteristics, the diversity of environments, and the variety of agent types will be discussed in this section.

### A. Intelligent Agents

Multiple definitions of agents have been proposed in the literature, arising from various application-specific aspects of their use. The agent can be defined as “anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators,” as illustrated in Fig. 1 [4].

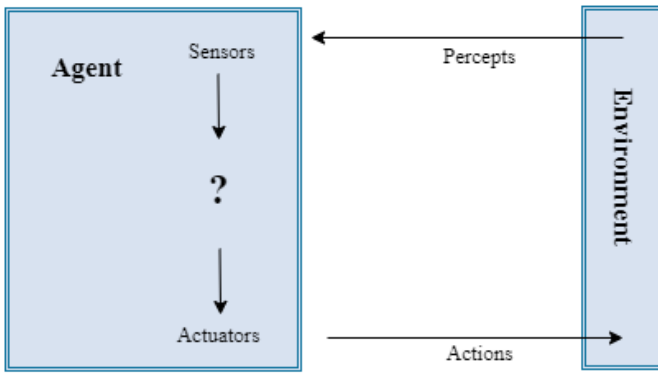


Fig. 1. Agents interact with environments through sensors and actuators.

Furthermore, a generalized definition of the agent was presented in [5]: The authors defined an agent as “an entity which is placed in an environment and senses different parameters that are used to make a decision based on the entity’s goal. Based on this decision, the entity performs the necessary action on the environment.” The preceding definition has four keywords that can be further expanded upon.

- Entity: This represents the type of agent. The agent can be software, hardware, or a combination of software and hardware.
- Environment: The agent's surroundings are referred to as the environment.
- Parameters: Parameters relate to the various types of data that an agent can get from its environment.
- Action: Each agent has the ability to take action that causes changes in its environment.

Table I presents some examples of agent types discussed in [4], as well as descriptions of their environments, actuators and sensors.

TABLE I. EXAMPLES OF AGENT TYPES

Agent Type	Environment	Actuators	Sensors
Taxi driver	Roads, other traffic, pedestrians, customers	Steering, accelerator, brake, signal, horn, display	Cameras, sonar, speedometer, GPS, odometer, accelerometer, engine sensors
Medical diagnosis system	Patient, hospital, staff	Display of questions, tests, diagnoses, treatments, referrals	Keyboard entry of symptoms, findings, patient’s answers
Satellite image analysis system	Downlink from orbiting satellite	Display of scene categorization	Color pixel arrays
Interactive English tutor	Set of students, testing agency	Display of exercises, suggestions, corrections	Keyboard entry

The agent’s environment can be physical, such as the control system, or computing systems, such as data sources and computing sources [6]. Moreover, Russell and Norvig (1995) recommended a categorization of environmental properties, as presented in Fig. 2.

- Accessible versus inaccessible: Accessibility refers to the ability of an agent to obtain comprehensive, precise, and up-to-date information from its environment. In this sense, the majority of real-world environments (such as the common physical world and the Internet) are inaccessible.
- Deterministic versus non-deterministic: A deterministic environment is one in which each action has a specific predetermined impact, and there is no ambiguity about the state that will emerge from that action.
- Static versus dynamic: Static environments are those in which changes can only happen due to the agent’s actions. On the other hand, a dynamic environment is affected by other processes and changes in directions that are outside the agent’s control.
- Discrete versus continuous: If an environment has a definite, limited number of activities and percepts, it is discrete. In contrast, a continuous environment, such as a moving agent in a physical environment, impacts the agent’s state by a continuous function.

The agent can be considered an intelligent agent when it meets its design objectives with flexible and autonomous action [7]. Flexibility has been summarized by [8] into three concepts. First, reactivity occurs when the agent can perceive and respond to its environment. Second, the agent shows a goal-oriented attitude, which is known as pro-activeness. Finally, there is social ability, allowing the agent to interact with other agents.

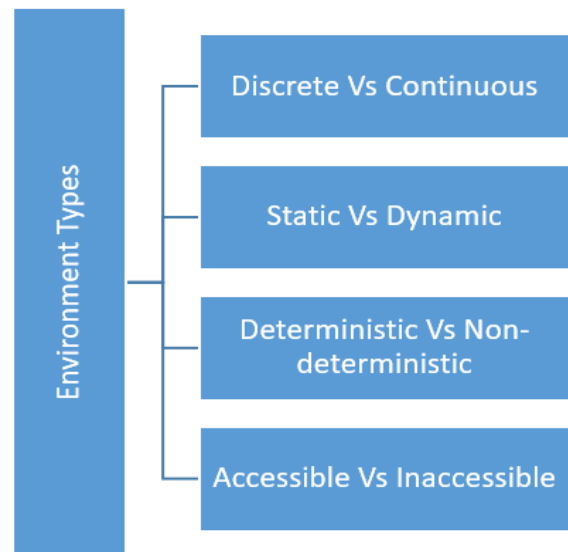


Fig. 2. Agent’s environment types.

### B. Applications of Agents

Agent applications can be variously categorized by the type of agent, the technology used to implement the agent, or the application domain. The applications, based on the domain type, have been classified by [2] as Industrial Applications, Commercial Applications, Medical Applications, and Entertainment. Fig. 3 shows some examples of these applications for each domain.

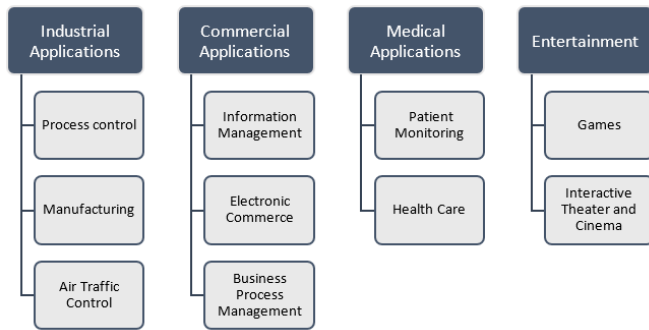


Fig. 3. Examples of some agent applications.

### III. MULTI-AGENT SYSTEMS

Generally, an agent can operate alone due to autonomy; however, the actual worth of agents can be increased when they collaborate with other agents. This has led to the creation of the MAS concept, in which two or more agents collaborate to solve a complex problem. Multi-agent systems can be defined as abstractions that can encapsulate the core of several software systems in varying degrees of detail [9]. The agents in these systems are autonomous entities that respond to input from humans and robots in a variety of possible contexts. Additionally, these systems accept information from various sources, including human and autonomous ones, and then respond with a computational strategy based on cross-referencing all the available data [10]. The MAS mainly consists of a collection of agents (Ag1, Ag2, etc.) and a set of potential environmental states in the form of a pair (A and Env) [11]. Fig. 4 presents the main characteristics of the MAS environment.

The MAS is an effective way to fix complicated activities because of its key characteristics, such as efficiency, relatively low cost, adaptability, and dependability [5]. Moreover, its effectiveness originates from the underlying distribution of resources, which divides a complicated task into several subtasks, each allocated to a different agent [12]. Additionally, the MAS can be classified based on features such as [5]:

- Leadership: The MAS can be categorized as leader-follow or leaderless based on the presence or absence of the leader agent (an agent that establishes objectives and tasks for other agents based on one primary goal).
- Mobility: An agent can be either mobile or static, based on its dynamicity. A mobile agent can move throughout the environment. Moreover, it can be hosted by other agents. On the other hand, a static agent remains in one place.

- Delay Consideration: Agents may face many delay sources while performing tasks. Based on this feature, the agents that take the delay sources into account have been classified as delay agents, while those that suggest that there are no sources of delay are known as without delay agents.
- Heterogeneity: MAS can be either homogeneous or heterogeneous. The heterogeneous MAS includes agents with a variety of properties, whereas a homogeneous MAS contains agents with the same features and functionalities.
- Topology: Based on the agents' locations and relations, the MAS can have either a static or a dynamic topology. In the former the agents' positions and locations remain fixed, while in the latter they continuously change; agents may move or leave, and they may be combined with other MAS.

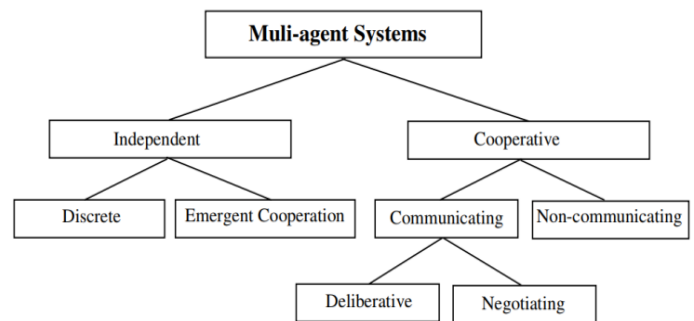


Fig. 4. Characteristics of the MAS environment [13].

### IV. AI IN HEALTHCARE

Recently, the use of AI has increased across all industries. As a result, AI has the potential to significantly change the field of medicine, thereby benefiting both patients and practitioners [14].

#### A. Benefits of AI in Healthcare Field

Artificial intelligence helps doctors streamline tasks, improve operational efficiencies, and simplify complex procedures. For instance, AI systems have significantly increased efficiency for radiography tasks, such as cardiac function assessment [15][16] and mammography interpretation [17][18].

In the field of pathology, there are still issues with how to quickly and automatically assess and determine an appropriate diagnosis from practical pathology images when the situation necessitates an immediate fix. Accordingly, AI has made significant progress in this field [19], and many scholars have improved blueprints in this regard, such as: [20], [21], [22], and [23]. Moreover, AI has made significant progress in diagnosing diseases, including several cancer types, such as gastrointestinal cancer [24], breast cancer [25], and colorectal cancer [26]. Another AI field, medical expert systems (ES), completes rather commonplace tasks in medical diagnostics [27]. The ES can be defined as “a computer program capable of automating decisions by asking questions and providing

answers or conclusions” [28]. Medical expert systems were created out of the need to assist with diagnosis and treatment of ailments. They can also inform and notify doctors and patients [29]. Examples of well-known ES include the following:

- MYCIN [30]: a computer-based system used to diagnose patients with bacterial infections.
- DERMIS [31]: a prompting system to diagnose skin disease.
- GIDEON [32]: a computerized system designed to diagnose patients with infectious etiology diseases.
- PNEUMONIA [33]: an improved system to diagnose community-acquired pneumonia.

In addition to diagnostic tasks, the recent development of AI has led to a significant improvement in the drug industry, in which it has played a role in the assembly and discovery of novel drugs [34][35].

### B. Drawbacks of AI in the Healthcare Field

Despite AI’s great benefits in health care, such as helping doctors diagnose diseases, saving time, and reducing costs, many studies have shown that defects can result from the employment of AI in the medical field, and some studies consider AI a disruptive tool [36]. For example, the authors of [37] showed multiple aspects of AI’s limitations:

- Data Collection Issue: It is known that some AI techniques, such as machine learning (ML) and deep learning (DL), require massive amounts of data to learn and produce accurate predictions. However, information accessibility in the healthcare sector may be challenging [38] since most are confidential.
- Social Concerns: The widespread use of AI always generates many concerns among health practitioners, as many believe they may lose their jobs and be replaced by AI tools and technologies.
- Clinical Implementation Concerns: Trust in AI-based medications is not completely possible due to the lack of empirical data that could validate these medications, which was an obstacle to successful deployment.

- Ethical Concerns: Due to the lack of universal guidelines for the moral use of AI and ML in healthcare, there is still debate about how far AI may be ethically used in the medical domain.

### V. MAS IN HEALTHCARE

Currently, MAS are used for many purposes in the medical field. These systems decrease the workload of healthcare professionals and gather data about a single patient from many specialties to enable them to make more accurate decisions [39]. Many other factors, as provided by [40], help to explain the benefits of using MAS in healthcare.

- MAS’s components could operate on various machines spread throughout many locations. Each agent may have access to some of the information needed to solve the issue, such as patient data stored in several hospital departments or across many hospitals, clinics, and surgeries. As a result, MAS could handle distributed problems.
- As the MAS can actively discuss how to divide an issue and how to distribute the necessary subtasks among them, MAS have the ability to decompose complex problems.
- Agents could provide information for patients and medical professionals because some agents are designed to gather and analyze data from various sources.
- Another crucial agent characteristic is proactivity—agents can perform actions that can be advantageous for the user, even when that user has not explicitly asked that they be done. For instance, if the agent is aware that the user is traveling abroad and that the user has experienced heart issues, the agent can determine which nearby medical facilities have a cardiology department in case the user urgently requires this information.

This study presents many previous works that have employed MAS in five fields of the healthcare domain, as shown in Fig 5. Moreover, Tables II and III provide a combined view of these studies by displaying the publication year, main field or domain, and research focus.

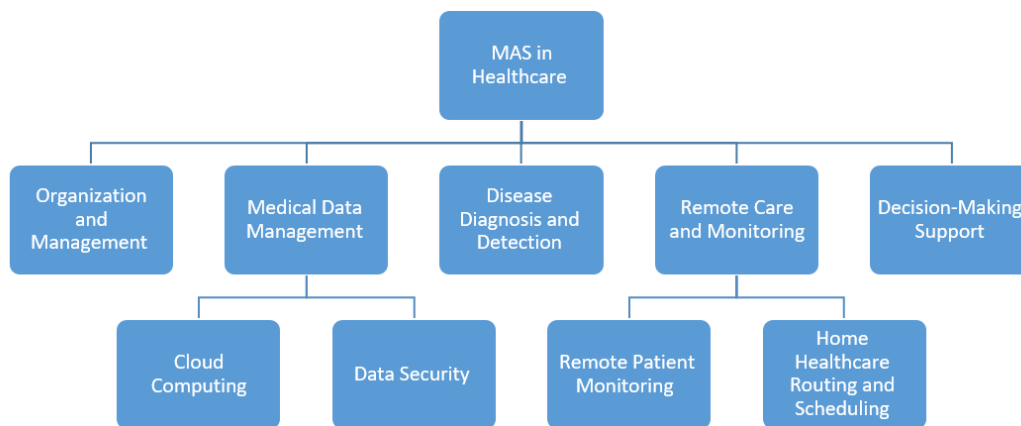


Fig. 5. The covered domains.



TABLE II. MAS FOR DIFFERENT PURPOSES

Main Field	Ref	Year	Research Focus	Main Field	Ref	Year	Research Focus
Orgnisation and Management	[41]	2015	Organization between hospital wards	Decision-Making Support	[49]	2022	Show the superiority over applied of a single-stage approach in the decision-making process.
	[42]	2015	Control patient flow and resource allocation		[50]	2017	Show the superiority over applied of a single-stage decision-making process in the healthcare delivery system.
	[43]	2019	Control patient flow for emergency status		[51]	2015	Use visualization techniques and MAS to improve IDSS
	[44]	2017			[52]	2020	Improve IDSS by use MAS to classify different types of cancer diseases
	[45]	2020	Scheduling of patients and resources		[53]	2021	Use MAS to simulate the surgery operating rooms to ensure timely decisions can be made"
	[46]	2020	Manage the maintenance workflow		[54]	2021	Use self-organizing multi-agent approach to extract probabilistic fuzzy rules from numerical data
	[47]	2020	Mange the unreasonable growth of medical expenses		[57]	2016	Home Health Care (HHC) Routing and Scheduling Problem
Medical Data Management	[55]	2017	Use semantic search approaches with MAS	[58]	2016	Home Health Care (HHC) Routing and Scheduling Problem	
	[56]	2016	MAS and Cloud Computing	[59]	2017		
	[60]	2021		[61]	2018		
	[62]	2018	MAS and Healthcare Data Security	[63]	2019		
	[64]	2021		[65]	2020		
	[66]	2016		[67]	2017		
	[68]	2019		[69]	2021		
	[70]	2021		[71]	2015		
[72]	2020	[73]	2015				

TABLE III. MAS FOR DISEASE DIAGNOSIS

Ref	Year	Disease Type					Reseach Focus
		Diabetes	Cancer	Heart Diseases	COVID-19	Other Diseases	
[74]	2020	*					Produce mobile application integrated within the CareWare architecture and the existing diabetes ontologies
[75]	2015		*				Enhance gene expression analysis through the automation of tasks related to cancer gene identification
[76]	2015		*				Identify genes that provoke triple negative breast cancer (TNBC)
[77]	2020	*					Investage the performance of machine learning algorithms based on the diabetes database
[78]	2020				*		Use MAS to simulate the spread of contagious disease during the COVID-19 outbreak
[79]	2021				*		
[80]	2020				*		Develop MAS to fight and handle COVID-19
[81]	2021				*		Adopt MAS to identify the plasma donors for COVID-19 patients
[82]	2020	*					Diagnosing diabetes using multi-agent data mining system
[83]	2016					*	Employ MAS for diagnosis of mental disorders
[84]	2015	*					Help type 2 diabetic patients
[85]	2017			*			Detect cardiovascular disease using Adaptive Neuro-Fuzzy Inference System and MAS
[86]	2021		*				Provide a customized support system for cancer survivors
[87]	2019		*				Adopt MAS for distributed classification tasks in cancer detection
[88]	2016			*			Design MAS for analysis and diagnosis of cardiac patients
[89]	2017					*	Adopt MAS for analyze and monitor diuresis
[90]	2019					*	Review the use of agents for sickle cell disease (SCD)
[91]	2022					*	Use MAS for disease detection using human eye images
[92]	2016					*	Use MAS for detection of autoimmune diseases

#### A. MAS for Organization and Management Problems

The special characteristics of MAS make them sufficient solutions for controlling and managing different kinds of organization and management problems, such as patient flow and services in the healthcare sector. Therefore, many researchers have mainly focused on this aspect.

A MAS-based system called MMAS (Medical Multi-Agent System) has been proposed in [41] to solve hospital challenges, such as collaboration between different units, elaborations of diagnostics, and the collection of patient information. Two layers of agents have been used: the super agent's layer and the Swarm layer. As a result, many services can now be completed remotely, such as patient appointments, patient registration, remote consultations, and others, which prove the effectiveness of the proposed system.

To control patient flow and emergency services, various agent technologies systems, such as multi-agent facility management systems, patient-centered MAS, and other systems have been proposed. For instance, a patient-centered MAS has been proposed by [42] to improve the ability to deal with unexpected issues, as well as reduce the costs and waiting time for patients, by supporting both the medical staff and the hospital managers and optimizing the distribution of resources. Therefore, the system architecture is constructed with two levels: patients from the higher level and shared resources from the lower.

In [43], emergencies such as natural disasters or accidents are handled by presenting a MAS that uses agents to direct the patient to the nearest hospital based on their current location. In addition, each patient is assigned a room more quickly than when using traditional methods. Similarly, the authors of [44] aimed to automate the prehospital emergency process using the multi-agent concept by categorizing the specialized care in keeping with the state of affairs at the right time for reducing patient mortality and morbidity. As a result, the proposed system provides intelligent decision-making capabilities due to the use of interactive agents.

The authors of [45] represent the outpatient clinic as a MAS and produce an intelligent real-time scheduler that schedules the patients and resources based on the current status of departments. Furthermore, all system entities are mapped to agent roles, either passive or active. As a result, performance measures such as waiting time, cycle time, and utilization notably improved.

To improve the maintenance management process, the authors of [46] suggested using MAS to shift from centralized systems into distributed systems that efficiently manage maintenance requests. Thus, a multi-agent facility management system (MAFMS) was conceptually proposed in which the agents belong to two categories: human resource agents and building components agents. The simulation results confirmed that the advantages of the proposed system outweighed the current systems.

Besides the well-known management problems in the healthcare sector, the increase in medical costs charged by public hospitals is another issue. Therefore, a MAS model was

proposed in [47] to provide useful suggestions for managing the immoderate increase in medical costs in China. The results suggested that these expenses can be reduced by using the community first-visit system and improving the government's financial investment.

#### B. MAS for Decision Making Support

The healthcare decision-making process is complex, risky, and essential, and it requires careful consideration of various factors. Therefore, it is crucial to have a tool that helps make accurate and correct decisions based on real-time data [48]. Recently, MAS have been pivotal in supporting and making decisions in the healthcare sector.

Due to the interrelated nature of decisions in the health field, [49] proposed an interrelated decision-making model (IDM) for an intelligent decision support system (IDSS) in healthcare that aims to produce an effective decision using MAS (known as IDM-IDSS-healthcare). Eight diabetes treatment datasets were used to conduct the experiments, and the results showed an improvement in decision-making efficiency with the proposed model, where the accuracy increased up to 56%.

For the same purpose, a CARE concept that uses MAS technology was introduced by [50] to support decision making in the healthcare delivery system. That system mainly consists of five stages; therefore, five corresponding agents have been developed: primary care agent, secondary care agent, tertiary care agent, quaternary care agent, and palliative care agent.

Visual data mining technology can play a vital role in a dynamic environment. For this reason, a new architecture was proposed in [51] to produce a visually intelligent clinical decision support system that uses MAS to resist nosocomial infections. The proposed agents are User interface, Coordinator, Data preparation, Data mining, Visualization, Evaluation, Knowledge integration, and Database. The evaluation of the proposed prototype noted some advantages, such as the presentation of the graphical data, which in turn reduced the complexity, and using agents guaranteed communication and cooperation between different modules.

The IDSS is a fundamental aspect of Computer Aided Diagnosis (CAD), and because of the need to construct decision-making systems that work in parallel, the authors of [52] suggested developing a CAD system that combines MAS with IDSS. The new system was proposed for cancer disease classification by gene expression profiles of DNA microarray datasets. Therefore, the contributing agents are Gene filtering, Diagnosis, Master, Inquiry, and Result. As a result, the proposed system has proved its practical ability to quickly classify different types of cancer diseases.

Because of the sensitivity of some hospital departments, such as operating theaters, making timely and well-reasoned decisions can be a critical issue that may require a tool. Thus, the emergency processes in the operating room have been modeled using an interactive support system decision embedded with MAS, in which the agents assist in allocating appropriate human and medical resources and planning elective surgery. Three types of agents are included: Supervisor, Service, and Coordinating. The simulation

confirmed that the proposed application could take full advantage of all the communication possibilities between the service agents [53].

Recently, efficiency and scalability have been considered essential attributes in decision support systems, for which the complexity of the dataset continues to grow. To handle dataset issues such as inconsistency, a Distributed Probabilistic Fuzzy Rule Mining (DPFRM) algorithm for clinical decision-making was proposed in [54]. The proposed algorithm used a self-organizing multi-agent approach to extract probabilistic fuzzy rules from numerical data. It used six agents (a1 to a6) that can communicate and exchange information with their neighbors. The results confirm that handling inconsistencies within the datasets by DPFRM can increase the accuracy and improve the training time due to the use of a parallel computer.

### C. MAS for Medical Data Management

Nowadays, a massive amount of data and information is generated in the healthcare field. Therefore, MAS have emerged as a powerful platform for managing and controlling how these data are exchanged.

The process of information exchange between a range of hospitals is a considerable challenge due to the lack of traditional information retrieval systems. Accordingly, the multi-agent concept has been adopted by the Statistics and Collaborative Knowledge Exchange (SCKE) system, within which the proposed MAS uses semantic search approaches to handle such problems. The pivot component is mainly hospital agents, where each agent represents an individual hospital. Thus, these agents can use the hospital database to accept and search queries to retrieve and exchange information. The system performance is examined, and its efficiency is proven by an improvement in the accuracy, regardless of the number of queries [55].

1) *MAS and cloud computing*: With the advent of mobile devices and cloud computing in different domains, the healthcare industry is shifting from direct care services to cloud computing. In addition to the reliability of cloud computing, MAS have proven to be effective in treating medical problems. For that reason, applications designed using cloud computing and MAS are expected to become more plentiful in the healthcare sector.

In [56], the authors suggested combining mobile cloud computing (MCC) with MAS to produce a Medical Mobile Cloud Multi-Agent System (2MCMAS), which takes advantage of both concepts to provide efficient care. The proposed architecture consists of agents grouped into two layers, Super-agent and Swarm agent, that interact in the environment, such as Expert, Search, Discharge, Access, Calendar, Doctor, Nurse, and Patient agents. The proposed system ensures flexibility by distributing knowledge between intelligent agents.

The wide spread of cloud computing has caused the emergence of different models, such as fog computing and edge computing, which will minimize end-to-end delays in the network. However, the fog-cloud-enabled network still suffers

from some issues for healthcare applications. Therefore, a Critical Healthcare Task Management (CHTM) model for ECG monitoring that uses MAS is proposed in [60]. The MAS is involved in managing the network from edge to the cloud and providing an efficient resource scheduling scheme. The MAS system consists of four kinds of agents: personal agent (PA), master personal agent (MPA), fog node agent (FNA), and master fog node agent (MFNA). As a result, network usage, response time, network delay, energy consumption, and instance cost are significantly reduced, as shown in the simulation.

Despite the effectiveness of cloud computing techniques, some researchers have reported the advantages of integrating MAS and Internet of Things (IoT) techniques to produce cloud-based applications to control medical data. Accordingly, the authors of [62] have designed a cloud-based system that collects and processes data to make accurate and timely decisions. The patient data are collected using three agents that form the mobile clients—Periodic analyzer, Manual handling, and Emergency agents—to be sent to the cloud module. The agent implementation used a pulse-oximetry sensor with Raspberry-pi hardware for the experiments. Thus, two simple periodic agents (a heart rate simple periodic agent and a SpO<sub>2</sub> simple periodic agent) were combined to represent a complex agent (Complex periodic agent - BPM and SpO<sub>2</sub>). The strengths of the model include scalability and the use of complex agents; however, the model suffers from hardware limitations.

2) *MAS and healthcare data security*: As mentioned in the previous sections, the MAS has been widely adopted to control the process of collecting, managing, and exchanging healthcare data remotely. However, medical data are private and sensitive and should not be accessed by anyone not specifically authorized to do so. To this end, many researchers have reported on how to protect data against external attacks.

In [64], a secure framework for remote healthcare systems was proposed to secure remote healthcare against some healthcare network attacks. The proposed architecture was constructed using two steps. The first step is to create and plan the environment's agents, which will collect the patient data from a sensor network and interact with each other; the contributing agents are Patient, Database, Ambient, Physician, and Nurse agents. The second step is to integrate the agents into groups according to the energy level of the corresponding sensors and the sensitivity of their data. To secure the sensor network, an Intrusion Detection System (IDS) is then instituted and monitored for each group. The experiment results prove the efficiency and effectiveness against the attacks frequently experienced by healthcare networks, such as Smurf, Buffer overflow, Neptune, and Pod attacks.

In healthcare organizations, the data are gathered from multiple sources and shared with other organizations or researchers using a common clinical data warehouse (CDW). However, preserving data privacy from source to destination remains a challenge. In response, the authors of [66] have proposed a multi-agent architecture for knowledge discovery for Evidence-Based Medicine (EBM), which is the modern standard for clinical decision-making known as Multi-Agent

Privacy Preserving for Medical Data (MAPP4MD). The agents are employed within three layers: local health organization agent (LHOA) in the local organization layer, broker agent (BA) in the coordination layer, and repository agent (RA) in the storage layer. The MAPP4MD evaluations prove that the privacy of medical records can be preserved at the source before they are integrated into a larger dataset, which resolves privacy issues that come with integrating medical data into a centralized data repository.

In [68], a novel MAS called the Access Control Security Model (IBAC) is proposed to maintain the security and privacy of eHealthcare data during the transmission phase. The system is mainly composed of three phases: User phase, Agent phase, and Information phase. The agent's role is concentrated in the second phase, in which it verifies user data and establishes an authenticated connection. The system workflow depends on several agents, such as a user interface agent, which is connected to the website or mobile application. The customer username and password are verified using an authentication agent. Finally, the user and server connection is established using the establishment agent and connection management agent. As a result, the proposed framework can provide secure, efficient, and easy eHealth services.

Similarly, the authors of [70] proposed MAS that combines both multi-agent concepts and fuzzy logic to monitor and protect data from unauthorized access and enable conversation between patients and professionals. The system consists of the following phases: Domain/ Information phase, Action/Computational agent, Customer phase, Operative phase, and Communication phase. The agents are employed as expert systems with their own functions. In addition, a healthcare database is used to keep all login credentials for authorized users and to retrieve and analyze data. The user interface agent determines the policies and procedures. Next, the users are validated using a user identification agent, and accordingly, the data transmission agent and a connection management agent establish an authorized connection. User authentication is performed by employing token-based authentication using fuzzy logic. The proposed architecture can prevent many types of outer attacks.

In [72], the authors took advantage of both MAS and Distributed Ledger Technology (DLT) blockchain to increase the protection and security of the eHealthcare databases. The multi-agent role is presented using two types of agents: the user interface agent and the DLT-based authentication agent. Moreover, the proposed system includes a server that is treated as a database to store the patient's health information. The user interface agent is responsible for defining the access rules, receiving the username and password, and establishing the connection between the users and the authentication agent. Then, the user information will be received by the DLT authentication agent to check whether it belongs to the users in the database. According to the verification process, it produces a digital certificate for the user. The research's conclusions will assist in directing the creation of new methods for processing data securely and effectively that combine AI and multi-agent-based systems supported by DLT technology.

#### D. MAS for Remote Care and Monitoring

Home health care (HHC) encompasses a wide range of health care services given to patients at home due to illness or injury. This reduces the cost of health structures. However, HHC's caregivers usually face routing and scheduling problems due to the increasing population. In order to deal with this kind of problem, many researchers have proven that using MAS can efficiently manage routing issues [57], [58].

In addition to routing problems, some patients reside in underserved or difficult-to-reach areas, and quick and accurate diagnoses are essential to starting therapy and addressing problem. Employing MAS to solve these kinds of problems has achieved notable success [65].

#### E. MAS for Diseases Diagnosis and Detection

A reliable, cost-effective, and quick computer-based medical diagnosis is still a challenge because medical diagnosis has always been a critical and complex topic [93]. The MAS approach helps to promote the creation of a readily scalable system. It implements scenarios for evaluating the functional condition of the human body, depending on the goal of the medical research and the available indications of the human body state [94]. Accordingly, many researchers have extensively employed and improved the MAS concept to detect, diagnose, and analyze various types of diseases. The MAS have proved their superiority over other traditional methods. This review investigates different studies related to those systems, including diabetes, cancer, heart diseases, COVID-19, and other diseases. Table III summarizes these studies with a focus on the publication year, type of disease, and the study's main objective.

### VI. CHALLENGES IN THE FUTURE

Despite the wide spread of MAS and their application, there are still some challenges involved in applying MAS, such as coordination between agents, security, and task allocation [5]. Moreover, the employment of MAS in the healthcare field may face the following challenges:

- Security issues: Due to the nature of MAS, sensitive data can be feasibly used by more than one resource, which may reduce the security and privacy of patients' data. There are some concerns about identity theft. Moreover, in the case of a geographically distributed environment, healthcare systems must interact with other systems. However, trusting the data provided from diverse resources can be a challenge.
- Implementation cost: Although it is assumed that MAS could reduce medical costs, some areas require more costs to employ AI techniques. For example, the instruments needed to collect data for AI systems can be quite expensive [14].
- Technical problems: Many issues may result from the development of MAS, such as those related to user expectations and acceptance, safety, and trust issues, as well as how to accurately manage the interactions between software agents, humans, and the preexisting healthcare systems [40].

- System reliability: The MAS needs to have a range of characteristics that gain users' trust. For example, the set of regulations is changed continuously, which requires more flexible and improved systems to adapt to these changes. Moreover, the MAS in this field are mainly used by many users with different technical abilities; therefore, the MAS needs to be easy to use and integrate with existing services.

## VII. CONCLUSION

This review sought to provide fundamental knowledge about multi-agent systems and MAS-related studies in the medical field. We have demonstrated how MAS has been applied to address various medical-related issues; starting with a brief description of the intelligent agents, their main characteristics, the diversity of environments, and the variety of agent types, followed by an introduction to AI and MAS in the medical field and an in-depth investigation of studies on the use of MAS in the medical sector from 2015 to 2022. Finally, the paper concluded with discussion of future challenges related to this topic. It is our hope that this review of medical MAS applications will be helpful to future researchers in this field.

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# Technology Adoption and Usage Behaviors in Field Incident Management System Utilization

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**Abstract**—This study utilized the Unified Theory of Acceptance and Use of Technology (UTAUT) model to analyze the adoption and utilization of field incident management system (IMS) in a manufacturing organization. The study specifically focused on the role of behavior as a key factor in the adoption and utilization of incident management system. Data was collected through a survey of employees who had utilized the IMS system and the UTAUT model was used to analyze the data. The results indicated that behavior in the system significantly influenced the adoption and utilization of IMS. The study also found that the UTAUT model provided a useful framework for understanding the adoption and utilization of IMS, particularly the importance of performance expectancy, effort expectancy, social influence, and facilitating conditions. The study provides valuable insights for organizations looking to implement IMS and improve their incident management processes. It highlights the importance of building behavior in the system through appropriate user experience and user training. The findings of this study have important implications for manufacturing organizations seeking to enhance their incident management procedures through the adoption and utilization of IMS.

**Keywords**—UTAUT; field incident management system (FIMS); regression analysis; user intention and acceptance; system adoption; usage behavior; manufacturing; IMS; effort expectancy; performance expectancy; social influence; facilitating conditions; behavioral intention; ANOVA

## I. INTRODUCTION

Effective incident management is critical to the success of organizations in today's complex and fast-paced business environment. Incident management systems (IMS) have become essential tools for managing incidents and minimizing their impact on business operations. Among the various IMS options available, Field IMS has gained popularity [1]. However, the adoption and deployment of IMS in organizations can be challenging [1, 7, 13]. To understand the factors influencing IMS adoption and use, the Unified Theory of Acceptance and Use of Technology (UTAUT) paradigm has been widely used [1, 16]. This paradigm identifies four key drivers of technological acceptability and utilization: performance expectations, effort expectations, societal impact, and facilitating conditions [2, 3, 5, 12]. In recent years, behavior has been recognized as a significant factor in technology acceptance and use in business settings [3, 14, 17, 19].

This study focuses on the role of behavior in the adoption and utilization of Field IMS within organizations, using the

UTAUT paradigm. The objective of the study is to provide recommendations for organizations seeking to enhance their incident management practices and gain insights into the factors that influence IMS adoption and use. The review of literature highlights the importance of IMS and the UTAUT paradigm in the context of technology adoption and use within organizations. The research question and hypotheses are introduced, followed by a description of the study's methodologies, including data collection processes. The study's findings are presented, followed by a discussion of their implications. Finally, conclusions and suggestions for future research are provided.

This study significantly contributes to the existing knowledge on technology adoption and deployment in businesses. The findings have practical implications for firms aiming to implement Field IMS and improve their incident management procedures. The study emphasizes the role of behavior in the adoption and utilization of Field IMS and demonstrates the applicability of the UTAUT model in understanding this process.

The paper identifies and examines the factors that influence the adoption and utilization of Field IMS, providing valuable insights for researchers and managers. Its specific focus on field incident management sets it apart from other studies, addressing a specific need and offering insights that may not be applicable to broader technology adoption contexts. This contextualization highlights the necessity of the paper, filling a gap in the literature by exploring technology adoption within a specific industry or setting. Also, the paper sheds light on the relative importance of different components within the UTAUT Model, with facilitating conditions and user effort emerging as the most influential factors in Field IMS adoption and utilization. This finding underscores the significance of organizational support, resources, infrastructure, ease of use, user-friendly interfaces, and training programs in promoting technology adoption and usage behaviors.

The paper acknowledges the study's limitations, including the sample size and reliance on self-reported data, and suggests directions for future research. It calls for larger and more diverse samples to enhance the robustness and generalizability of the findings. Incorporating objective measures or observational data is recommended to improve the validity of results.

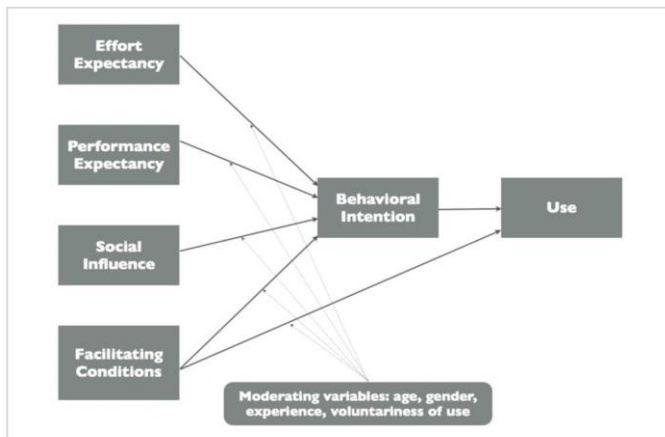


Fig. 1. The UTAUT model based on the original framework by [16].

The paper proposes exploring additional variables to enhance the predictive power of the UTAUT Model, such as perceived risk, trust, or personal innovativeness. This forward-thinking approach demonstrates the paper's commitment to advancing the understanding of technology adoption by incorporating relevant factors.

The value lies in its contextual focus, contribution to the theoretical understanding of technology adoption and usage behaviors, and identification of influential factors specific to field incident management. It also highlights the need for further research to enhance the model's performance and validate the findings in different contexts, ultimately improving the understanding of technology adoption and usage behaviors. The practical implications of the study's findings can inform decision-making, resource allocation, and technology acceptance and usage within organizations, leading to increased productivity, efficiency, and overall performance.

## II. RELATED WORKS

This review aimed to explore the factors affecting the adoption of Field Incident Management System (IMS) using the Unified Theory of Acceptance and Use (UTAUT) model as illustrated in Fig. 1. The UTAUT model is used to understand factors influencing the acceptance and use of information technology (IT) systems [3]. The findings of the literature review revealed that several factors influence the adoption and use of Field IMS [4].

According to the UTAUT model, performance expectancy, effort expectancy, social influence and facilitating conditions significantly impact the decision to adopt new information technology systems such as Field Incident Management System [5].

Performance expectancy refers to the degree to which a user believes that using an information technology system will improve their job performance. Some of the factors that contribute to performance expectancy include the system's perceived usefulness, ease of use, and compatibility with existing processes [6]. Effort expectancy, on the other hand, refers to the degree of ease associated with using an IT system [7, 8]. This encompasses factors such as the system's complexity, technical support available, and the user's perceived level of skill required to use it. Social influence, as a

factor in the UTAUT model, refers to how social factors such as colleagues and management can encourage or discourage users from adopting new IT systems such as Field IMS [8, 9].

Social influence can also include the opinions of external stakeholders and experts. Facilitating conditions are another important factor in the UTAUT model, which include both technical and organizational support aspects such as training, infrastructure availability, and resource availability, which can impact users' ability to adopt and utilize new IT systems [9]. Taken together, the findings from this literature review underscore the multifaceted nature of factors that influence adoption and use of new IT systems within organizations.

### A. Attitude, Behavior, And Usage of a Field Incident Management System

1) *Behavior and Intention to use FIMS*: Behavior is an essential factor in the adoption and usage of technology. The authors in [10] found that behavior has a positive effect on the intention to use Internet of Things (IoT) devices in e-Health. The study applied a modified UTAUT model to investigate the role of behavior in the adoption of IoT in a consumer context. The findings revealed that behavior positively affects the behavioral intention to use IoT devices, which is consistent with previous studies [10]. Therefore, behavior can be considered a critical factor in the adoption and usage of FIMS. Factors Influencing Healthcare Professionals to Adopt AIMDSS [11] conducted a study to investigate the factors that impact healthcare professionals' adoption of artificial intelligence-based medical diagnosis support systems (AIMDSS) using the UTAUT framework. The results showed that performance expectancy, effort expectancy, and social influence positively influenced the intention to use AIMDSS [11]. However, facilitating conditions did not show a significant effect on the intention to use. These findings suggest that perceived usefulness and ease of use are significant determinants of intention to use technology [12].

### B. Behavior Theory in Field Incident Management System

1) *Behavior and FIMS acceptance*: Behavior has been identified as a significant factor in the adoption of technology, including FIMS [16]. According to [13], behavior has a direct and positive impact on the acceptance of mobile medical platforms. Similarly, [10] found that behavior significantly influences the intention to use the Internet of Things (IoT) in e-Health. The study showed that behavior had a more significant effect on the intention to use the IoT than performance expectancy, effort expectancy, and social influence. In the context of FIMS, [14] found that behavior significantly influenced behavioral intention to use mobile health (mHealth) applications. The study found that behavior moderated the relationship between performance expectancy and behavioral intention. Similarly, [15] identified behavior as a significant factor in the acceptance of telemedicine in the Philippines. The study found that behavior had a positive effect on perceived usefulness and perceived ease of use.

2) UTAUT and Behavior: Several studies have investigated the relationship between behavior and the constructs of the UTAUT model [17]. For example, [11] found that performance expectancy, effort expectancy, and social influence were significant predictors of the adoption of artificial intelligence-based medical diagnosis support systems. The study also found that behavior moderated the relationship between performance expectancy and intention to use the system. Study [17] investigated the factors that influence consumer behavior in Internet of Things (IoT) products and applications. The study identified performance expectancy, effort expectancy, and social influence as significant predictors of consumer behavior in IoT. Similarly, [20] integrated the UTAUT model and the Task-Technology Fit (TTF) model to understand the acceptance of healthcare wearable devices. The study found that behavior moderated the relationship between performance expectancy and behavioral intention. The adoption of FIMS is significantly influenced by user acceptance. Behavior has been identified as a significant factor in the acceptance of FIMS, and it has a direct and positive impact on behavioral intention to use the system [18].

The UTAUT model has been a popular framework for studying user acceptance of technology. Several studies have investigated the relationship between behavior and the constructs of the UTAUT model, with behavior moderating the relationship between performance expectancy and behavioral intention [18, 19]. Therefore, behavior should be considered an essential factor when designing and implementing FIMS in various fields [19].

### C. UTAUT in Field Incident Management System

1) *Behavior and User Intention:* Research [10] found that behavior plays a significant role in the intention to use the Internet of Things (IoT) in e-Health. Similarly, [20] investigated the consumer acceptance of healthcare wearable devices and found that behavior is a vital determinant of user acceptance. The study [11] investigated the factors impacting the adoption of artificial intelligence-based medical diagnosis support systems (AIMDSS) and found that behavior, compatibility, and perceived usefulness are the most significant determinants of user adoption.

The literature reviewed in this study indicates that the UTAUT framework is an effective model for analyzing technology acceptance in the context of FIMS adoption. The studies identified several factors influencing the adoption of technology, including behavior, user intention, and acceptance. The findings of this literature review can be used to inform the design of FIMS systems and to develop strategies to increase user acceptance and adoption. The UTAUT framework can also be applied to other technologies not limited to manufacturing but also to other industries that has an incident management to gain a deeper understanding of the factors influencing technology adoption [20].

## III. METHODOLOGY

The aim of this study is to investigate the factors that influence behavior and its impact on the intention to adopt IMS. To achieve this, the study will use the UTAUT theoretical framework, which has been widely used to examine technology adoption in organizations [21]. Specifically, the study will focus on the relationships between the four main constructs of UTAUT, i.e., performance expectancy, effort expectancy, social influence, and facilitating conditions, and their relationships with behavior intention and use behavior, and how they affect behavioral intention and use behavior [22, 23, 24, 25, 26]. To collect data, a quantitative research method will be used, and a survey questionnaire will be designed based on the UTAUT model as shown in Fig. 2. The questionnaire will include items related to the four main constructs of UTAUT and behavior, which will be measured using a 5-point Likert scale. The survey will be distributed to employees who use IMS in their daily work.

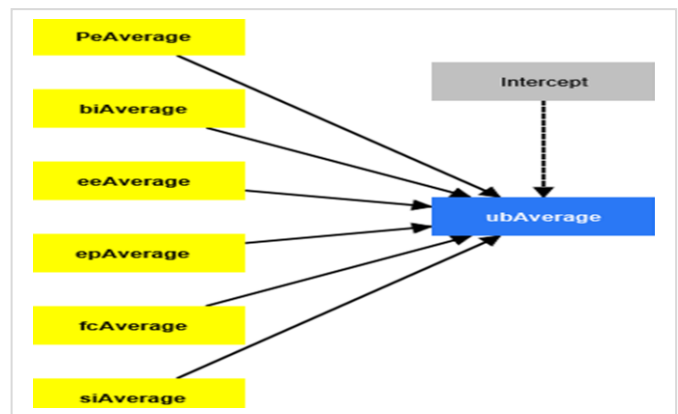


Fig. 2. Adapted model of UTAUT by [16].

To analyze the data, regression analysis will be used. Regression analysis is a statistical method that examines the relationship between variables and allows the researcher to identify the variables that have a significant effect on the outcome variable [27]. Regression analysis will enable the identification of the variables that significantly affect the intention to adopt and use IMS [28, 29]. It will be a use of a convenience sampling method to gather data from employees who use IMS in their daily work [30, 31, 32, 33]. A power analysis will be conducted to determine the appropriate sample size. Organizations that have implemented IMS will be surveyed, and the study will adhere to ethical standards. The results will have practical applications for organizations that are considering the adoption of IMS.

## IV. RESULTS

### A. Summary Coefficient

The researchers utilized the UTAUT Model to examine the factors influencing the dependent variable. The Smart PLS analysis yielded several interesting findings.

Regarding the predictor variables, it is clearly shown in Table I that siAverage demonstrated a non-significant positive relationship ( $\beta = 0.052$ ,  $p = 0.584$ ) with the dependent variable. This suggests that the social influence factor may have a weak

impact on the outcome. Similarly, eeAverage exhibited a non-significant weak positive relationship ( $\beta = 0.122$ ,  $p = 0.210$ ), indicating that the effort expectancy factor may not significantly affect the dependent variable. On the other hand, PeAverage displayed a marginally significant negative relationship ( $\beta = -0.186$ ,  $p = 0.053$ ) with the dependent variable. This implies that the performance expectancy factor may have a weak negative influence on the outcome, although further research is needed to confirm this relationship. Two variables, fcAverage and epAverage, showed significant positive associations with the dependent variable. fcAverage had a moderate positive relationship ( $\beta = 0.223$ ,  $p = 0.021$ ), suggesting that facilitating conditions may play an important role in shaping the outcome. Similarly, epAverage exhibited a moderate positive relationship ( $\beta = 0.246$ ,  $p = 0.013$ ), indicating that effort expended by users may significantly impact the dependent variable. Lastly, biAverage and the intercept term did not significantly affect the dependent variable, as indicated by their non-significant coefficients ( $p > 0.05$ ).

TABLE I. SUMMARY OF COEFFICIENT

Constructs	Unstandardized coefficients	Standardized coefficients	SE	T value	P value
siAverage	0.045	0.052	0.082	0.550	0.584
PeAverage	-0.166	-0.186	0.085	1.961	0.053
fcAverage	0.174	0.223	0.074	2.344	0.021
epAverage	0.245	0.246	0.097	2.521	0.013
eeAverage	0.102	0.122	0.081	1.262	0.210
biAverage	0.004	0.005	0.085	0.051	0.959
Intercept	2.678	0.000	0.815	3.286	0.001

### B. Summary ANOVA

The ANOVA results provide valuable insights into the overall model fit and the significance of the regression. The total sum of squares indicates the total variability in the dependent variable, which was found to be 10.222. The degrees of freedom (df) associated with the total sum of squares are 99.

The error sum of squares represents the unexplained variability in the dependent variable, which amounted to 8.199. The error degrees of freedom are 93. The mean square error, calculated by dividing the error sum of squares by the error degrees of freedom, is 0.088. The regression sum of squares reflects the portion of the total variability in the dependent variable that is explained by the predictor variables in the model. In this case, the regression sum of squares was found to be 2.023. The regression degrees of freedom, which correspond to the number of predictor variables in the model, are 6. The mean square regression, calculated by dividing the regression sum of squares by the regression degrees of freedom, is 0.337.

The F-test statistic is computed by dividing the mean square regression by the mean square error. In the analysis, the F-value was 3.825, indicating a significant relationship between the predictor variables and the dependent variable. The associated p-value of 0.000 further confirms the statistical significance. These results suggest that the predictor variables

included in the UTAUT Model collectively explain a significant portion of the variance in the dependent variable. The model demonstrates a good fit, as indicated by the significant F-test and low p-value.

Researchers and practitioners can interpret these findings as evidence supporting the usefulness of the UTAUT Model in understanding the factors influencing the dependent variable. The identified predictor variables contribute significantly to explaining the variation in the outcome, indicating their importance in technology adoption and usage behaviors.

### C. Unstandardized and standardized Coefficients

1) The unstandardized and standardized coefficients provide important insights into the magnitude and direction of these relationships. In Table II, the unstandardized coefficients of the study were evidently presented.

**siAverage:** The unstandardized coefficient for siAverage is 0.045. This suggests that a one-unit increase in siAverage is associated with a 0.045-unit increase in the dependent variable.

**PeAverage:** The unstandardized coefficient for PeAverage is -0.166. This indicates that a one-unit increase in PeAverage is associated with a decrease of 0.166 units in the dependent variable.

**fcAverage:** The unstandardized coefficient for fcAverage is 0.174. This means that a one-unit increase in fcAverage is associated with a 0.174-unit increase in the dependent variable.

**epAverage:** The unstandardized coefficient for epAverage is 0.245. This implies that a one-unit increase in epAverage is associated with a 0.245-unit increase in the dependent variable.

**eeAverage:** The unstandardized coefficient for eeAverage is 0.102. This suggests that a one-unit increase in eeAverage is associated with a 0.102-unit increase in the dependent variable.

**biAverage:** The unstandardized coefficient for biAverage is 0.004. This indicates that a one-unit increase in biAverage is associated with a 0.004-unit increase in the dependent variable.

**Intercept:** The unstandardized coefficient for the intercept term is 2.678. This term represents the constant or baseline value of the dependent variable when all predictor variables are zero.

TABLE II. UNSTANDARDIZED COEFFICIENT

Constructs	ubAverage
siAverage	0.045
PeAverage	-0.166
fcAverage	0.174
epAverage	0.245
eeAverage	0.102
biAverage	0.004
Intercept	2.678

2) Switching to the standardized coefficients as shown in Table III, findings:



**siAverage:** The standardized coefficient for siAverage is 0.052. This indicates the strength and direction of the relationship between siAverage and the dependent variable, taking into account the scales and variances of both variables.

**PeAverage:** The standardized coefficient for PeAverage is -0.186. This provides information about the standardized effect of PeAverage on the dependent variable.

**fcAverage:** The standardized coefficient for fcAverage is 0.223. This quantifies the standardized effect of fcAverage on the dependent variable.

**epAverage:** The standardized coefficient for epAverage is 0.246. This represents the standardized effect of epAverage on the dependent variable.

**eeAverage:** The standardized coefficient for eeAverage is 0.122. This signifies the standardized effect of eeAverage on the dependent variable.

**biAverage:** The standardized coefficient for biAverage is 0.005. This shows the standardized effect of biAverage on the dependent variable.

**Intercept:** The standardized coefficient for the intercept term is 0.000. Since it is zero, the intercept does not contribute directly to the explanation of the dependent variable.

TABLE III. STANDARDIZED COEFFICIENT

Constructs	ubAverage
siAverage	0.052
PeAverage	-0.186
fcAverage	0.223
epAverage	0.246
eeAverage	0.122
biAverage	0.005
Intercept	0.000

These coefficients provide valuable insights into the relative importance and impact of the predictor variables on the dependent variable within the UTAUT Model. Researchers and practitioners can use these coefficients to understand which variables have stronger or weaker effects and prioritize their focus accordingly.

#### D. Quality Criteria

The results provide insights into the goodness-of-fit of the model and the presence of multicollinearity. The R-square value, which represents the proportion of variance explained by the model, is 0.198. This indicates that the predictor variables included in the UTAUT Model explain approximately 19.8% of the variance in the dependent variable. The R-square adjusted value, which considers the number of predictor variables and sample size, is 0.146. This adjusted value accounts for the complexity of the model and provides a more conservative estimate of the explained variance.

The Durbin-Watson test statistic is used to assess the presence of autocorrelation in the model residuals. In this

case, the test yielded a value of 1.917, which falls within the acceptable range of values (between 0 and 4). This suggests that there is no significant autocorrelation in the model residuals. Moving on to the collinearity statistics, we examined the Variance Inflation Factor (VIF) for each predictor variable. The VIF measures the extent to which multicollinearity may be present in the model. In our analysis, all VIF values are close to 1, indicating a lack of substantial multicollinearity among the predictor variables. This suggests that the predictor variables in the UTAUT Model are relatively independent of each other and do not exhibit high collinearity.

Additionally, we examined the condition index, which provides information about the collinearity structure among the predictor variables. The condition index values, along with their corresponding eigenvalues, indicate the degree of collinearity among the variables. In our analysis, the condition index values range from 1 to 78.594, with higher values indicating stronger collinearity. The eigenvalues associated with the condition indices show that the majority of the variables do not exhibit severe collinearity, except for index 6, where an eigenvalue of 6.966 is observed. This indicates that the variables included in this condition index may have a higher degree of collinearity.

The results of the quality criteria and collinearity statistics suggest that the UTAUT Model provides a moderate level of explanation for the dependent variable, without significant multicollinearity among the predictor variables. However, the presence of some collinearity in condition index 6 should be taken into consideration. Researchers and practitioners can interpret these findings as an indication that the UTAUT Model, while explaining a modest proportion of the variance in the dependent variable, may still provide meaningful insights into the factors influencing technology adoption and usage behaviors. Future research should explore additional variables and evaluate the model's performance in different contexts to enhance its predictive power.

#### E. Descriptive Statistics, Covariances, and Correlations

The descriptive statistics provide an overview of the mean, median, minimum, maximum, standard deviation, excess kurtosis, skewness, number of observations, and Cramér-von Mises test statistics for each variable in the UTAUT Model. Looking at the means, we can see that the average scores for siAverage, PeAverage, fcAverage, epAverage, ubAverage, eeAverage, and biAverage are relatively high, ranging from 4.387 to 4.520 on a scale of 1 to 5. This suggests that the respondents generally perceive positive levels of the respective constructs.

The covariances and correlations provide information about the relationships between the variables in the UTAUT Model. Looking at the covariances, there is an observance of a positive values between siAverage and fcAverage, siAverage and eeAverage, fcAverage and epAverage, and ubAverage and epAverage. On the other hand, there is also an observance of negative covariances between siAverage and epAverage, PeAverage and ubAverage, siAverage and biAverage, and eeAverage and biAverage. These values indicate the direction



and strength of the relationships between the variables. Analyzing the correlations, similar patterns has been observed. For example, *siAverage* is positively correlated with *fcAverage* and *eeAverage*, while it is negatively correlated with *epAverage* and *biAverage*. *PeAverage* is negatively correlated with *ubAverage* and positively correlated with *biAverage*. These correlations provide insights into the interplay between the different constructs in the UTAUT Model.

The descriptive statistics, covariances, and correlations provide a preliminary understanding of the relationships and characteristics of the variables included in the UTAUT Model. Further analysis, such as structural equation modeling using Smart PLS, can help determine the significance and strength of these relationships and provide more robust insights into the factors influencing technology adoption and usage behaviors.

## V. DISCUSSION

The results of the study using the UTAUT Model to examine the factors influencing the dependent variable yielded several interesting findings. The summary coefficient analysis revealed that social influence (*siAverage*) and effort expectancy (*eeAverage*) had non-significant positive relationships with the dependent variable. This suggests that these factors may have a weak impact on the outcome. On the other hand, performance expectancy (*PeAverage*) displayed a marginally significant negative relationship, indicating a potentially weak negative influence. Facilitating conditions (*fcAverage*) and effort expended by users (*epAverage*) showed significant positive associations with the dependent variable, suggesting their importance in shaping the outcome. The other variables, *biAverage* and the intercept term, did not significantly affect the dependent variable. The results indicate that facilitating conditions and effort expended by users are the most influential factors in determining the outcome variable. Social influence, performance expectancy, and effort expectancy were not found to be significant predictors. However, it is important to note that the non-significant relationships should be interpreted with caution, as the sample size and effect sizes may influence the statistical significance.

The ANOVA results further supported the significance of the regression model. The F-test statistic indicated a significant relationship between the predictor variables and the dependent variable, with a low p-value. This suggests that the UTAUT Model, as represented by the included predictor variables, explains a significant portion of the variance in the dependent variable. The model demonstrated a good fit, providing evidence for the usefulness of the UTAUT Model in understanding the factors influencing technology adoption and usage behaviors.

The unstandardized coefficients provided insights into the magnitude and direction of the relationships. For example, a one-unit increase in *fcAverage* was associated with a 0.174-unit increase in the dependent variable. Similarly, a one-unit increase in *epAverage* was associated with a 0.245-unit increase in the dependent variable. These coefficients allow researchers and practitioners to understand the specific effects of each variable on the outcome.

Switching to standardized coefficients, researchers can assess the relative importance of the predictor variables. For instance, the standardized coefficient for *epAverage* was 0.246, indicating a stronger effect compared to other variables. These standardized coefficients help prioritize focus on variables with stronger or weaker effects.

The quality criteria analysis revealed that the UTAUT Model explained approximately 19.8% of the variance in the dependent variable. The R-square adjusted value, considering the complexity of the model, provided a more conservative estimate. The absence of significant autocorrelation in the model residuals and the lack of substantial multicollinearity among the predictor variables indicated good model fit. The results of the quality criteria and collinearity statistics suggest that the UTAUT Model provides a moderate level of explanation for the dependent variable, without significant multicollinearity among the predictor variables. However, the presence of some collinearity in condition index 6 should be taken into consideration. Researchers and practitioners can interpret these findings as an indication that the UTAUT Model, while explaining a modest proportion of the variance in the dependent variable, may still provide meaningful insights into the factors influencing technology adoption and usage behaviors. Future research should explore additional variables and evaluate the model's performance in different contexts to enhance its predictive power.

However, some collinearity was observed in condition index 6, suggesting a higher degree of collinearity among the variables in that index. Future research should consider addressing this issue and exploring additional variables to enhance the model's predictive power.

The descriptive statistics, covariances, and correlations provided a preliminary understanding of the relationships and characteristics of the variables in the UTAUT Model. These findings can guide further analysis using structural equation modeling to determine the significance and strength of the relationships.

### A. Implications of the Findings

1) *Influence of predictor factors*: The results of the analysis indicate that facilitating conditions and user effort are the most influential factors in determining the adoption and utilization of the FIMS. Facilitating conditions, as measured by the *fcAverage* variable, had a positive and significant relationship with the dependent variable, indicating that the presence of supportive conditions, resources, and infrastructure plays a crucial role in promoting the adoption and usage of the FIMS. This finding aligns with prior research that emphasizes the importance of organizational support and resources in facilitating technology adoption and implementation [16].

Similarly, user effort, as measured by the *epAverage* variable, was found to have a positive and significant relationship with the dependent variable. This suggests that users' perceived effort in using the FIMS influences their adoption and utilization behavior. It implies that ease of use, user-friendly interface, and user training programs can

contribute to enhancing technology adoption and usage behaviors. These findings are consistent with the technology acceptance literature, which emphasizes the significance of perceived ease of use and user experience in shaping technology adoption [16].

On the other hand, social influence, performance expectancy, and effort expectancy were not found to be significant predictors of FIMS adoption and utilization in the study. While this may seem contradictory to some prior research that has highlighted the importance of social influence and outcome expectations in technology adoption [16], it is important to note that the context of the study—specifically, the adoption and utilization of the FIMS in field incident management—may differ from previous studies that examined broader technology adoption contexts. The unique nature of field incident management systems and the specific tasks and requirements involved may contribute to different adoption and usage patterns.

2) *Model fit and explained variance*: The analysis of the model fit and explained variance provides insights into the goodness-of-fit of the UTAUT Model and its ability to explain the variance in the dependent variable. The findings indicate that the UTAUT Model explains a modest proportion of the variance in the adoption and utilization of the FIMS. The R-square value of 0.198 suggests that 19.8% of the variation in the dependent variable can be explained by the predictor factors included in the model. While this may appear relatively low, it is important to consider that technology adoption and usage behaviors are influenced by a multitude of factors beyond those captured by the UTAUT Model. Future research should explore additional variables and factors that may contribute to a more comprehensive understanding of technology adoption and utilization in the field incident management context.

Furthermore, the collinearity statistics indicate that there is no significant multicollinearity among the predictor variables in the UTAUT Model, except for the presence of collinearity in condition index 6. This suggests that the predictor variables are reasonably independent of each other and do not excessively overlap in their explanatory power. However, the presence of collinearity in condition index 6 should be considered and further investigated in future studies.

## VI. CONCLUSIONS AND IMPLICATIONS

### A. Conclusion

This study identified several important findings regarding the factors impacting technology adoption and usage behaviors within the UTAUT Model. The study revealed that social influence and effort expectancy had no significant influence on the dependent variable, suggesting that social factors and perceived ease of use may not be substantial drivers of technology adoption and usage behaviors in this context. On the other hand, performance expectancy exhibited a moderately negative connection with the dependent variable, indicating that people's expectations about technology's performance may have a minor detrimental impact on their adoption and usage behaviors. Facilitating conditions and user effort, however,

demonstrated significant positive relationships with the dependent variable, highlighting the importance of resource availability and effort exerted by users in determining technology adoption and usage behaviors. Behavioral intention and the intercept term did not have a significant effect on the dependent variable, indicating that they do not directly contribute to explaining heterogeneity in technology adoption and usage behaviors.

The study contributes to the theoretical understanding of technology adoption and usage behaviors by shedding light on the relative importance of different components within the UTAUT Model. It also highlights the need for further research to explore additional variables and validate the model's performance in different contexts, ultimately improving the understanding of technology adoption and usage behaviors.

### B. Theoretical Implications

The theoretical implications of the conclusion provide insights into the relative importance of different factors within the UTAUT Model and highlight the need for further research to enhance the understanding of technology adoption and usage behaviors. The findings contribute to the refinement and development of theoretical frameworks and provide guidance for researchers and practitioners in understanding and promoting technology adoption and usage in various contexts.

### C. Managerial Implications

The managerial implications of the conclusion guide managers in prioritizing facilitating conditions, encouraging user effort, contextualizing social influence and performance expectancy, continuously improving their understanding of adoption factors, and being mindful of collinearity and model fit considerations. By implementing these implications, managers can enhance the adoption and effective usage of technology within their organizations, leading to improved productivity, efficiency, and overall performance.

### D. Limitations and Directions of Research

Conducting the study with a larger and more diverse sample would provide a more robust understanding of the relationships between the variables. The non-significant relationships found in the study should be interpreted with caution. The lack of significance may be influenced by the sample size or effect sizes, and further research with a larger sample is needed to confirm or refute these relationships. Additionally, the study focused on a specific context or population, which may limit the generalizability of the findings to other settings. Future research should consider the influence of contextual factors, such as cultural differences or industry-specific characteristics.

To address these limitations and further advance the field, future research directions can be pursued. One direction is to explore additional variables that could enhance the predictive power of the UTAUT Model. Factors like perceived risk, trust, or personal innovativeness could be included to provide a more comprehensive understanding of technology adoption and usage behaviors.

Moreover, conducting comparative studies across different contexts or populations would help validate the findings and

identify potential variations in the relationships between the variables. This would contribute to the development of a more robust and contextually relevant model.

While the current study sheds light on the factors influencing technology adoption and usage behaviors, it is crucial to consider the limitations and pursue future research directions to strengthen the knowledge in this area. By addressing these limitations and expanding the scope of the investigation, researchers can make significant contributions to theory and provide more practical insights for managers and practitioners.

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# Damage Security Intelligent Identification of Wharf Concrete Structures under Deep Learning and Digital Image Technology

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**Abstract**—Artificial Intelligence (AI) technology has quickly developed under the mighty computing power of computers. At this stage, there are many mature non-destructive testing methods in civil engineering, but they are generally only suitable for simple structures and evident damage characteristics. Therefore, it's necessary for us to investigate the damage identification of wharf concrete structures under deep learning and digital image technology. The article propose a damage detection and localization method based on Neural Network (NN) technology in deep learning and Digital Image Correlation (DIC) to identify internal damage to concrete used for wharf construction. Firstly, the identification model of concrete structure is constructed using NN technology. Then, structural damage identification of concrete is further investigated using DIC. Finally, relevant experiments are designed to verify the effect of the model. The results show that: (1) The damage model of concrete structure constructed by NN technology has high convergence and stability and can control the test error well. (2) The image output by the DIC equipment is processed and input into the NN. The errors of the various parameters of different concretes can be within the acceptable range. This paper aims to provide good ideas and references for follow-up structural health monitoring and other topics and has significant engineering application value.

**Keywords**—Structural damage identification; deep learning; neural network; digital image; concrete

## I. INTRODUCTION

In recent years, deep learning and artificial intelligence have developed rapidly. Structural damage identification methods based on AI are gradually applied in practical engineering. In AI, domestic and foreign experts and scholars generally focus on techniques such as the Genetic Algorithm (GA), wavelet analysis, and Neural Networks (NNs) [1]. Zhang and Zhang used GA to locate and quantify the degree of damage and proposed a new form of genetic search optimization objective function. They proved that the method could effectively identify the damage location and degree of an elastic structure through the numerical simulation analysis of the visible structural damage of a flexible structure based on the modal analysis theory [2]. Huang et al. proposed a damage identification method based on GA. The method combined the modal flexibility matrix to identify the structural damage to the shear wall. The results showed that the method could identify damage under insufficient dynamic data through experimental analysis and numerical simulation [3].

Li et al. proposed a damage identification method based on GA and the damage structure model. For the cracked cantilever beam structure, the optimization calculation of binary and continuous GA was used to prove that this method accurately identified the structure's damage location and degree [4].

Scholars proposed the Digital Image Correlation (DIC) at South Carolina State University in 1981. Scholars calculated the surface displacement of the sample by converting the ultrasound information into a two-dimensional digital ultrasound image. After comparison, the image strain of the sample could be obtained and used to measure the average thickness of the material [5]. Later, it was found that a fast Fourier transform could be used to obtain the corresponding local displacement data caused by the displacement change of the sub-region by dividing the two speckle images. It could be successfully applied to studying the deformation field at the crack tip, developing this method [6]. At present, in the field of civil engineering, the DIC measurement method is mainly applicable in two directions: one is to observe the crack propagation and deformation status of reinforced concrete components in real-time, and the other is to observe the strain and displacement fields on the surface of reinforced concrete components after deformation in real-time. Now certain research results have been achieved in both aspects. Molina Viedema et al. used a frame structure as the research object and extracted the working modes of the structure under random vibration excitation using the three-dimensional dynamic displacement field provided by DIC method. Local mode filtering method was used to identify and locate the damage of the frame beam, achieving high positioning accuracy [7]. Kleinendorst used DIC measurement technology to study the stiffness damage identification of reinforced concrete beams, and compared it with the measured values of deflection displacement and the results of finite element modeling of beams at various stages. He concluded that DIC measurement error is very small and has high accuracy, and that it can be used for Structural health monitoring [8]. Through the research literature, it is found that the current research on damage identification of DIC technology focuses on the extraction of damage modes and features. After the strain cloud map is obtained, the stiffness characteristics and other information are still obtained according to the traditional method, and the combination with AI is weak. This paper proposes a quantitative identification method for concrete

internal damage based on Deep Learning (DL) and finite element modeling. The performance of the NN is verified based on the measured value of concrete based on DIC, and the non-destructive detection of concrete damage is realized. The innovation is that You Only Look Once (YOLO) technology is introduced into the concrete damage identification model, which improves the detection effect of the model. Most of the previous work still stayed at the level of damage mode and feature extraction, and the damage index was taken as the input of the neural network through preprocessing, instead of directly learning from the data and using convolutional neural network to directly learn the damage features. At present, the research on the internal damage of concrete by using two-dimensional convolutional neural network and digital image correlation method is still in the initial stage. The combination of deep learning and DIC methods in structural damage identification not only obtains the true state of the structure, but also fully utilizes the advantages of neural networks in solving inverse problems, ensuring that a large number of samples can be used as training sets for deep learning, while also ensuring the reliability of neural networks in real structural problems.

The second chapter briefly introduces the characteristics and network structure of YOLO network, the way of prediction output and the composition of Loss function. Based on YOLO, the neural network model required for this study is built, which lays a good foundation for the subsequent network training. Then, the basic theory of DIC and the experimental research content of concrete damage identification based on DIC were summarized, and the prediction effect of neural networks under real concrete damage was verified. The third section provides a detailed analysis of the experimental results, which indicate that DIC technology and deep learning technology can be effectively integrated for the detection of internal damage in concrete, and the overall detection accuracy is high.

In this paper, the article aims to provide a new development direction for the realization of non-destructive testing inside the concrete. The article introduced the AI-related technologies including NNs, target detection technology, YOLO and DL. The article trained the NN using the Anaconda environment and provided the detailed parameters in the experiments. For the image processing, the article adopted the finite element simulation method and simulated the pictures of each concrete beam. The Root Mean Square Error was adopted to measure the error of each parameter.

## II. METHODS AND MODEL DESIGN

### A. AI and NNs

AI is a discipline that studies and develops human intelligent systems, involving extensive research in robotics, Computer Vision (CV), Natural Language Processing (NLP), and expert systems [9]. In achieving this goal, Machine Learning (ML) is required to provide technical support. The core of ML is to use algorithms to guide computers to use data to obtain appropriate mathematical models. ML is widely used in solving AI problems [10]. Therefore, ML is an implementation method of AI, and it is also the most critical

implementation method. ML has become the method of choice for AI to develop helpful software for CV, Automatic Speech Recognition (ASR), NLP, robot control, and other applications [11]. Research on NN has appeared for a long time. Initially, it was a biological concept. After that, AI was inspired by NN, and Artificial Neural Networks (ANN) appeared [12]. ANNs are based on the basic principles of biological NNs. Its theoretical basis is the knowledge of network topology. ANN simulates the processing mechanism of complex information by the nervous system of the human brain [13]. Like the human nervous system, the NN is a complex network structure composed of many simple neurons connected and transmitted, as shown in Fig. 1.

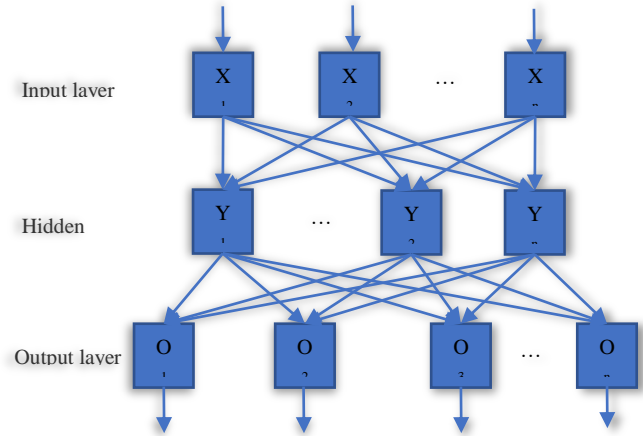


Fig. 1. ANN

DL enables many applications of ML and expands the field of AI. DL has enabled AI systems to achieve significant performance improvements in many important problems such as CV, ASR, and NLP. It has become the key to the current breakthrough of AI [14]. Fig. 2 shows the relationship of AI-related concepts.

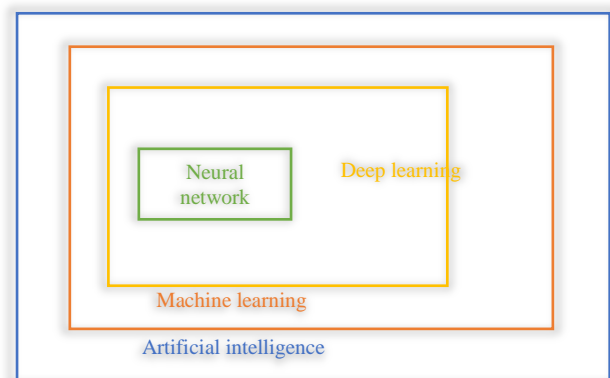


Fig. 2. Relationship of AI-related concepts.

### B. Target Detection Technology

Target Detection (TD) uses the powerful computing ability of computers to find objects of interest in an image or video and determine their location and size. TD is a key problem in CV [15]. Since the era of DL, the development of object detection has focused on two directions. The first is the Two-



Stage algorithm, such as the Region-Convolutional Neural Network (R-CNN) series. The second is the One-Stage algorithm, such as Single Shot MultiBox Detector (SSD) [16]. The Two-Stage algorithm needs to generate Proposal and then perform fine-grained object detection. The One-Stage algorithm extracts feature directly in the network to predict object classification and location [17]. In the Two-Stage algorithm, Faster R-CNN structurally integrates feature extraction, candidate region extraction, target box regression, and classification into an end-to-end network. The comprehensive performance, especially the detection speed, has been dramatically improved. So, Faster R-CNN has become the classic network of Two-Stage. In the One-Stage algorithm, SSD converts detection into regression and completes target positioning and classification. A similar Prior Box concept is proposed based on the prior box concept in Faster R-CNN. In addition, the detection method based on the feature pyramid is added. Targets are predicted on feature maps of different receptive fields. Compared with Faster R-CNN, Prior Box has obvious speed advantages and has become the classic One-Stage network [18].

### C. Design of Damage Identification Model Based on YOLO and DL

1) *Introduction to YOLO:* YOLO is an object identification and localization algorithm based on DNNs. This algorithm is a typical one-stage TD algorithm. The core idea is to use the entire image as the network's input and directly return the position of the bounding box and its category at the output layer [19].

YOLO has some unique advantages in the algorithm. These advantages are advantageous for identifying damage within concrete. First, YOLO is very fast at detecting objects. The detection process is simple. The image to be tested is input into the NN to output the detection result. Therefore, the detection speed can be improved a lot. The standard version of YOLO can process 45 images per minute on the Titan X GPU [20]. The traditional Two-stage network has low detection efficiency, but it can be trained with the help of the network pre-trained by the algorithm designer, which can greatly speed up the training process. The image cardinality of this paper is large. There are ten thousand images of concrete beams alone, and the images are all self-made. There are no pre-training parameters for reference, so detection efficiency is essential. Moreover, YOLO's AccessPoint (mAP) is more than twice that of other previous real-time object detection systems, achieving high accuracy in real-time detection algorithms. In addition, YOLO can learn generalization features of objects. Existing tests have shown that YOLO's performance is much better than the object detection systems before DPM and R-CNN when using artworks for testing after it is trained on natural images. It indicates that YOLO can learn highly generalized features, which is helpful for this paper to study the learning of the information projected by internal damage to the concrete surface [21].

2) *Network structure:* Factors such as input accuracy and training duration are considered comprehensively. Darknet-19

is used as the main network for training and testing. Fig. 3 displays the structure of Darknet19.

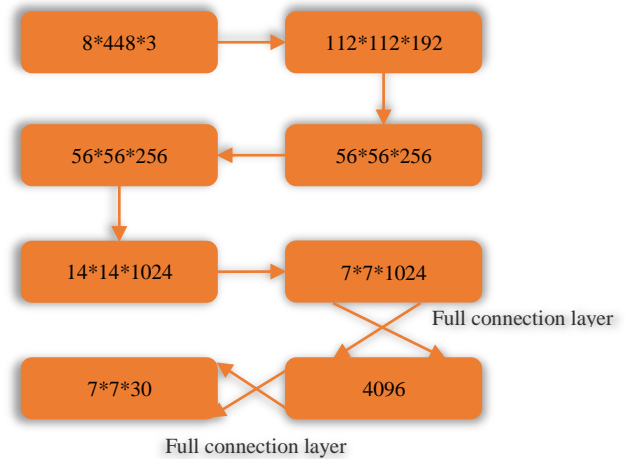


Fig. 3. Schematic diagram of darknet-19 network structure.

The Darknet-19 network is improved based on the GoogLeNet classification network structure. It refers to the experience of the Visual Geometry Group network. It uses a 3×3 convolution kernel and doubles the number of channels after each pooling layer. The Darknet-19 network draws on the idea of the Network in Network and uses global average pooling at the end of the network. The 1×1 convolution kernel is placed between the 3×3 convolution kernels to compress the features, improving the abstraction ability of the convolution layer. Meanwhile, the batch normalization method is used in each network layer. The neurons in the NN of each layer that gradually deviate with the training are pulled back to the standard normal distribution with a mean of zero and a variance of one and normalized. The purpose of stable model training is achieved while improving the training speed.

3) *Prediction of the output:* YOLO has two different approaches to predicting the output. YOLO-v1 uses a method of directly regressing the position of the bounding box, which can utilize the complete information on the entire image. The a priori frame is referenced when predicting from YOLO-v2, and the bounding box size of the final detection is fixed to 9 types. Different sizes of a priori frames are used for detection on various receptive fields, which can improve the recall rate of the prediction results but reduce the prediction accuracy. Besides, the Intersection of Union (IoU) of the predicted bounding box and the ground-truth box is also affected by the size of the prior box. The types of damage are not distinguished here, and the classification requirements of the NN are not high. In contrast, the regression requirements of the damage location are high, so the direct regression bounding box method is selected to predict the output.

4) *Loss function:* The loss function is a measure used to evaluate the degree to which the model's predicted value differs from the true value. The better the loss function, the better is the model's performance in general [22]. The loss function of YOLO-v1 consists of four parts: center coordinate error, width and height coordinate error, confidence error, and

category prediction. The TD here adds the positioning in the depth direction, as shown in the following equation.

$$Loss = Loss_{xy} + Loss_{wh} + Loss_{oc} + Loss_{noc} + Loss_c + Loss_d + Loss_{IoU} \quad (1)$$

In Eq. (1),  $Loss_{xy}$  refers to the loss function of the center coordinate prediction part. It can be expressed as:

$$Loss_{xy} = \lambda_{coord} \sum_{i=0}^{S^2} \sum_{j=0}^B I_{ij}^{obj} \left[ (x_i - x_i)^2 + (y_i - y_i)^2 \right] \quad (2)$$

In Eq. (2),  $I_{ij}^{obj}$  is used to determine whether the  $j$ th box in the  $i$ th grid is responsible for the prediction of the object. If the grid contains objects, the value is one. If not, it is zero.  $\lambda_{coord}$  is the loss weight coefficient, which is generally five.  $x_i$  and  $y_i$  are the coordinates in the  $x$ -direction and  $y$ -direction, respectively, within the bounding box.  $S^2$  is the area of the prediction box, and  $B$  is the area of the ground-truth box.

$Loss_{wh}$  refers to the loss function of the width and height coordinate prediction part. It is expressed as:

$$Loss_{wh} = \lambda_{coord} \sum_{i=0}^{S^2} \sum_{j=0}^B I_{ij}^{obj} \left[ (\sqrt{w_i} - \sqrt{w_i})^2 + (\sqrt{h_i} - \sqrt{h_i})^2 \right] \quad (3)$$

In Eq. (3),  $w_i$  and  $h_i$  are the coordinates in the width and height directions of the predicted bounding box, respectively.

$Loss_{oc}$  is the loss function for the confidence prediction of bounding boxes containing objects.

$$Loss_{oc} = \sum_{i=0}^{S^2} \sum_{j=0}^B I_{ij}^{obj} (C_i - C_i)^2 \quad (4)$$

In Eq. (4),  $C_i$  represents the predicted bounding box.

$Loss_{noc}$  is the loss function for the confidence prediction without the object's bounding box.

$$Loss_{noc} = \lambda_{noobj} \sum_{i=0}^{S^2} \sum_{j=0}^B I_{ij}^{noobj} (C_i - C_i)^2 \quad (5)$$

In Eq. (5),  $\lambda_{noobj}$  is the weight coefficient generally 0.5.

$Loss_c$  refers to the loss function of category prediction.

$$Loss_c = \sum_{i=0}^{S^2} I_{ij}^{obj} \sum_{c \in \text{classes}} (p_i(c) - p_i(c))^2 \quad (6)$$

$Loss_d$  refers to the loss function of depth coordinate prediction.

$$Loss_d = \sum_{i=0}^{S^2} \sum_{j=0}^B I_{ij}^{obj} \left[ (s_i - s_i)^2 + (d_i - d_i)^2 \right] \quad (7)$$

In Eq. (7),  $d_i$  represents the value of the pier concrete beam in the depth direction.

$Loss_{IoU}$  refers to the loss function of the prediction of the intersection and ratio.

$$Loss_{IoU} = \sum_{i=0}^{S^2} \sum_{j=0}^B I_{ij}^{obj} (IoU - IoU)^2 \quad (8)$$

In Eq. (8),  $IoU$  measures the accuracy of detecting corresponding objects in a specific dataset.

The loss function adds depth-wise and cross-union ratio predictions. If each part's weight loss in YOLO-v1 continues to be used, the NN cannot achieve good results. Therefore, the above loss function combination is used as the loss in the network construction and debugging stage. After the network debugging is completed, the parameters are adjusted, and the loss function is recombined according to the error of the test results, which can ensure the accuracy of the NN learning.

#### D. Training and Testing of Concrete Damage Identification NN

1) *Network training and testing process:* According to the damage identification NN designed by YOLO above, the process of training and testing its NN is shown in Fig. 4.

2) *Dataset source:* Images of concrete damage in civil engineering are collected and modeled in batches using finite element software. The exported images are used to make datasets for DL.

3) *Experimental environment:* The NN is trained using the Anaconda environment, and Table I reveals the parameter settings in the environment.

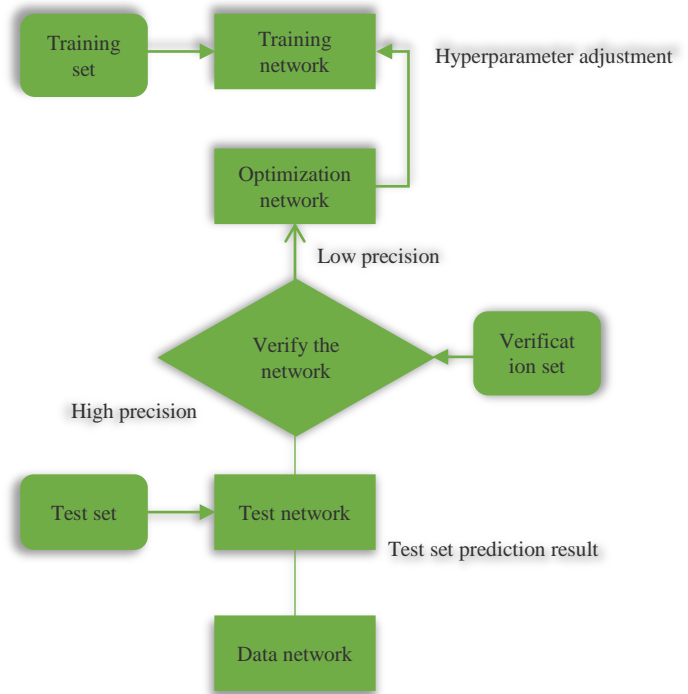


Fig. 4. NN training and testing process.

TABLE I. EXPERIMENTAL ENVIRONMENT AND PARAMETER SETTINGS

Parameter Name	Value
System language	Python3.8
Editor	Py Charm
GPU (Graphic Processing Unit)	Titan RTX (Ray Tracing Texel eXtreme)
Server bits	64
Graphics card name	NVIDIA Titan RTX
Graphics memory	24G
Epoch	25
The number of training sets for a single learning	
Loss function	Equation (1)

### E. Concrete Damage Identification Method Based on DIC Technology

1) *DIC technology*: The basic theory of the DIC method is to obtain the surface displacement deformation by extracting the differential information of the surface of the object. The natural speckle on the object's surface can be directly used, and the speckle can be artificially produced. The gray gradient is the carrier of the deformation information of the structure surface. Artificial speckles can increase the number of feature points on the surface of the object under test, thereby increasing the gray value of the surface under test. The displacement of the feature points in the coordinate system before and after the deformation is calculated by the correlation algorithm to determine the deformation value of the whole image [23].

2) *Correlation function*: Before calculating the correlation algorithm, it is necessary to discriminate and define the degree of matching between the sample sub-region and the target sub-region, so a correlation function is introduced. The correlation function is the function of the deformation parameter to be obtained. The DIC method calculates the similarity of the two sub-regions before and after deformation using the gray gradient value of the speckle image to get an accurate deformation parameter estimation. Commonly used criteria can be divided into cross-correlation and variance synthesis criteria according to the algorithm [24].

3) *Error analysis of displacement measurement*: The displacement measurement accuracy of the DIC method is affected by the specimen's gray gradient, the equipment's imaging system, and the related algorithms. The role of speckle is to improve the characteristics of the specimen surface. During the test, a series of problems, such as the difference in the grayscale gradient of the speckle image, the reflection on the component's surface, and the change of the light during the test, will affect the clarity of the image capture. The imaging system inevitably produces errors due to device angle, camera lens position, and quality differences. The clarity of the image will be affected due to a series of problems, such as the difference in the grayscale gradient of the speckle image, the reflection on the component's surface,

and the change of light during the test. At the algorithm level, selecting the sub-region size, interpolation algorithm, and shape function of the study area will cause different systematic errors in the calculation [25].

4) *Camera calibration*: Camera calibration is the process of obtaining the internal and external parameter matrices of the camera. The internal and external parameter coefficients obtained through calibration can be used to correct the images captured by the camera later to obtain images with relatively small distortions. The accuracy of calibration directly affects the final measurement results, so it is the most basic and important part of binocular stereo vision [26].

5) *Composition of the measuring system*: Here, the measurement and reading of the concrete surface information adopt the DIC method. The measurement system consists of hardware and software. The hardware is mainly image acquisition and reading equipment, and the software includes algorithm selection for image correlation operations. It is important to ensure that the environment cannot change greatly during the image acquisition process to ensure the accuracy of the deformation measurement of the structure surface by the relevant algorithm, including the erection position of the camera and the lighting conditions of the structure surface. Therefore, the fill light is erected during the test, and the camera should not move after the erection is completed. The loading process is recorded by a 3D DIC method based on the principle of binocular stereo vision to identify the changes in the concrete surface, reduce the distortion, and prevent the partial out-of-plane displacement of the concrete from affecting the test results. Fig. 5 shows the measurement system of the 3D DIC method [27].

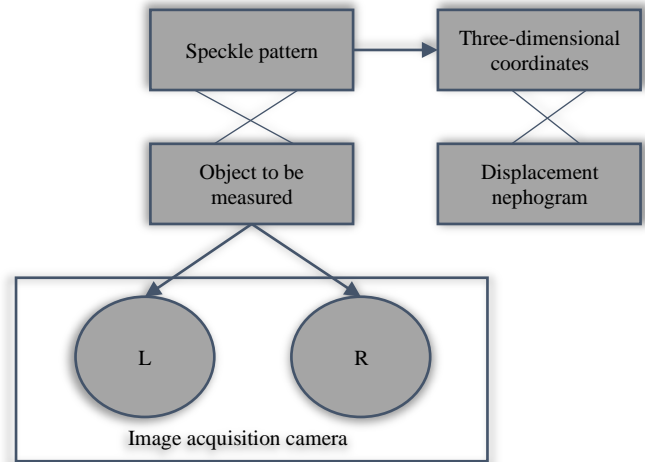


Fig. 5. 3D DIC method measurement system.

### F. Concrete Damage Identification Process Based on DIC Technology

According to the relevant theory of DIC technology, the concrete damage identification process based on DIC technology is shown in Fig. 6.

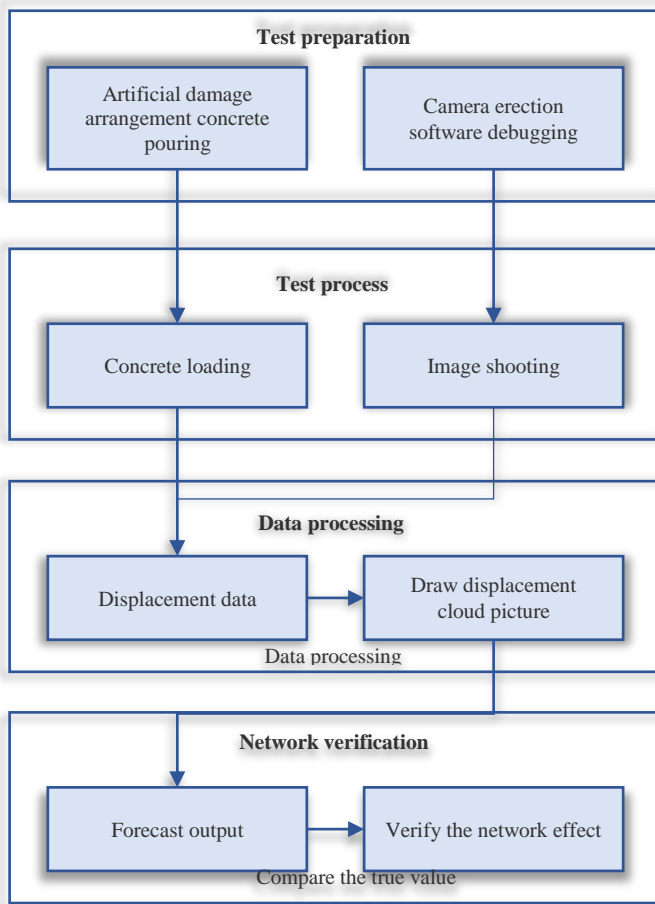


Fig. 6. Concrete damage identification test process based on DIC technology.

### G. Experimental Design

A total of seven reinforced concrete beams for constructing the wharf are selected in the experiment, represented by A-G, respectively. The dimensions of the concrete beams and the internal reinforcement arrangement are consistent with the finite element modeling results. First, the pictures of reinforced concrete beams are extracted by DIC equipment. Then, the finite element simulation method is adopted, a load of concrete is set to 21kN, and the pictures of each concrete beam are simulated. Finally, the processed images are input into the previously trained NN. The prediction results of seven parameters, including the damage center coordinates, the bounding box's size, and the confidence level corresponding to each image, are generated. The predicted value is compared with the actual size and position of the foam block prevented during the test, and the error of each parameter is obtained. The standard of measurement is the Root Mean Square Error [28].

## III. RESULTS

### A. Effect of Damage Model of Wharf Concrete Structure based on YOLO and DL

1) *Concrete beam test results:* The NN completes learning after 100 cycles of training with the selected NN. The training situation of the obtained NN is presented in Fig. 7. From Fig.

7, the overall loss of the NN decreases smoothly during the training process. The method of adjusting the learning rate by gradient makes the network converge rapidly in the early stage of training. In the middle and later stages of training, there is no situation where the predicted value exceeds the real value, resulting in a significant rebound in the loss value. During the later stages of training, the validation loss stabilizes at around 0.24. However, the training set's loss value still decreases, indicating that the NN is overfitting, but the overall effect on the validation set is not large.

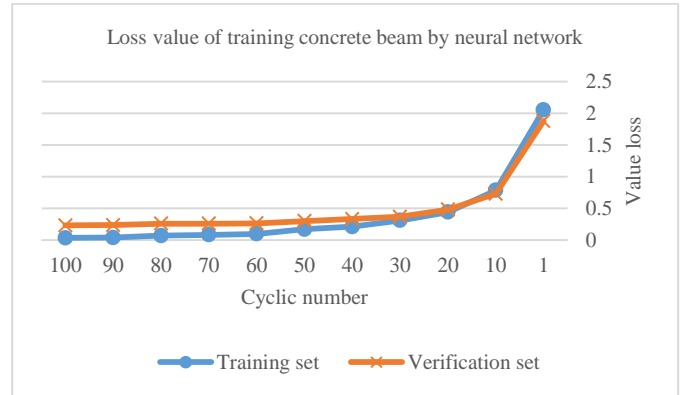


Fig. 7. Loss values for training a concrete beam with an NN.

2) *Test results of the concrete column of the wharf:* The concrete piles are also trained using the previously selected network for 100 cycles. The judging criteria also use the network loss value and the test set accuracy. Fig. 8 reveals the concrete column test results. Fig. 8 indicates that the overall convergence of the network is good, and the curve is smooth. Compared with the training of concrete beams, the fluctuation of the validation set of concrete piles is more prominent, and there is also some overfitting phenomenon. The loss value stabilizes around 0.38, and the network accuracy is slightly inferior to the concrete beam network. The number of images in the training set of concrete piles is only about 0.14 of that of concrete beams. Therefore, the difference between the loss values of the two is within an acceptable range.

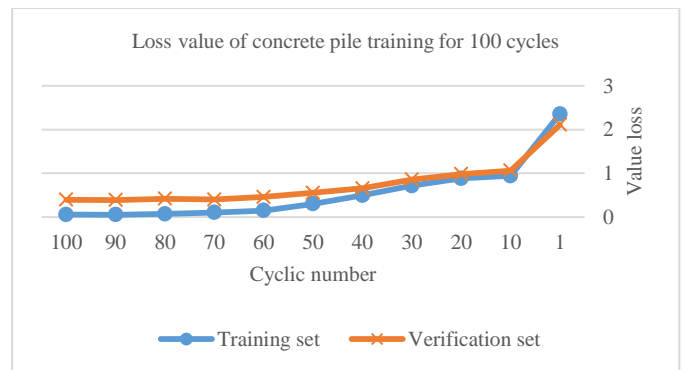


Fig. 8. Loss values for 100 epochs of concrete pile training.



### B. Verification of Concrete Damage Identification Method Based on DIC Technology

The load on the concrete is set to 21kN. At this time, the processed images are input into the previously trained NN. The prediction results of seven parameters, including the damage center coordinates, the bounding box's size, and the confidence level corresponding to each image, are generated. The predicted value is compared with the actual size and position of the foam block prevented during the test. Fig. 9 shows the error of each parameter. Fig. 9 shows that the errors differ for different concrete beams. The prediction error tends to be large when the concrete damage is minor. The overall data show that the error of each concrete beam is within the acceptable range, and the estimation of the damage position and size of the concrete has been accurate. It shows that the damage identification network constructed here has good robustness.

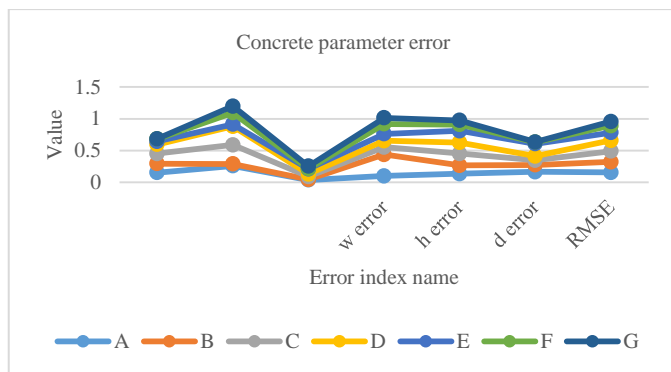


Fig. 9. Concrete beam parameter error.

### IV. CONCLUSION

This paper is the first time to carry out a series of research on the internal damage location of concrete structures based on the plane distribution information in China, and provides a good idea and reference for the follow-up Structural health monitoring and other topics, which has important engineering application value.

To sum up, this paper uses the finite element model to simulate the internally damaged concrete structure. This research article took the position and size of the concrete damage learned and predicted in the DLNN as input. Meanwhile, the article applied the DIC and applied concrete surface parameters in laboratory tests. Then, the NN is input to train again to obtain the identification errors of different concrete structural damages. The results show that: (1) The YOLO algorithm in the one-stage algorithm has the advantages of fast detection speed, strong generalization ability, and low background identification error rate. (2) When predicting the damage size and depth of concrete beams, it is found that the prediction accuracy increases as the damage size and depth decrease. (3) The trained NN has a good prediction effect on each parameter of the concrete structure. The disadvantage is that the NN in this paper is built based on the YOLO algorithm, which can achieve multi-damage prediction. However, due to time constraints, multi-damage structures are not considered in the modeling phase. In subsequent work, multiple damages can be arranged in the

concrete members. In the prediction, the non-maximum suppression method can be used to output multiple damage locations at one time. Then, the prediction ability of the NN for multiple damages in concrete is tested. This paper is of great significance and value for applying and promoting prefabricated structures. It also provides new ideas for the damage of concrete internal defects and the batch detection of prefabricated structures. (4) The neural network in this study is built based on the YOLO algorithm and can achieve multi damage prediction. However, due to time constraints, the construction of multi damage was not considered in the modeling phase. In subsequent work, multiple damages can be considered in concrete components, and non-maximum suppression methods can be used to output multiple damage locations at once during prediction, to test the predictive ability of the neural network for multiple internal damages in concrete. (5) In the DIC based experimental verification section, the quality of the concrete surface displacement cloud images generated by some components is poor, which is closely related to hardware equipment, experimental environment, etc. In the subsequent work, a higher lens quality camera can be used for shooting in a more stable environment to ensure the quality of the generated displacement cloud map.

### ACKNOWLEDGMENT

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# Application of Top-N Rule-based Optimal Recommendation System for Language Education Content based on Parallel Computing

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**Abstract**—In recent years personalized recommendation services have been applied to many areas of society, typically in the fields of e-commerce, short videos and so on. In response to the serious performance problems of the current online language education platform content recommendation, so in the face of the above opportunities and challenges, this paper designs a new online English education model to allow university students to get a full and more three-dimensional training of English language learning. Based on the MU platform, this paper obtains data from the platform and uses crawler technology to sample and standardize the learning resources for online education. Then user information, such as explicit and implicit ratings of courses, is selected as the main basis for training a user interest preference model. Immediately afterwards, a PRF algorithm combining data parallelism and task parallelism optimization was executed and implemented on Apeche Spark to provide some optimization of data accuracy and content recommendation methods. Finally, the top-N recommendation rule is used to propose a dynamic evolutionary process of identifying students' preferences or learning habits through the results of previous data analysis, so as to make more accurate course content recommendations and learning content guidance for students' English learning. The online three-dimensional teaching model proposed in this paper focuses more on time-series research than traditional algorithms, and can more accurately capture the dynamic changes in students' learning abilities.

**Keywords**—Data parallel computing; cloud computing; data crawlers; top-N rules; PRF algorithm

## I. INTRODUCTION

With the rapid development of the Internet, the mobile Internet has created more opportunities for education, and online education has emerged, and synchronous online education in higher education has gained widespread attention. According to "China Internet Education Market Trends Forecast 2018-2020" released by Analysis Eiconet, as the degree of mobile further deepens, the types of mobile education platforms: become more and more rich and diverse. After the outbreak of the epidemic, social awareness of online education has risen tremendously, and formal learning platforms as well as informal learning platforms can now be found everywhere. Traditional forms of education that have been in place for thousands of years are also gradually changing with the changes in society and the environment. Existing education products are becoming more and more

integrated and easier to use, enhancing the efficiency of the learner [1].

With the rapid rise of cloud computing, mobile internet technology and the Internet of Things, as well as the emergence of various information dissemination methods, the volume of business data in various application areas is exploding and the value of big data applications in various fields is becoming increasingly important. The emergence of the Big Data era has brought unlimited opportunities for everyday life, production and research, while at the same time raising unprecedented challenges.

On the one hand, through the analysis and mining of big data, we can discover the valuable information and laws implied in it and provide us with various decision support. With the support of rich Big Data processing technologies, such as consumer behavior analysis, product sales forecasting, precise personalized marketing, scientific research analysis, etc., the quality of production and services in various fields of application can be improved and optimized in a comprehensive manner.

On the other hand, such a rapidly growing and complex data resource poses a huge challenge to traditional data processing technology and computing power. The processing of big data has become even more complex due to its large scale, high dimensionality, complexity and noise characteristics. At present, traditional machine learning and data mining algorithms cannot directly analyses and process massive amounts of data effectively and accurately. Data parallelism is a parallel strategy whose main logic follows the principle of Single Program Multiple Data.

In data-parallel model training, the training task is split across multiple processes (devices), each maintaining the same model parameters and the same computational tasks, but processing different data. Data parallelism splits up the data that can be used to solve the problem and places the split data on one or more cores for execution; each core performs similar operations on this data.

High-performance computing, distributed computing and cloud computing provide powerful computing capabilities for large-scale data analysis and machine learning techniques. Apache Hadoop and Spark are both well-known cloud computing platforms widely used for big data analysis and massively parallel computing. Many parallel machine learning

and data mining algorithms have been implemented based on the Hadoop MapReduce and Spark RDDI69 models with significant results. Spark supports a parallel programming model for Resilient Distributed Datasets (RDD) and Directed Acyclic Graphs (DAG), which is built into the in-memory computing framework. Zaharia et al. propose a fast interactive Hadoop data query architecture based on Spark, by caching data in memory, the architecture is able to provide a fast interactive data query service with a 40 times speed advantage over Hadoop [2-5].

In the implementation of high school English courses, teachers focus more on students' learning of English language knowledge, while university English courses pay more attention to the development of students' language skills and their ability to use language in future work and real-life social communication. However, some scholars have found that in an analysis of university students' English listening and speaking ability dilemmas, it was found that students' pronunciation was not accurate enough, their vocabulary for language expression was inadequate, the training of oral listening and speaking ability was in a single form, and the lack of learning objectives for listening and speaking ability restricted the improvement of students' listening and speaking ability. Therefore, with the rapid development of computer technology, many educators adopt the online education platform, with the computer data processing algorithm, to carry out three-dimensional teaching for students according to local conditions.

## II. DATA COLLECTION AND PROCESSING OF MU ONLINE PLATFORM

Web crawlers have been broadly used in information series and acquisition in current years, and wealthy crawler frameworks are reachable to meet the desires of crawler builders for precise facts acquisition. In this chapter, we graph a disbursed crawler software primarily based on python scrapy crawler framework to crawl and manner the path records in the on line getting to know path platform Mucu in parallel [6,7]. The received statistics will be saved in the high-performance mongoDB to relieve the storage stress of the database, and then the statistics in the mangodb will be pre-processed and the pre-processed statistics will be saved in the mysql database to facilitate the subsequent evaluation and processing of the statistics.

### A. Design of Data Crawler

1) *Scrapy crawler framework*: Scrapy is a web crawler framework developed based on python program. scrapy is characterized by its ability to quickly extract structural data from websites and is one of the most widely used crawler frameworks in python. scrapy framework is customized according to user requirements to facilitate the acquisition and structured storage of web data, and its framework consists of eight main The framework consists of eight parts: python crawler engine, scheduler, downloader, spider, project pipeline, scheduling middleware, downloading middleware, and crawler middleware. Scrapy runs as shown in Fig. 1.

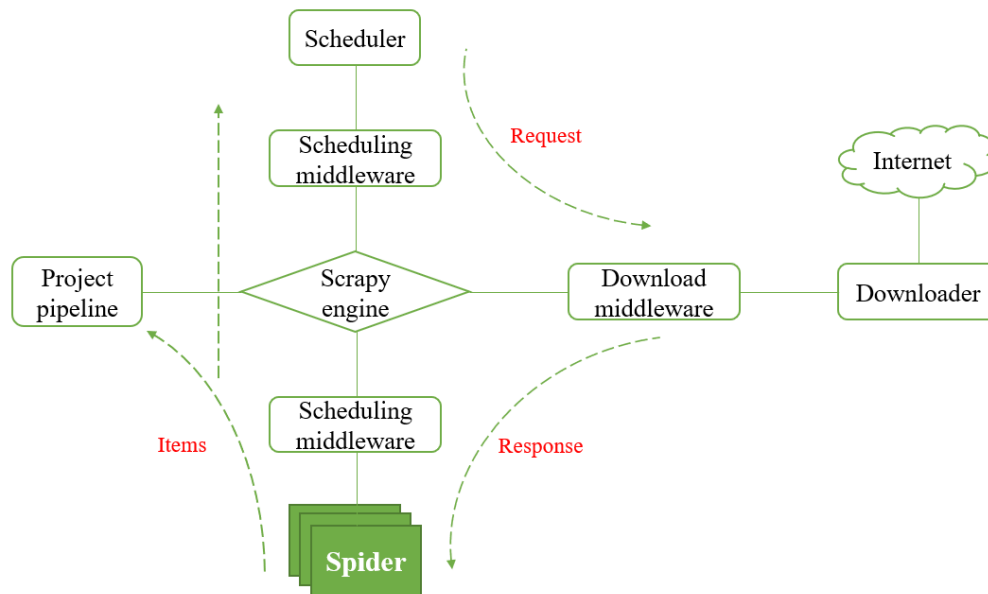


Fig. 1. Scrapy framework operation.

a) *Scrapy engine*: used to get the preliminary requests request internet records and manage the whole crawler facts flow, in a position to manage a couple of request duties at the identical time. After inquiring for the scheduler, it is usually prepared for the subsequent requests request.

b) *Scheduler*: The main task of the scheduler is to receive requests from the scrapy engine and store them in the

queue in a certain order and return the next requests to the scrapy engine.

c) *Downloader*: The scrapy engine returns the request results to the downloader, which downloads the corresponding web content and notifies the scrapy engine of the downloaded content.

d) When the scrapy engine receives the net content material back through the downloader, it returns to the spider for processing thru middleware. The spider can be described by way of the consumer in accordance to his personal needs, and the consumer can use the net factor positioning science xpath or css to function the internet factors to get the internet content material in a unique element.

e) After spider processing, the web content will be parsed into user-defined data, and the new request task will be sent to the scrapy engine through middleware, after storing the obtained web data items.

f) The scrapy engine sends the processed facts objects to the task pipeline and returns the requests to the scheduler, which plans to system the subsequent request. Whenever a request is done and records are fetched, the subsequent request will be made till all requests are finished.

2) *Course data crawler design and implementation:* In this paper, the object of crawling is the route statistics of the on-line gaining knowledge of platform study room website, and the public facts of the on-line course, such as direction name, direction id, route comment, direction remark time, route remark user, etc., is bought via the net crawler. Since the crawling website has anti-crawling restriction, which restricts the IP that is visited multiple times within a short period of time, this paper sets the time interval for requesting web pages as a random number of 1-2s to confuse the anti-crawling mechanism of the crawler when designing the crawler program, but after setting the interval, the crawling speed and efficiency decrease. In order to compensate for the crawling efficiency problem, in this paper, a distributed crawler design scheme is adopted. Multiple cloud servers are used to deploy web crawlers, and distributed crawler acquisition architecture is realized [8,9].

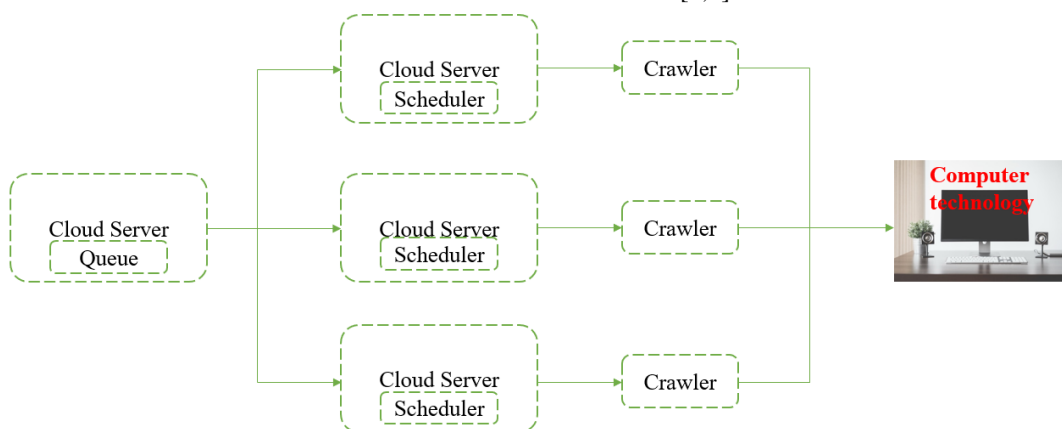


Fig. 2. Crawler algorithm framework.

The plan of dispensed crawler structure shares the queue in the cloud server to different cloud servers, and after the scheduler in different servers receives the request queue, the crawler software downloads the internet pages of the crawled website, and the crawler software locates the content material in the net web page factors to be bought and shops them in the database.

The crawler application is constructed the usage of the scrapy framework, and the waft of the crawler application to

attain Tencent school room information is proven in Fig. 2. Firstly, the url generator is deployed in the server, and the crawler is assigned the crawling url [10]. The downloader downloads the net web page content material in accordance to the url request, and the crawler shops the crawled factor content material into the database. When the url generator no longer generates the url, the request url is no longer acquired in the queue of the scheduler, and the crawler ends its operation at this time (as shown in Fig. 3).

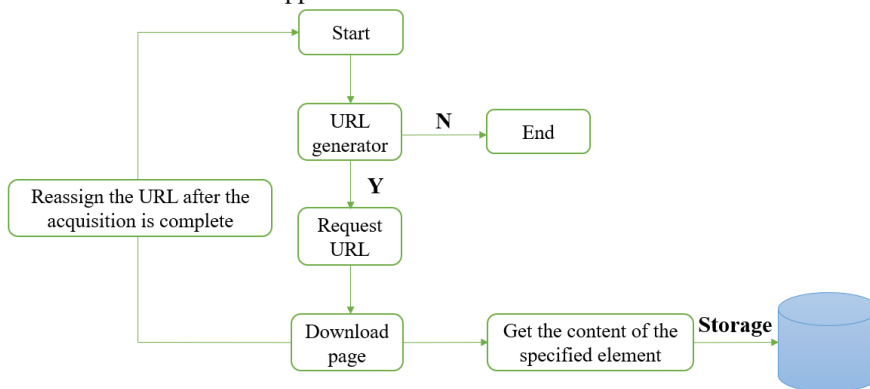


Fig. 3. Crawler algorithm flow chart.

## B. Data Pre-processing

Through the crawler program, this paper obtains a complete of 100,000 portions of data, the records carry direction information, as properly as the user's feedback on looking at the path information. Since the obtained textual content statistics has the following characteristics: First, there are greater extraordinary characters in Chinese text, such as emoticons and exotic punctuation marks, which are challenging to represent the traits of textual content content material information [11]. Second, Chinese textual content phrases are coherent with every other, and the distinction with English textual content is that English textual content phrases are separated by means of areas between words, which will be extra handy in textual content characteristic representation, whilst Chinese textual content wishes Chinese textual content wants to be divided into phrases with the aid of the use of phrase separation techniques. Based on the bought Chinese textual content information, there are two primary steps in the facts pre-processing stage: clearing the distinctive symbols in the textual content facts and deactivating the phrases and setting apart the textual content facts into phrases.

1) *Clear special symbols and deactivated words:* In the text processing, special symbols, such as “△▲★♠♣↑↓” and other characters, have little meaning in Chinese text and interfere with the vectorization of text, and there is also a category of deactivated words, such as “one by one, one by one”, which are less relevant to the semantic understanding of text. Words with low relevance are removed in the text preprocessing [12]. Then, based on the data obtained by the crawler, we observed and found the special characters that were applicable to the recommended text of this course, and expanded them to the general word list. Finally, we filtered the data according to this word list and got the preliminary cleaning data.

2) *Text segmentation:* Since there is no space in the middle to distinguish a word like English, Chinese is composed of a series of Chinese characters to form a sentence, so to make the machine understand the meaning of Chinese more accurately, word segmentation must be performed, that is, Chinese word separation. In the field of Chinese word segmentation, common word segmentation tools include: jieba, SnowNLP, THULAC, and NLPPIR.

Jieba Chinese phrase splitting system: jieba phrase splitting is one of the most famous Chinese phrase splitting systems, which has a sturdy integration with Python language. jieba phrase splitting helps three phrase splitting modes, which are precise mode, full mode and search engine mode. The actual mode is to break up Chinese sentences precisely, which is appropriate for Chinese textual content analysis; the full mode is to pick out all the phrases that can be linked into phrases in a sentence, which is quicker than different modes, however can't remedy the hassle of phrase ambiguity. The search engine mannequin is primarily based on the actual model, which cuts lengthy phrases greater cautiously to enhance the recall of phrase separation. jieba key algorithms for phrase separation are Viterbi algorithm for lexical annotation of Chinese words, tf-idf and textrank fashions for extracting key phrases [13].

SnowNLP is a library written in Python with rich Chinese text processing features that facilitate the processing of Chinese text content in the Python language. The main features of SnowNLP are Chinese text word separation, lexical annotation, simple sentiment analysis, plain Bayesian-based text classification, pinyin conversion, traditional and simplified character conversion, keyword and text summary extraction, and computation of text recall, etc.

THULAC is a Chinese lexical analysis tool led by the Natural Language Processing and Social Humanities Computing Laboratory of Tsinghua University, with the main functions of Chinese word separation and lexical annotation.

NLPPIR is a Chinese word sorting system developed by Beijing Institute of Technology, with rich features and powerful performance, it is a set of software that can handle and process text sets, providing visual display features, its main functions include: Chinese word sorting, word annotation, named entities, user dictionaries, new word discovery and keyword extraction. It can be used in a variety of programming languages, including python [14].

3) *Sentiment analysis data annotation:* Sentiment evaluation is a famous lookup center of attention nowadays, and the principal work is to mine the sentiment tendency in users' comparison texts, and analyze, process, summarize and conclude these texts. At present, sentiment evaluation has been utilized to many fields, which can assist users' selection making, opinion monitoring, etc. The coaching of deep gaining knowledge of primarily based sentiment evaluation neural community first off requires sentiment corpus, so constructing sentiment evaluation corpus statistics is a vital records prerequisite for this paper. Currently, there are two main ways to build sentiment annotated corpus: manual construction and machine learning-based construction. The manual method of building sentiment annotated corpus mainly involves multiple annotators to annotate this paper with sentiment and then uses voting to determine the final sentiment of the sentences; the machine learning based method needs to annotate the unannotated corpus with sentiment through machine learning with the help of annotated corpus. Due to the emotional tendency of the text of course review studied in this paper, there is no widely used corpus of course reviews annotation in the current research, so this paper adopts the method of manual annotation by multiple people to manually annotate the text data.

4) *Multi-person manual annotation:* In this paper, the annotation of route overview textual content is primarily based on sentence as the annotation granularity, which is the simple unit of semantic appreciation of text, and the annotation granularity of sentence can be extra correct to discover users' emotional mind-set and favorite choice of course [15]. After organizing the annotation granularity of textual content data, the guide annotation system adopts the annotation system of Nakagawa et al.

a) Three data annotators independently annotate the sentiment of text sentences, and the annotation results are

divided into three categories: positive, neutral, and negative. In the process of manual labeling, there are some sentences that are difficult to judge, and the sentences that are difficult to judge are labeled as difficult sentences.

b) Identification of annotation results: For non-difficult sentences, the voting principle is used, i.e., if two or more people label a sentence as the same sentiment category, the sentence will be judged as the category with more annotations. For difficult sentences, five people will be introduced for annotation, and the final annotation result will be taken as the category with the higher number of annotations.

c) Inspection and modification of annotation results: In the process of manual annotation, there will inevitably be manual errors, resulting in errors in the results of the annotated data, so in the annotation process a, the results of the inspection and modification is essential, this paper uses the manual check to check the accuracy of the annotated results.

d) Through the above manual annotation, a total of 8120 course review texts were obtained from the annotated data.

5) Evaluation of annotation results: In order to evaluate the quality of data annotation, this paper uses manual evaluation to evaluate the annotation results in the annotation process. The evaluation process is divided into two steps.

Step 1: 30% of the annotated corpus is randomly selected as the evaluation sample, and two annotators (PM1 and PM2) are assigned to judge the sentence results, which are either correct or incorrect in two dimensions.

Step 2: Establish the evaluation indexes, and the accuracy rate of the adoption of the evaluation indexes in this paper. The experimental evaluation results are shown in Table I below.

TABLE I. ASSESSMENT OF ACCURACY RESULTS

Evaluators	Active	Neutral	Negative
PM1	96.21%	93.66%	98.74%
PM2	94.13%	97.43%	96.48%

Through the evaluation of the labeled data, the labeled data in this paper achieved excellent accuracy, and the average accuracy of the sampled data reached 95.82%.

### III. DISTRIBUTED PARALLEL STOCHASTIC ALGORITHM DESIGN

This section describes the data parallel optimization strategy of the PRF algorithm, which includes vertical data partitioning and data reuse methods. First, a vertical data partitioning method is proposed to make full use of the logical independence of computational tasks and computational resource independence of the RF algorithm for training data feature variables to effectively partition large-scale training datasets [16-17]. Second, to solve the problem that the size of the sampled training data set in the original RF algorithm increases linearly with the expansion of the RF scale, this section modifies the traditional data sampling method and proposes a data reuse method for the PRF algorithm. The expansion of the PRF scale does not lead to changes in the

training data size and storage location. In this section, the proposed data parallel optimization method can effectively reduce the training data size and reduce the data transfer operations in the distributed computing environment, while ensuring the accuracy of the algorithm.

#### C. Vertical Data Partitioning

In the distributed parallel training process of PRF algorithm, the task of calculating the information gain rate of the characteristic variables of each training data subset occupies most of the training time. However, each computation task only needs to use the data of the current feature variable and the target feature variable. Therefore, in order to reduce the data communication overhead in distributed environment, a vertical data partitioning method is proposed, which makes full use of the RF algorithm's logical independence of computing task and computing resource independence of training data feature variables to effectively partition large-scale training data sets [18].

Suppose the size of the training dataset X Train is N, and there are M feature variables and one target variable in each sample record, i.e.  $y_1 \sim y_M$  are the input feature variables and  $y_A$  is the target variable. In the vertical data partitioning method, for each training subset  $X_i$ , each feature variable  $y_j = (j = 1, \dots, M)$  of all samples of  $X_i$  is extracted separately and combined with the target variable  $y_A$  to form a feature subset  $FS_j$ , denoted as  $FS_j = \{j, y_j, y_A\}$ . In this way, the training subset  $X_i$  can be divided into M feature subsets based on the feature variables, and there are no data dependencies and communication relationships among the subsets during the growth of the meta-decision tree model [19]. In the subsequent Apache Spark distributed parallel computing process, each feature subset will be loaded as an RDD object and independent of the other subsets. The execution of the vertical data partitioning method of the PRF algorithm is shown in Fig. 4.

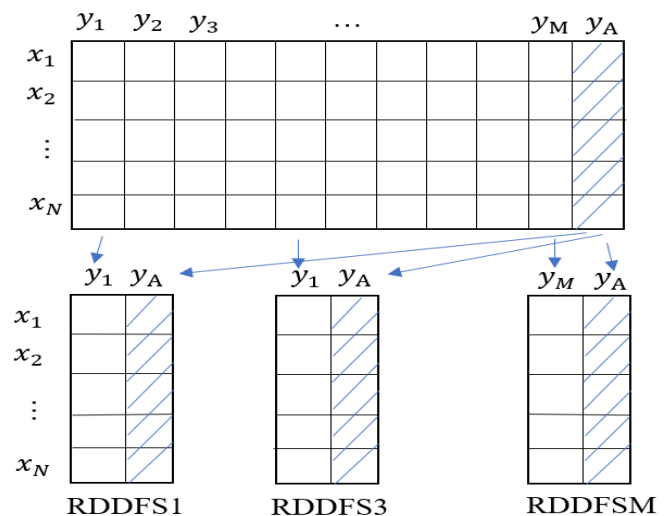


Fig. 4. Execution process of the vertical data division method of the PRF algorithm.



#### D. Data Reuse Method

In the original RF model, the training data set needs to be randomly sampled with put-back to form  $k$  subsets of training data, which are then trained by  $k$  meta-decision trees, respectively. Thus, when the size of the RF model increases (i.e. the number of meta-decision trees increases), then the size of the training data subsets also increases linearly. To solve this problem, this section modifies the traditional sampling method and proposes a data reuse method oriented to the PRF algorithm. Instead of actually replicating the sampled sample data in each data sampling cycle, its index is simply recorded into a data sampling index table [20-21]. The DSI tables are then assigned to all computational nodes along with a subset of features. For each meta-decision tree training process, the individual computational tasks can load the corresponding data from the same feature subset according to the corresponding sampling index in the DSI table. Thus, each feature subset is effectively reused, and the size of the entire training dataset does not increase even if the PRF size increases indefinitely.

First, a Data Sampling Index (DSI) table is created to hold the indexes of the samples extracted during all sampling. As mentioned earlier, the number of meta-decision trees for a PRF model is  $k$ . This means that the training dataset is sampled  $k$  times and  $N$  sample indexes are recorded during each sampling process.

Next, the DSI table is assigned to the corresponding compute node of the Spark cluster along with each feature subset, i.e. each compute node contains one or more feature subsets and one DSI table. In the subsequent parallel training process, the task of computing the information gain rate of different decision trees with the same feature variables is assigned to the compute node where the subset of features belongs to [22].

Finally, in each computation node, the information gain rate computation tasks for the different decision tree models

will access the corresponding sampling indices from the DSI table and fetch the sample feature variables from the feature subset of the current computation node based on these indices. An example of the execution process of the data reuse method of the PRF algorithm is given in Fig. 5.

In Fig. 5, each  $RDD_{FS}$  represents an RDD data object for a feature subset, and each TGR represents an information gain rate computation task during the growth of a particular meta-decision tree. For example, the feature subset  $RDD_{FS1}$  is assigned to the Slave1 compute node, followed by the compute tasks  $\{T_{GR1.1}, T_{GR1.2}, T_{GR1.3}\}$  associated with this feature subset also assigned to Slave1. Similarly,  $RDD_{FS2}$  and the associated compute tasks  $\{T_{GR2.1}, T_{GR2.2}, T_{GR2.3}\}$  are assigned to the from a meta-decision tree perspective, these computational tasks in the same computational node belong to different decision tree growth processes. For example, the tasks  $T_{GR1.1}$ ,  $T_{GR1.2}$  and  $T_{GR1.3}$  in Slave1 belong to Decision Tree 1, Decision Tree2 and Decision Tree3 respectively. The information gain rate of the feature variable is calculated. The intermediate results of these tasks in each distributed computing node are then aggregated and submitted to the corresponding subsequent tasks to build the meta-decision tree. For example, the results of tasks  $\{T_{GR1.1}, T_{GR2.1}, T_{GR3.1}\}$  are collected and aggregated from Slave1, Slave2, and Slave3 respectively, and used in the tree node splitting process of Decision Tree1". The results of tasks  $\{T_{GR1.2}, T_{GR2.2}, T_{GR3.2}\}$  are collected and aggregated from Slave1, Slave2 and Slave3 respectively, and are used in the tree node splitting process of "Decision Tree2". Algorithm 3.3 gives the steps of the vertical data partitioning and data reuse method of the PRF algorithm. In Algorithm 3.3, the RDDs are first divided into  $M$   $RDD_{FS}$  objects by the vertical data division function, and then the  $RDD_{FS}$  are allocated to the compute nodes according to the compute capacity and available storage capacity of each compute nod [ 23-25].

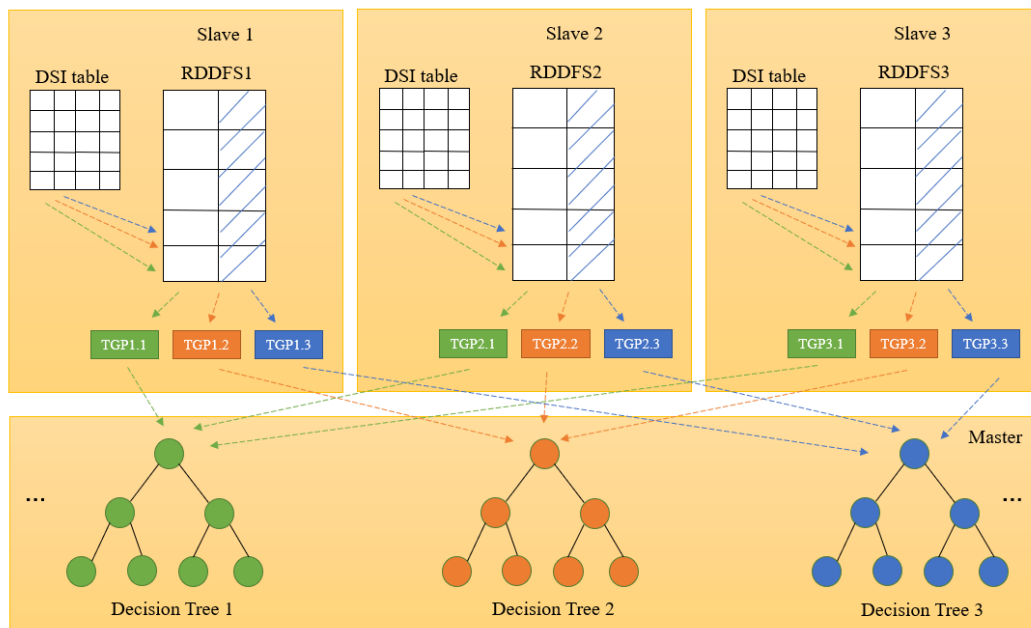


Fig. 5. Execution process of the data reuse method of the PRF algorithm.



IV. APPLICATION OF TOP-N RULE-BASED  
RECOMMENDATION MODEL FOR ONLINE EDUCATION COURSES

A. User-Course Matrix

The Matrix Factorization approach represents a matrix as a multiplication of two or extra matrices, becoming the observations in the unique matrix [26]. It is now extensively used in many contexts in the discipline of recommendation. The authentic matrix R is used to report all located person path ranking matrices, which are decomposed into two function matrices U and V. The closing goal feature L is as follows:

$$L = \sum_{i=1} \sum_{j=1} (R_{ij} - U_i^T V_j) \quad (1)$$

Fig. 6 suggests the building and decomposition of the user-course matrix. After cleansing and processing, the preliminary user-course dataset is obtained. The matrix decomposition is carried out at some point of the advice algorithm, on the one hand by using filtering comparable customers via User-matrix-based recommendations, and on the different hand via filtering comparable gadgets thru Item-matrix recommendations. For function extraction, social networks can then be developed for extraction, sooner or later main to the optimization of hybrid tips.

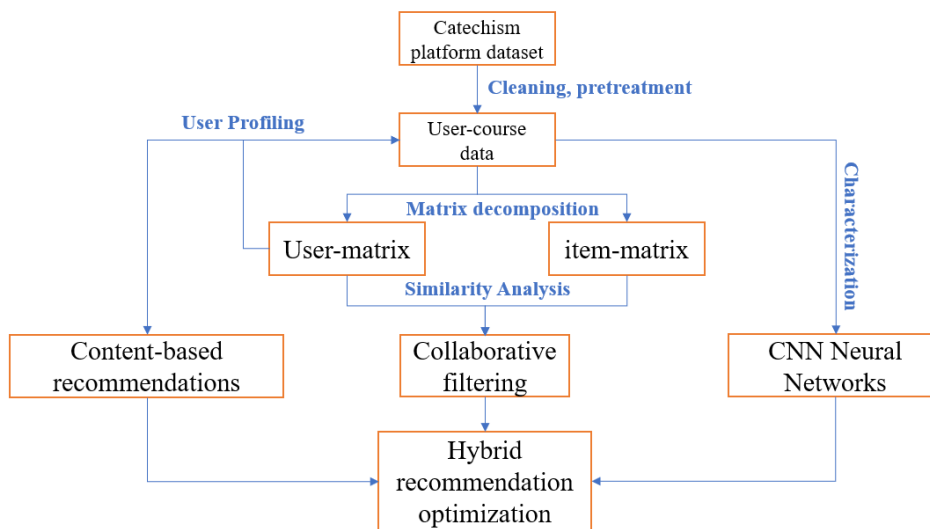


Fig. 6. Schematic diagram of the user-course recommendation path.

B. The Construction of Temporal Behaviour

In recent years, there has been a gradual shift in research from traditional (user, item) binary interactions to (user, item, timestamp) three-way interactions. The following are three statistical models that are often used to capture temporal information in sequential recommendations [27-30].

1) *Markov chain model in sequential recommendation:* The Markov chain model makes the important assumption that the probability P of the current state occurring is only correlated with the n-1 states preceding it, but not with the states at other times. n-order Markov chain models have the following probability formula.

$$P(W_T | W_1, W_2, W_3, \dots, W_{T-1}) = P(W_T | W_{T-n+1}, W_{T-n}, \dots, W_{T-1}) \quad (2)$$

2) *The word2VEC model:* Word2vec mainly includes Skip-Gram method and CBow method, and the model has three layers of computing logic, namely input layer, projection layer and output layer [31-32]. There are two kinds of algorithm framework, one is hierarchical normalization and the other is

negative sampling. The Word2vec model based on hierarchical normalization constructs Huffman tree according to the vocabulary in the output layer [21]. The terrible sampling based totally Word2vec mannequin does no longer assemble a complicated Huffman tree in the output layer, however a noticeably easy random poor sampling instead, which can considerably improve the computational pace and the excellent of the built phrase vectors.

3) *Time-decay model:* The exponentially decaying temporal function is shown below.

$$f(x) = \exp(-a(R_{ti} - R_{tj})) \quad (3)$$

In this equation a represents the coefficient of exponential decay, while R<sub>ti</sub> and R<sub>tj</sub> are historical data at different times. u is the user and V is the course item. Fig. 7 illustrates how the exponential decay function uses historical data to predict ratings. For R, the data closest to the present is assigned a higher weight for prediction purposes, and in a continuous correction, user U and course V are combined for recommendation.

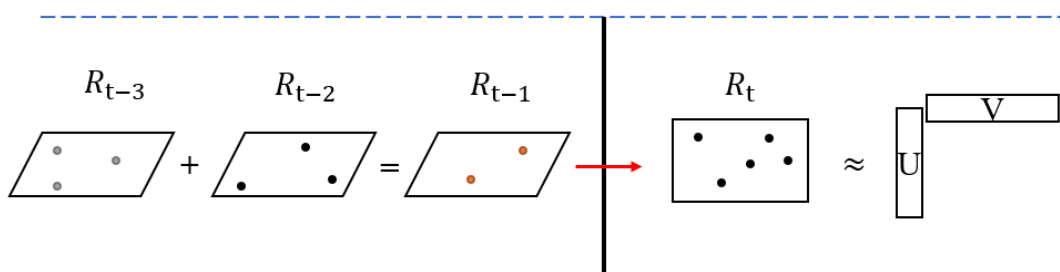


Fig. 7. Time-series decay prediction.

Taking user, a as an example, as shown in Fig. 8, as a sample of observations, we find that it focuses mainly on English courses, which in a traditional recommendation model

would be considered more focused on recommending programming-related courses from a library of items (courses) [22].

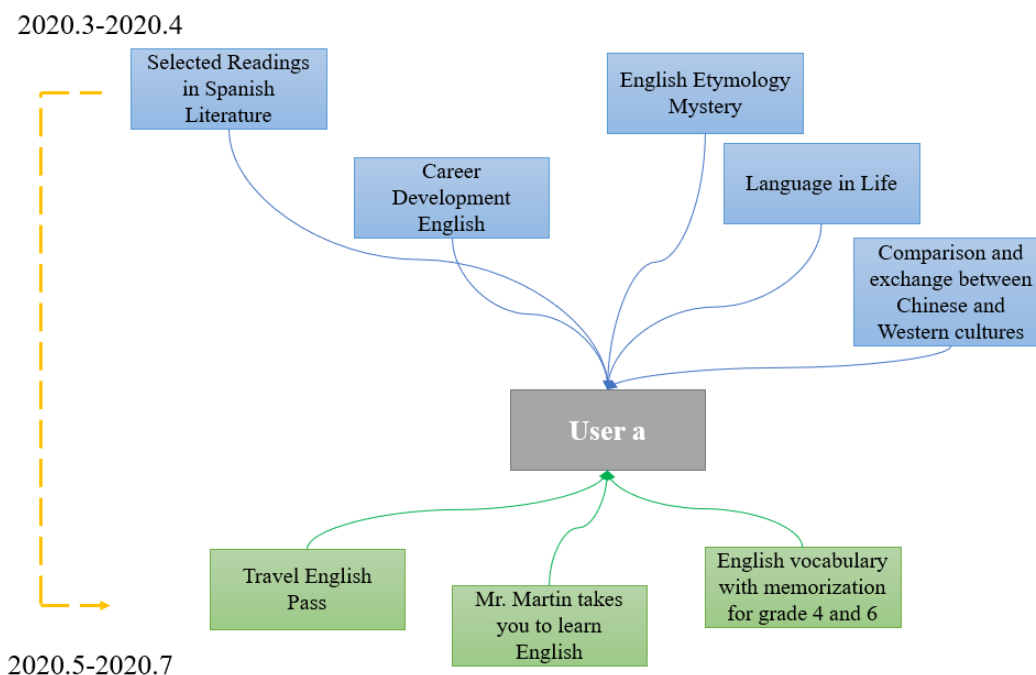


Fig. 8. Sequence of user behaviour (with user 'a' as an example).

### C. Model Results and Analysis

1) *Cold start*: For a new user, with less information captured about his history, we followed the previous idea of setting the cold start threshold to 10 and obtained five recommended courses under cold start as follows, Table II:

TABLE II. COLD START RECOMMENDATIONS

ProductName	Rating	Number of ratings
Selected Readings in Spanish Literature	4.26	642
Career Development English	4.33	355
English Etymology Mystery	5.68	482
Language in Life	7.15	499
Chinese and Western Cultural Contrasts and Exchanges	6.44	816

Once the cold start problem has been solved, you should start building the course-user matrix. The first step is to construct a data frame containing the average rating of each course and the number of times it has been rated, which is used to calculate the correlation between courses. In the above analysis we know that the higher the correlation coefficient of a course, the higher the probability of it being recommended by the portfolio [23].

In this paper we will use the Pearson correlation coefficient, the nearer the correlation coefficient is to 1, the greater the correlation is, and the weaker the correlation is. A Dataframe is created the usage of pandas, the dataset is grouped with the aid of header column and the common rating for every direction is calculated.

Next, depends the range of instances each path was once rated and see how it relates to the common direction rating. A path with a rating of 5 is probable to have solely one consumer

rating. It is no longer statistically practical to reflect on consideration on this as a 5-point course. Therefore, when constructing this phase of the suggestion system, we want to set a threshold for the wide variety of ratings. Using the group by characteristic in pandas, we created the number of ratings columns, grouped it with the aid of the Title column, and then used the counted feature to calculate the quantity of instances every direction was once rated [33].

The subsequent step is to construct the item-based advice system. We want to seriously change the dataset into a matrix with the route title as the column, the consumer identification as the index and the ranking as the value. We get a Dataframe, the place the columns are the direction titles, the rows are the person ids and every column represents the scores of all users for all courses. If the ranking is empty, it signifies that the person has not rated a path any longer.

This matrix is then used to calculate the correlation between courses. The course matrix is created using the pivot\_table in pandas.

To create the course matrix.

After calculation, we obtain similar course recommendations for each user based on historical behavior, and then introduce the temporal sorting matrix, filling in the viewing order for classes with viewing records and 0 for those without records, to obtain a matrix of users' temporal behavior. The final ranking result is obtained after normalization.

Similarly, user a, for example, is recommended by user id=12331(as shown in Fig. 9).

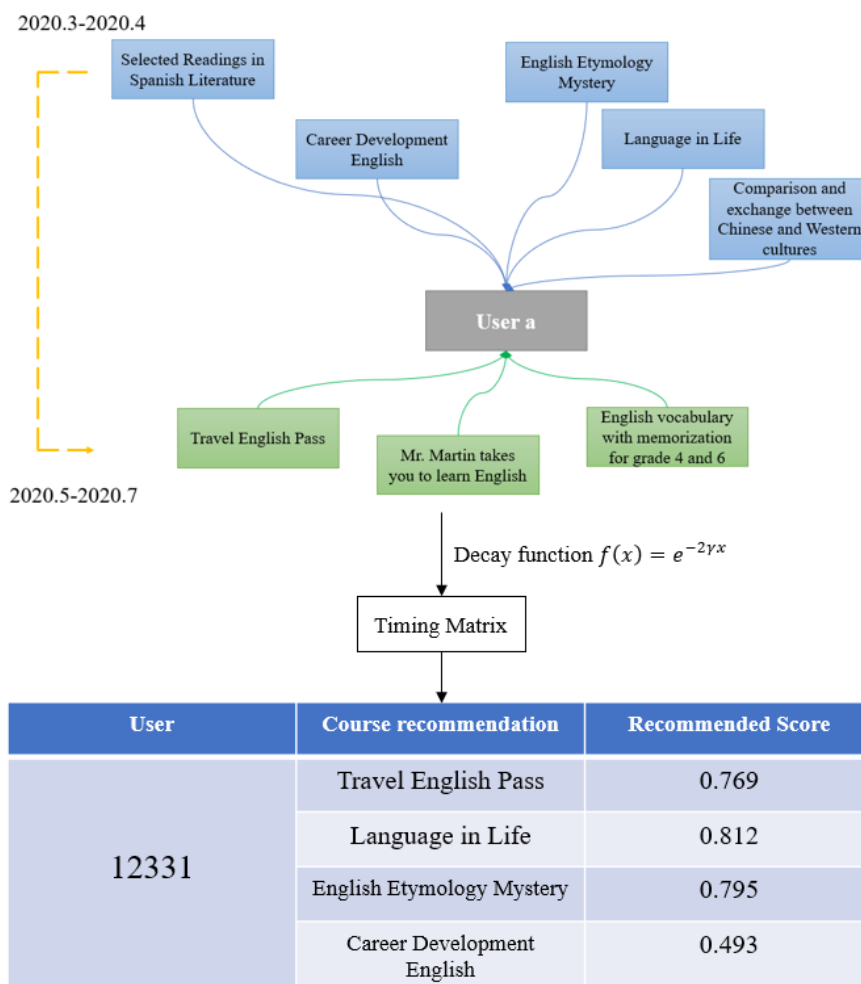


Fig. 9. Course recommendation score ranking.

#### D. Model Evaluation

In this chapter, the serialized studying behaviors of customers on the MU platform are captured, a temporal decay characteristic is designed to be included into the user-course matrix, and a time lag feature is proposed to be built to analyses the temporal statistics implied in the gaining knowledge of behaviors. Meanwhile, in order to check the

effectivity of the temporal sequential advice mannequin built in this paper, the paper is validated on the catechism dataset of consultant home on-line schooling systems in the empirical phase. Under the Top-N rule, the personalized recommendation to the user is completed through the recommendation score. Through the training accuracy and partial user sampling, the model has a good effect on the course recommendation results.

## V. CONCLUSION

Traditional big data computing methods are dedicated to the calculation and classification of data, with little involvement in data prediction and data derivation. With today's increasingly sophisticated cloud computing platforms, the content recommendation panel of an online education system can be very useful when combined with the data analysis of a cloud computing cloud platform. The online education system tablet designed in this paper embraces the educational concept of adaptive learning based on top-N recommendation algorithms, in addition to the sharing of educational resources and changes in the form of education. In order to study the recommendation model for online education, the recommendation system constructed in this paper is based on the representative NetEase Cloud Classroom to build the recommendation method. In future recommendations, we combine several online systems to collect more users to train and evaluate the model. In addition, a collaborative filtering system can be constructed for courses in the future by constructing a more sensitive temporal function model to better deal with scalability and sparsity issues. Finally, when the amount of data handled is very large, we can also build advanced recommendation systems in conjunction with auto-encoders to improve the performance of recommendations in the direction of timely response.

The research in this paper is divided into four main parts. The first part is data crawling and analysis of course and user information. Based on the platform's overall user temporal behavior of recommendations, a threshold is set for the number of ratings when building a cold-start recommendation system. The problem caused by too sparse data situation is solved.

The second part proposes a parallel random forest algorithm for big data. The PRF hybrid parallel approach combining data parallelism and task parallelism optimization is executed and implemented on Apache Spark. The training dataset is reused and the amount of data is significantly reduced.

The third part designs and investigates a recommendation method for online education learning resources with user temporal behavior, incorporating temporal information into the reordering of learner preferences by introducing an exponential decay function, and constructing a user-course matrix by matrix decomposition. This matrix more highly latitudinally and subtly incorporates temporal order into the user-program matrix and reduces the dimensionality of the user-program matrix according to the prediction score.

The fourth part constructs the prediction matrix for similarity calculation and recommendation ranking. The prediction score generates a recommendation list for the user, and the recommendation score reflects to some extent the degree of similarity in joining the chronological historical behavior.

Finally, the score prediction is carried out using the study habits and learning behavior, and the results of these four parts are used to carry out learning path planning in which users learn the courses and plan personalized recommendation paths

for the users, ultimately making the student user English language learning play a three-dimensional teaching effect.

## ACKNOWLEDGMENT

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# A Novel ML Approach for Computing Missing Sift, Provean, and Mutassessor Scores in Tp53 Mutation Pathogenicity Prediction

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**Abstract**—Cancer is often caused by missense mutations, where a single nucleotide substitution leads to an amino acid change and affects protein function. This study proposes a novel machine learning (ML) approach to calculate missing values in the tp53 database for three computational methods: SIFT, Provean, and Mutassessor scores. The computed values are compared with those obtained from the imputation method. Using these values, an ML classification model trained on 80,406 samples achieves an accuracy of 85%, while the impute method achieves 75%. The scores and statistics are used to classify samples into five classes: Benign, likely pathogenic, possibly pathogenic, pathogenic, and a variant of uncertain significance. Additionally, a comparative analysis is conducted on 58,444 samples, evaluating six ML techniques. The accuracy obtained by each of these is mentioned alongside the algorithm: logistic regression (89%), k-nearest neighbor (99%), decision tree (95%), random forest (99.8%), support vector machine with the polynomial kernel (91%), support vector machine with RBF kernel (84%), and deep neural networks (98.2%). These results demonstrate the effectiveness of the proposed ML approach for pathogenicity prediction.

**Keywords**—Decision tree (DT); deep neural networks (DNN); imputation; k-nearest neighbor (KNN); logistic regression (LR); missense mutations; Mutassessor; pathogenicity; Provean; random forest (RF); SIFT; support vector machine (SVM)

## I. INTRODUCTION

Years of research have identified the tp53 gene, a tumor suppressor gene that encodes the tumor protein p53 (tp53), as a significant barrier in cancer development [1][2][3]. The tp53 protein acts as a tumor suppressor by regulating cell division, growth, and apoptosis processes. It has been found that approximately 90% of cancer cases exhibit tp53 mutations [4]. Notably, the mutations commonly occur between positions 102-292, resulting in approximately 190 mutated codons, with over 60% of them being missense mutations [5]. Studies by Fiamma Montovani et al. discuss the role of mutant p53 proteins in supporting malignant cell survival and cancer evolution, as well as therapeutic opportunities related to tp53 missense mutations [6]. Gaoyang Zhu et al. explore therapeutic options targeting the Gain-of-Function (GOF) feature of full-length p53 mutant proteins [7]. Additionally, Alvarado-Ortiz E et al. investigate the impact of mutp53 on metabolic reprogramming and the Warburg effect observed in cancer cells, highlighting chemo-resistance and the role of autophagy in survival [8]. Xiang Zhou et al. identify tp53 hotspots as potential barriers for novel cancer therapies and

study the mechanisms underlying GOF for p53 [9]. Furthermore, cancer cells employ various strategies to disarm p53 and promote their growth and survival [10]. One approach involves mutating the tp53 gene itself, removing the protective function and allowing unmonitored cell activities [11]. Nonsynonymous Single-Nucleotide Variants (nsSNVs) are considered a primary reason for cancer, as they alter proteins with a single residue change in the amino acids [12][13]. Yong Li et al. demonstrate the predictive value of tp53 in the untranslated region (UTR) of cancer specimens, highlighting the impact of germline SNVs on tp53 protein levels and cell apoptosis [14]. Oliver Poirion et al. propose using expressed SNVs (eSNVs) from RNA sequences to locate tp53 variations in tumor subpopulations [15]. Computational procedures have been developed to assess the influence of amino acid substitutions and the frequent occurrence of missense variants in cancer patients [16] [17]. Understanding the effect of missense mutations is crucial for clinical use, especially in distinguishing pathogenic and infectious variants among numerous missense variants.

## II. RELATED WORK

With the rapid development of Machine Learning (ML) and its applications in various fields, ML has emerged as a potential solution for cancer research [19][20]. Efforts have been made to apply ML/AI-based diagnostics for cancer using vast genomic data. Techniques such as REVEL, CADD, FATHMM, and PolyPhen employ ML algorithms like Random Forest (RF), Naïve Bayes (NB), and Logistic Regression (LR) to predict pathogenicity [21][22]. Jiaying Lai et al. introduce LYRUS, a machine-learning tool that predicts pathogenicity based on missense variants [23]. LYRUS utilizes an XGBoost classifier incorporating sequence, structure, and dynamic features. The tool is evaluated using F-scores and specificity metrics, outperforming alternative methods. However, LYRUS estimates pathogenicity based on the actual protein structure and does not consider the mutated protein. It is also limited to proteins with available structures in the Protein Data Bank (PDB). Hua Tan et al. differentiate cancer-causing driver mutations from normal ones using SVM classification based on distinguishing features [24]. Their approach demonstrates higher efficiency compared to existing methods. In clinical research, computational techniques such as SIFT, Mutassessor, and Provean are used to predict the pathogenicity of missense mutations. However, there is a lack of ML-based methods to calculate these scores. Therefore, the present study proposes a novel approach to calculate SIFT,



Provean, and Mutassessor scores using K-nearest neighbors (KNN) regression. The study also focuses on classifying samples into pathogenicity classes based on the guidelines suggested by the American College of Medical Genetics and Genomics (ACMG) [25]. Section III of the paper delves into the materials and methods utilized in the research study. Following this, Section IV elaborates on the implementation of the algorithms employed. The subsequent section, Section V, presents the results and output obtained from the study, providing a detailed analysis. Finally, in Section VI, the paper concludes by summarizing the main findings and implications, offering a comprehensive conclusion to the research.

### III. MATERIALS AND METHODS

#### A. Computational Techniques for Pathogenicity Prediction

1) *SIFT score*: The SIFT (Sorting Intolerant from Tolerant) method is a prediction tool that assesses the relationship between amino acid substitutions and protein functions [26]. It is based on the hypothesis that amino acids tend to be conserved within a protein family. Therefore, any changes at well-conserved amino acid positions are likely to be damaging. SIFT also considers the presence of hydrophilic amino acids, such as valine, and checks if the substituted amino acid is another hydrophilic amino acid, like isoleucine or leucine. In such cases, the changes are predicted as tolerated. However, substitutions to other types of amino acids are assumed to result in functional changes. The SIFT method takes the protein sequence as input and aligns it with related proteins. It calculates the probability of amino acid occurrence at each position during the alignment. If the probability falls below a certain threshold, SIFT predicts the substitution as deleterious, otherwise, it is considered tolerated. The threshold value typically ranges from 0.0 to 1.0, where scores between 0.0 and 0.05 are considered deleterious, and scores greater than 0.05 are considered tolerated.

2) *Provean score*: The Provean (Protein Variation Effect Analyzer) score operates similarly to the SIFT method [27]. It calculates an alignment score for each protein sequence. A set of closely related sequences, typically the top 30 clusters, is selected as a supporting sequence set. The scores within each cluster are averaged, resulting in a Provean score. This score is then compared to a predefined threshold, typically set as -2.5. If the score is equal to or lower than the threshold, the protein variant is considered deleterious; otherwise, it is considered "neutral."

3) *Mutassessor score*: The Mutassessor score (Mutation Accessor) predicts the functional impact of an amino acid change based on the evolutionary conservation of the affected amino acid among protein homologs [28]. The default threshold for pathogenicity classification is set to -1.93, distinguishing high or medium functional impact variants from low or neutral predicted variants.

Note: These scores, namely SIFT, Provean, and Mutassessor, are utilized in computational techniques to predict the pathogenicity or functional impact of missense mutations in proteins.

#### B. The Proposed ML-based Method to Calculate the Missing Values of SIFT, Provean, and Mutassessor Scores

In this section, two algorithms related to the present research study are discussed. Algorithm-1 presents the proposed ML-based approach for calculating missing values of three different computational scores. Algorithm-2 outlines the process of classifying each sample into pathogenicity classes. The classification results are compared using six different ML techniques.

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#### Algorithm – 1: Proposed algorithm for predicting the missing values of Sift, Provean, and Mutassessor Scores in tp53 database

---

Input: tp53 mutation samples (80346, 133) → 80346 rows X 133 columns; Output: Predicted scores for the missing values in Sift, Provean, and Mutassessor scores

- Step 1: Preprocess the tp53 original dataset.
  - Step 2: Perform feature selection to select the features required for the proposed task.
  - Step 3: Separate rows with and without Sift scores.
  - Step 4: Consider the rows that have Sift scores.
    - i. Create a dataframe (x\_train) to store the features.
    - ii. Create another dataframe (y\_train) to store the corresponding labels.
    - iii. Use the KNN regressor model to predict values of y\_train, and save the predictions as y\_predict.
    - iv. Compute the Mean Absolute Error (MAE) score of y\_train and y\_predict for each 'k' value from 2 to 20.
    - v. Determine the 'k' value with the minimum MAE score among all the MAE scores.
    - vi. Train a new model using this 'k' value and save it as final\_model.
  - Step 5: Use final\_model to calculate the missing values of Sift scores from step 3 using the KNN regressor technique:
    - i. Consider the complete feature set of missing and present Sift values.
    - ii. Calculate the Euclidean distance (ED) for each feature set where Sift scores are present and where Sift scores are missing.
    - iii. Tabulate all ED values in ascending order.
    - iv. Select the top 'k' values (from step 4.vi).
    - v. Calculate the average of these scores and save it as the new predicted Sift score.
    - vi. Return the new predicted Sift score.
  - Step 6: Predict Sift scores using all the features selected in step 2 with the help of the impute method.
  - Step 7: Compare the final predicted values from steps 5 and 6.
  - Step 8: Repeat steps 3-5 to determine Provean scores.
  - Step 9: Repeat steps 3-5 to determine Mutassessor scores.
  - Step 10: Stop.
-

**Algorithm – 2: Classification of samples into five classes of pathogenicity using different ML techniques**

Input: tp53 mutation samples.  
Output: Pathogenicity classification.

- Step 1: Choose features and labels from the tp53 database (features computational scores + stat scores).
- Step 2: Remove samples with null values.
- Step 3: Perform the classification of each sample into pathogenicity classes using the following ML techniques:
  - i) Logistic regression,
  - ii) KNN,
  - iii) SVM,
  - iv) Decision tree,
  - v) Random forest,
  - vi) Feedforward neural network.
- Step 4: Compare the results of each technique using evaluation metrics.
- Step 5: Tabulate the results.
- Step 6: Stop.

**C. ML Techniques used in the Proposed Research Study**

- To predict the computational scores

1) *K-Neighbors Regressor*: This technique is a regression method derived from the KNN model. It calculates values based on the representation of the 'k' nearest neighboring target values from the training dataset. The values present in the training class are stored, while those that are missing are later calculated using similarity scores such as Euclidean, Manhattan, or Hamming distance. The accuracy of the calculated values relies on the selection of a primary measure, 'k'. Choosing an appropriate 'k' value is crucial, as a large 'k' value can potentially exploit the distance boundaries and result in overfitting or blurring of the feature space. Conversely, a low 'k' value can lead to underfitting of the model [29]. Hence, an optimal 'k' value is determined by discarding the missing values from the target variable field and predicting the target variable values using different 'k' values. These predicted values are then compared with the actual target values, and the difference is evaluated using the Mean Absolute Error (MAE) score. The 'k' value that yields the lowest MAE score is selected as the final 'k' value for the K-Neighbors Regressor. Table I provides a tabular representation of the procedure.

TABLE I. THE KNN REGRESSOR METHOD WAS USED TO CALCULATE THE MISSING VALUES. THE TABLE SHOWS THE SAMPLE VALUES TAKEN FROM THE TP53 DATABASE. IT CONTAINS A COMBINATION OF VALUES PRESENT AND ABSENT INDICATED WITH DIFFERENT COLORS

L_sta t	C_sta t	T_sta t	G_sta t	S_sta t	Sm_sta t	Sift_scor e	ED
0.01	0.08	0.05	0.44	0.71	0.331	0.19	0.34
2.84	2.80	2.87	2.77	1.40	2.107	0	5.83
0	0.00	0.00	0.91	0	0.01	?	0.34
0.02	0.03	0.03	0	0.03	0.083	0.89	0.915 5

Note: L: Leukaemia, C: Cell\_line, T: Tumor, G: Germline, S: Solid\_state, Sm: Somatic, ED: Euclidean Distance

Calculating ED individually for rows (i), (ii), and (iv) containing SIFT score values and SIFT score=? Different arrows indicate this in Table I. Below is the ED calculation for row (i).

$$\sqrt{(0.014 - 0)^2 + (0.082 - 0.001)^2 + (0.053 - 0.001)^2 + (0.071 - 0)^2 + (0.331 - 0.01)^2} = 0.342$$

Likewise, EDs for all the rows (ii and iv) w.r.t data\_pre

Sort ED: 0.34, 0.91, 5.83. Consider, k=2, so pick the first 2 points and take the average.

$$\frac{0.34 + 0.91}{2} = 0.625$$

The new sift\_score predicted is 0.625

**D. To Classify Samples into Various Pathogenicity Classes**

- *Feature selection*: With the help of data visualization and pre-processing using principal component analysis (PCA), the dataset was prepared for the training phase [30]. With PCA, highly correlated features (both positive and negative) were removed from the original dataset. For the strongly correlated features, only one of the features is retained. To decide this, the following aspects were identified; if two features are to -1, they are negatively correlated, and if the values are closer to +1, they are positively correlated. After performing the feature reduction process, the dataset had 58444 X 10 records that were finally used for the classification process using six different ML techniques. In the end, each ML technique is compared to study the best method for classifying a sample. The model was evaluated using F-score and parameter tuning to ensure robustness. Finally, the models are evaluated on the test set for full and reduced features. Feature reduction, indeed, has an impact on the overall algorithm performance of these ML techniques. Fig. 1 depicts the framework of this modeling process. The implications of these methods are described below.

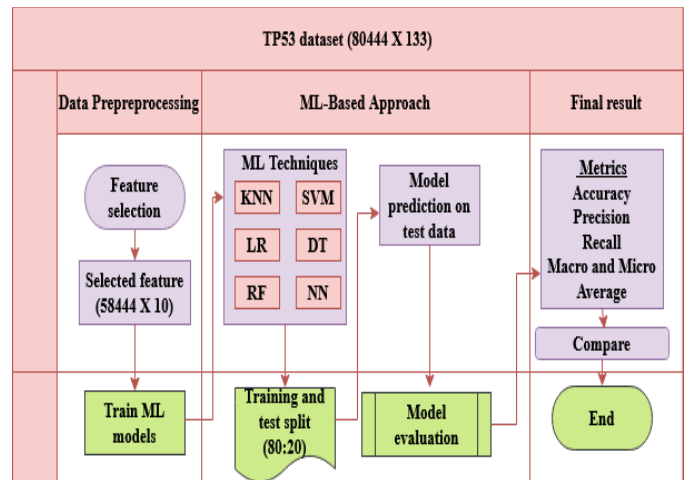


Fig. 1. The proposed schematic hybrid framework of the modelling process to predict the pathogenicity of a sample using tp53 database and various ML algorithms such as Logistic Regression (LR), K-nearest neighbors (KNN), Support Vector Machine (SVM), Decision Tree (DT), Random Forest (RF) and lastly, Feed-Forward Neural Network (NN).

- **Logistic regression:** The LR is, by default, a regression model whose prediction is based on the logistic function [31]. The decision is associated with the probability that a given feature belongs to some categorical class, say, 1. If a sigmoid logistic function is used to make the prediction, then if sigmoid function (S) resorts to an infinite value when the prediction variable ( $\hat{y}$ ) will become one and  $\hat{y}$  will be 0 if 'S' is a negative value, given by Eq. 1

$$\text{sig}(s) = \frac{1}{1+e^{-x}} \quad (1)$$

A crucial parameter in logistic regression for the present classification task is multinomial data distribution since the categories of the classes (5 pathogenicity classes) are without any specific ordering. The classification of a sample is performed based on the threshold. The threshold value is vital in estimating the probability that a sample belongs to one out of these five classes. Say if  $\hat{y}$  ranges between 0-0.2, then the sample is classified as '0 - benign', for  $\hat{y}$  between 0.2 – 0.4, the sample will be classified as '1-LP', with a range between 0.4 - 0.6 the class will be '2-P', 0.6 – 0.8 for class '3-PP' and finally 0.8 – 1.0 for class '4-VUS'. This is usually the first ML algorithm to be used for any classification task.

- **K-Nearest Neighbors:** This is the simplest of all the ML techniques that intend to classify a record (unlabelled) based on the class of the neighbouring data points (labelled) [32]. Using a distance measure, say ED, the distance between the features of the unlabelled and labelled records is calculated. Using an optimal 'k' value, the nearest top 'k' neighbours are chosen. Finally, the class label with the highest number is tagged for the unlabelled data point. The main idea behind this intuition is that similar points tend to be close to each other. As this is a multi-class classification problem, a sample will be classified into one of the five classes. The best 'k' value obtained on the dataset is 5. Thus, k=5 was used to train the final model.
- **Support Vector Machine (SVM):** SVM is a versatile algorithm used for classification and regression tasks. It aims to find an optimal hyperplane, or decision boundary, that maximizes the separation between different classes [33]. When classes are not linearly separable, SVM employs the kernel trick, using functions like linear, polynomial, RBF, or sigmoid. Data points close to the hyperplane are called support vectors. For multi-class classification, SVM utilizes the one-vs.-one approach, explicitly indicated by defined\_function\_shape=ovo. By default, it uses the one-vs.-rest approach (defined\_function\_shape=ovr), where data points of one class are compared with the rest [33]. In our case with five pathogenicity classes, SVM is applied using both 'rbf' and 'poly' kernels, with specified parameters such as gamma=0.5, C=0.1, and degree=3 for 'rbf', and C=1 for 'poly'.
- **Decision Tree:** This rule-based classifier resembles a tree-like structure and makes decisions based on a series of questions. At each node, a question is asked, and depending on the answer (yes or no), the algorithm

progresses to other nodes at subsequent levels, similar to an if-else structure. Decision trees consider one feature at a time from the input data (X) to create branches. The feature can be categorical or continuous, using categories or thresholds as decision criteria. Different criteria, such as Gini impurity and Entropy, can be used to determine the root node and subsequent decision-makers. Gini impurity calculates the frequency at which a sample in the dataset will be incorrectly labeled, while Entropy measures the disorder of features (X) with respect to the target label (y) [34].

$$\text{Gini Impurity} = 1 - \sum_i p_i^2 \quad (2)$$

$$\text{Entropy} = -\sum_i p_i \log_2 p_i \quad (3)$$

Where  $P_i$  is the probability for class 'i' such that  $i=1$  to 5. In the present study, the question would be: 'is the leukemia\_stat greater than a threshold value, say, x? Or is leukemia\_stat less than or equal to the threshold value? Thus, the DT will traverse each node and evaluate the condition before deciding which branch to proceed with until the leaf node (last) is hit. Here, there will be a total of five leaf nodes for each pathogenicity class. Both entropy and Gini impurities are used separately in the present study with max\_depth=3.

- **Random Forest:** It is based on the concept of ensemble algorithms, which combines multiple classifiers, and decision trees, solves the problem independently, and combines the results in the last step [35]. With this approach, the overall performance is improved. The model with correct prediction is retained, and incorrect predictions are pruned. The prediction rules are not visible to the user, thus enforcing a black-box concept. The multiple final DTs are combined, and the class with a majority vote will be assigned to the sample. With multiple DTs, the model obtains a higher accuracy and eliminates the problem of overfitting. RF will achieve the best accuracy compared to the previous models discussed here. The following parameters are used in the present study; n\_estimators=100 (overall trees the forest has), bootstrap = True (randomize the samples in the dataset), max\_features = 'sqrt' (takes the square root of the total features present in the dataset. Total features = 10 (computational scores+stat values + pathogenic class).  $\sqrt{10} \sim 3$ , so three features are tried randomly for each tree).
- **Artificial Neural Network:** ANN represents the working of a real human brain where the brain will generate outputs based on the past information trained earlier in life. ANN is suitable for any function, especially datasets that exhibit non-linear relationships. Feedforward neural network is a variation of ANN with three layers, an input layer, one or more hidden layers, and an output layer. Every layer has multiple nodes/neurons to process the input. The neural networks learn when fed with input and propagate to subsequent layers; hidden and output. This is called the learning/training phase. At each node at every layer, the network calculates the product of input values and weights, and the sum of these product terms along with

a bias value is calculated at every hidden node and sends the value to the next layer. That is, the network calculates a function, say 'f', for a predetermined input feature in 'X' and results in a training pair (X,y) such that  $f(X) \approx (y)$ . The actual and predicted values are calculated to understand the loss incurred by the network [36]. At the output layer, an activation function is used to obtain the result. The activation functions are: Sigmoid (the output value ranges between 0 and 1), tanh (ranges between -1 and +1), Rectified Linear Unit (ReLU) (returns the max (0, X)), softmax (return the probability of belonging to each output class, such that, when the values are added, we get 1). In the present study, a simple sequential model is trained using Keras that uses TensorFlow objects. The input\_dim was set to 9, matching the number of input parameters (computational scores + stat values), and the activation was ReLU with 16 neurons in the input layer. Two hidden layers were used, each with 32 and 64 neurons and the same activation function. The output layer has five neurons as there were five pathogenicity classes with softmax activation. The loss function was "sparse\_categorical\_crossentropy", optimizer='adam', metrics were set to accuracy with 100 epochs.

#### IV. IMPLEMENTATION

##### A. Dataset Collection

The dataset used in this study was collected from the UMD-tp53 database (Universal Mutation Database). The database, which initially had only 360 mutations in 1992, has now grown to contain over 80,000 mutation samples [37]. It consists of two files: variant and mutation. The mutation database includes samples of all patients with a tp53 mutation, while the variant database contains unique tp53 variants found in these patients. For this study, the mutation database with 80,406 samples (TP53 Mutated data, 2017 Release R2, available at <https://p53.fr/the-database>) was utilized. The database includes various variant classifications for mutant types, such as missense (58,517), nonsense (8,460), Frame-shift-del (5,212), splice-site (2,348), synonymous (2,016), frame-shift-ins (1,701), Indel (1,194), Ins (290), and others (668). The database was downloaded in CSV format.

##### B. Data Pre-Processing Phase

The initial mutant database downloaded from the tp53 website consisted of 80,406 rows and 133 columns. The prediction scores were based on various statistical values and computational scores present in the database. However, when the features start\_DNA and end\_DNA had a value of '?', most of the remaining features also had '?' (119 columns), and the pathogenicity class was labelled as 'no prediction.' Therefore, the rows with values start\_DNA and end\_DNA = '?' were removed as the first step in the pre-processing phase. This resulted in 80,346 rows and ten columns. Additionally, the start and end\_DNA features were not used in the prediction or classification process, so they were dropped from the feature set, resulting in a final dataset size of 80,346 X 8. The next step in pre-processing was to handle null values. Although there were no null values, three features (Sift, Mutassessor, and Provean scores) contained string values such as 'No data,'

'No protein,' 'Not known,' and 'Inframe.' As part of data cleaning, these string values were replaced with '?', as these values would be calculated using the proposed algorithm. Furthermore, the pathogenicity feature consisted of categorical data such as benign, likely pathogenic, pathogenic, possibly pathogenic, and VUS. To handle this, a label encoder was used to transform the string values into integer values. The respective classes were assigned the numbers 0, 1, 2, 3, and 4.

##### C. Data-Splitting:

The new DataFrame (new\_df) with a size of 80,346 X 8 was further divided into two DataFrames: data\_abs, which contained rows where the Sift\_score was '?', with a size of 21,902 X 8, and data\_pre, which included rows with available Sift\_score values, with a size of 58,444 X 8. From data\_pre, the features and labels were separated and named data\_pre\_temp and 'y', respectively. The '.values' function was used to convert the DataFrame data\_pre\_temp into a list named Xin. The KNeighborsRegressor class was then employed to train the model using Xin as the input features and y as the target labels in an 80:20 ratio. To find an ideal 'k' value, the 'k' value was varied from 2 to 20, and the Mean Absolute Error (MAE) was calculated for each 'k' value. The MAE represents the mean absolute difference between the actual and predicted values. The 'k' value that yielded the lowest MAE value was considered the optimal 'k' value for training the final model to predict the missing values. The DataFrame data\_abs was split into data\_abs\_temp (features) and ydim (labels). The '.values' of data\_abs\_temp were stored in Xdim as features, with ydim representing the labels. A new DataFrame named data\_predict was created with a column of the same name, Sift-score, to store the predicted values of ydim. This DataFrame was then joined with data\_abs\_temp and renamed as 'dataframe\_1'. The values of Sift\_score were extracted from data\_pre and stored in a new DataFrame called df\_join, which was further joined with data\_pre\_temp and renamed as 'dataframe\_2'. Finally, dataframe\_1 and dataframe\_2 were concatenated to form a new DataFrame named 'dataframe' with a size of 80,346 X 8, which matched the original size of the initial DataFrame new\_df. The DataFrame 'dataframe' now contained values that originally had missing values (21,902)

#### V. RESULTS

The predicted values obtained using the proposed algorithmic approach were compared with the state-of-the-art ML library method called Impute. KNNImputer was utilized with the same 'k' value as in the previous method. The values calculated by both methods were compared, and it was found that they were 85% similar. Additionally, two KNN models were trained separately, one using the proposed method and the other using the imputer method. The proposed model demonstrated superior accuracy compared to the built-in method.

##### A. Evaluation of Computational Scores Prediction using the Proposed Method and Built-In Method

The objective is to develop an ML-based approach to calculate missing values in three important pathogenicity prediction methods based on amino acid substitutions in protein sequences. In the tp53 database, certain values for

these three features were missing. Instead of using existing algorithms, this study employs the KNN regressor, an ML technique, for estimating these values. Additionally, each method requires a threshold, which can be adjusted based on user requirements. Hence, the threshold value was redefined to align with the existing value range. Table II presents the threshold used in this study to classify the scores into their respective variant classes. Fig. 2(a) to 2(c) shows the graphical illustration of the values computed for all three computational scores from both methods impute and code-based.

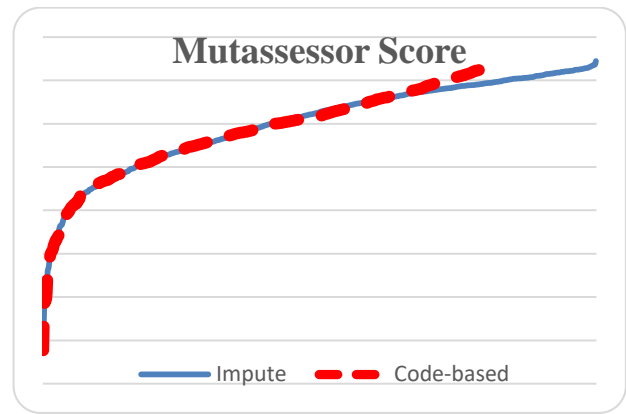
TABLE II. THE THRESHOLD VALUES ARE USED FOR DIFFERENT COMPUTATIONAL METHODS IN THE PATHOGENICITY CLASSIFICATION TASK

Computational Methods	Threshold values: Class type		
	Sift	$\leq 0.05$ : <b>Harmful</b>	$> 0.05$ : <b>Tolerated</b>
Provean	$\leq 2.5$ : <b>Deleterious</b>	$> 2.5$ : <b>Neutral</b>	--
Mutassessor	$\leq 1.0$ : <b>Neutral</b>	$> 1.0 \ \&\leq 2.0$ : <b>Low</b>	$> 2.0 \ \&\leq 4.0$ : <b>Medium</b>

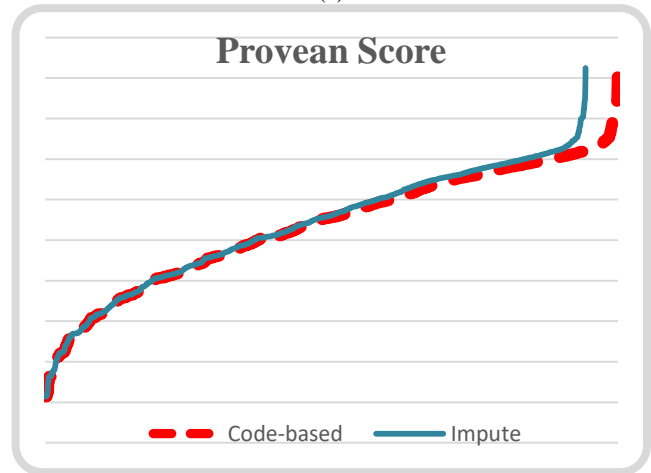
Note: Shown in bold letters are the category labels used for each of the threshold values

Do the values computed by the proposed procedure outperform the reference method? - A Case study:

As depicted in Fig. 2, the computed missing values from both methods closely align, with minor variations observed at the beginning and end of the graph. However, the question arises whether these slight differences hold any predictive significance. Therefore, a case study was conducted to demonstrate that the proposed method exhibits superior classification performance for tp53 mutation samples. After calculating the missing values, an SVC classifier was employed to classify the samples based on pathogenicity variants using the computational methods. To further assess the results, the impute method, an ML library method for calculating missing values, was employed, and the same process was repeated. The trained SVC classifier effectively classified the samples using both the code-based and impute methods. The code-based approach achieved higher classification accuracy compared to the existing impute method for all three computational techniques. Additionally, the match percentage for each variant class was also calculated. The proposed and built-in methods achieved a match rate of over 81%. The significance of this evaluation is summarized in Table III.



(b)

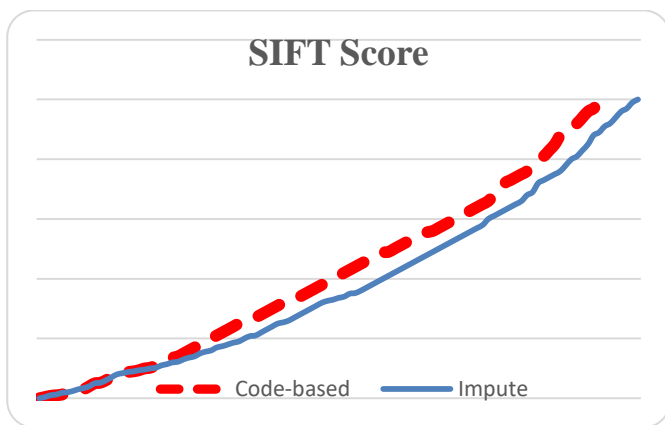


(c)

Fig. 2. (a) SIFT scores computed using code-based and reference methods (impute), (b) Mutassessor scores computed using code-based and reference methods (impute), (c) Provean scores computed using code-based and reference methods (impute).

TABLE III. THE NUMBER OF SAMPLES CLASSIFIED TO EACH PATHOGENICITY LABEL FOR BOTH PROPOSED AND BUILT-IN METHODS. THE CLASSIFICATION ACCURACY IS THE MEASURE CALCULATED FOR THE CLASSIFIED DATA IN COLUMN-WISE, REPRESENTED IN BLUE COLOUR. THE GREY COLOUR FIELD REPRESENTS THE PERCENTAGE OF A MATCH IN THE VALUES CALCULATED BY BOTH APPROACHES

Computation al Method		ML-based proposed approach	Built-in impute method	% of a match between proposed and built-in method
Sift	Damaging	74761	73092	85.32
	Tolerated	5585	7254	
	Classification Accuracy	0.879	0.764	
Provean	Deleterious	72733	71838	81.91
	Neutral	7613	8508	
	Classification Accuracy	0.875	0.781	
Mutassessor	Medium	73810	73894	84.89
	Low	4539	4203	
	Neutral	1997	2249	
	Classification Accuracy	0.872	0.783	



(a)



B. Evaluation Metrics to Assess ML Model Performances

TABLE IV. THE NUMBER OF SAMPLES IN EACH PATHOGENICITY CLASS FOR THE TRAINING AND TEST DATASET

0: BENIGN, 1: LIKELY PATHOGENIC, 2: PATHOGENIC, 3: POSSIBLY PATHOGENIC, 4: VUS

	Data split 80:20	Class #				
		0	1	2	3	4
No. of training samples	46755 80%	50	5146	30509	7981	3069
No. of test samples	11689 20%	11	1303	7636	1998	741
Total	58444 100%	61	6449	38145	9979	3810

Table IV gives the number of samples in each pathogenicity class for the training and test dataset.

Confusion Matrix (CM) is a tabular representation of the performance in the classification task [38]. It contains the true values along the y-axis and estimated values along the x-axis. The number of rows and columns depends on the number of classification classes.

TABLE V. A CONFUSION MATRIX FOR A RANDOM FOREST ALGORITHM FOR MULTI-CLASS CLASSIFICATION OF PATHOGENICITY LABELS

N REPRESENTS A CLASS NAME; CM IS THE CONFUSION MATRIX C. A GREEN COLOUR ROW REPRESENTS AN FN, AND THE YELLOW COLUMN REPRESENTS AN FP, AND PINK IS THE ACTUAL TRUE POSITIVE FOR THE CLASS N=1. ACTUAL CLASS : AC

C M ( C )	N class es	Prediction Class					Total
		N=0	N=1	N=2	N=3	N=4	
AC	N=0	CC <sub>00</sub> =11	0	0	0	0	11
	N=1	0	CC <sub>11</sub> =1293	0	0	10	AN=2=1303
	N=2	0	0	CC <sub>22</sub> =7636	0	0	7636
	N=3	0	0	0	CC <sub>33</sub> =1994	4	1998
	N=4	0	4	0	0	CC <sub>44</sub> =737	741
	Total	11	PN=2=1297	7636	1994	751	T=11689

Table V describes a CM matrix of the RF algorithm, illustrating the different numbers obtained from the ML model. Here, CCNN indicates the correctly classified samples, T is the count of test samples, AN is the total times a sample is correctly classified to its actual class, and PN represents the number of times a sample is predicted. The main components of a CM are as follows: A true positive (TP) is when a true class 0 (benign) is predicted as 0 (benign). A true negative (TN) is when an actual class is not 0 and is predicted correctly as not class 0. A false positive (FP) is when a true class 0 is wrongly predicted as class 1 or any other class, and lastly, a false negative (FN) is when a true class is not 0 but is mispredicted as class 0. Further, the standard performance metrics derived from CM are described in Eq. [4 – 7]. Those are i) A recall is a measure of all positive samples that the

model predicted correctly for the class; this indicates how much the model correctly predicted for the total samples of class 0. ii) A precision indicates the quality of the prediction, i.e., how many times the model correctly predicted a sample as class 0 out of all the total number of class 0 true samples. iii) F-Score is the average of both recall and precision. iv) accuracy is the actual number of samples that the model correctly classifies over the total number. v) The macro average scores are calculated by considering the weighted mean for each R, P, and F for every predicted class without considering each label's proportion. vi) The weighted average score is calculated by taking the product of the sum of individual recall, precision, and f-score and each classified sample over the actual number of samples for the classification class. This is similar to the macro score except that the weighted score considers the proportion of individual labels. vii) The micro average considers the total TP, FP, and FN irrespective of the prediction made by the model for each class

$$Recall (R) = \frac{TP}{TP+FN} \quad (4)$$

$$Precision (P) = \frac{TP}{TP+FP} \quad (5)$$

$$F\ Score = 2 * \frac{PR}{P+R} \quad (6)$$

$$Accuracy = \frac{TP+TN}{TP+FN+TN+FP} \quad (7)$$

Table VI illustrates the performance achieved for each of the ML techniques on the test dataset.

TABLE VI. THE TABULATION OF VARIOUS EVALUATION METRICS ON THE TEST DATASET FOR EACH ML METHOD. THE RF RESULTED IN THE HIGHEST ACCURACY, CLOSELY FOLLOWED BY KNN AND DL METHODS

Method	Class	P	R	F	Macro	Micro	Weighted	Accuracy
KNN	0	1.00	1.00	1.00	P	0.99	0.99	0.994
	1	0.99	0.99	0.98	R	0.98	0.99	
	2	1.00	1.00	1.00	F	0.98	0.99	
	3	0.97	1.00	0.99				
	4	0.96	0.95	0.95				
SVM	0	1.00	1.00	1.00	P	0.86	0.91	Poly: 0.910 RBF: 0.84
	1	0.78	0.74	0.76	R	0.84	0.91	
	2	0.99	0.99	0.99	F	0.85	0.91	
	3	0.74	0.85	0.79				
	4	0.80	0.61	0.70				
LR	0	1.00	1.00	1.00	P	0.85	0.89	0.891
	1	0.84	0.48	0.61	R	0.79	0.89	
	2	0.99	0.99	0.99	F	0.81	0.89	



	3	0.6 7	0.8 9	0.7 6						
	4	0.7 7	0.6 0	0.6 7						
DT	0	1.0 0	1.0 0	1.0 0	P	0.72	0.9 5	0.95	Gini:0.95 4 Entropy:0. 952	
	1	0.9 2	0.8 7	0.9 0	R	0.72	0.9 5	0.95		
	2	1.0 0	1.0 0	1.0 0	F	0.72	0.9 5	0.95		
	3	0.8 8	0.9 0	0.8 9						
	4	0.7 8	0.8 1	0.8 0						
RF	0	1.0 0	1.0 0	1.0 0	P	0.99	1.0 0	1.00	0.998	
	1	0.9 9	0.9 9	0.9 8	R	1.00	1.0 0	1.00		
	2	1.0 0	1.0 0	1.0 0	F	1.00	1.0 0	1.00		
	3	1.0 0	1.0 0	1.0 0						
	4	0.9 8	0.9 9	0.9 9						
DL	0	1.0 0	1.0 0	1.0 0	P	0.96	0.9 8	0.98	0.982	
	1	0.9 7	0.9 6	0.9 6	R	0.97	0.9 8	0.98		
	2	1.0 0	1.0 0	1.0 0	F	0.96	0.9 8	0.98		
	3	0.9 7	0.9 5	0.9 6						
	4	0.8 8	0.9 2	0.9 0						

Cross-validation is the most famous evaluation metric to estimate the actual prediction of an ML model [39]. This method splits the entire dataset into ten folds (k-cross fold where k=10) to form a training and test set with 0-9 folds consisting of 0 - 5844 samples and the 10<sup>th</sup> fold containing 5845 - 5848 samples. After executing the final model 10 times, all ten folds accuracy scores were obtained using cross\_val\_score (Table VII). The average scores for all 10-folds are obtained using cross\_val\_predict.

TABLE VII. TABULATION OF ACCURACY FOR EACH ML METHOD FOR EACH FOLD IN CROSS-VALIDATION APPROACH. THE K VALUE IS 10, WHERE 0-9 FOLDS RANDOMLY SERVE AS THE TRAINING SET, AND THE REMAINING ONE FOLD ACTS AS A TEST SET

	1	2	3	4	5	6	7	8	9	10
KN	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
N	93	92	92	88	92	94	92	91	88	94
LR	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	92	80	94	86	81	96	89	90	83	89
SV	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
M	15	99	14	12	07	24	09	16	06	17
DT	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	55	52	51	53	50	54	50	57	51	61
RF	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	98	96	97	96	97	98	97	98	96	98
DL	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	81	79	78	82	82	81	82	83	82	81

### C. Discussions

So far, the pathogenicity of cancer types has been studied using computational scores calculated using various statistical approaches. However, the rapid growth of machine learning applications has sparked interest in designing an ML-based

strategy for calculating these scores. In the first approach of this research study, three computational scores were calculated based on the data available in the tp53 database. The thresholds for these scores were kept unchanged, consistent with those used in the tp53 repository. The results were compared with the existing ML library's impute method. Subsequently, a separate KNN model was trained using the calculated scores from the code and the built-in approaches. It was observed that the code approach outperformed the built-in method in terms of accuracy. This process was repeated for all three computational techniques used to calculate the scores. Furthermore, when three or more statistical scores were equal to zero, the predicted Sift score was always zero. However, when these values were utilized for the classification task, the model achieved only 78% accuracy. Consequently, input features with a high number of zero values were dropped, and the remaining samples were considered for the classification task. In the second part of the study, six different ML techniques were evaluated to classify tp53 samples into pathogenicity classes. The investigation revealed that ML algorithms efficiently classified the data with very high accuracy in most models. Among the six algorithms, the RF algorithm yielded the best results, achieving an F-score of 1 in many cases. As mentioned in the introduction, missense mutations are highly prevalent in approximately 80% of cancer samples. Scientists worldwide dedicate their valuable time to understanding the significance of these mutations and devising novel techniques to combat cancer. Therefore, the present research study offers practical solutions in significantly less time compared to manual evaluation. In terms of clinical significance, clinicians can utilize these techniques to swiftly obtain computational scores and classify records into pathogenicity classes without the need for clinical tools or equipment intervention. Moreover, RF and NN techniques could be adopted for risk analysis and the design of predictive diagnostic procedures. Although this hypothesis was not proven in the present study, literature reports suggest that NN techniques could outperform other ML algorithms in such tasks.

1) *Drawbacks:* The present study has several limitations. Firstly, the proposed prediction strategy heavily relies on the existing dataset values. It can only predict missing values in a feature column, assuming that the column already contains some pre-processed values. Consequently, the predictive ability of ML models is contingent upon the values present in the database, which may result in sampling errors when applying feature selection techniques. Furthermore, the study compares the classification accuracy of six prominent ML algorithms. However, without any specific reason, other efficient ML models were not investigated. For instance, deep neural network-based models could have potentially addressed the problem of feature selection in a more effective manner. The omission of such efficient algorithms limits the comprehensive exploration of potential solutions for feature selection. These limitations should be taken into consideration when interpreting the results and implications of the study. Future research should aim to overcome these drawbacks and explore the application of additional ML models to improve

feature selection and enhance the predictive performance of the proposed approach.

2) *Future work*: There are several potential areas for further extension in this research study. First, it involves locating the actual disease-causing missense variants among all gene-specific mutations in a patient's sample. Typically, a single cancer patient may have approximately 500 missense mutations. However, only a few of these mutations exhibit cancer-related symptoms, while the majority may be non-cancerous or benign. ML-based models can assist in narrowing down the candidate mutations based on predictive scores, thereby reducing the time required for pathogenicity prediction and minimizing diagnostic costs. Second, a prediction model can be developed for pathogenicity classification based on different types of mutations, such as missense and frameshift mutations. Such a model can utilize amino acid sequences as input features and forecast the functional domains of genes and proteins involved in causing these deleterious mutations. Third, the focus could be on identifying the pathogenic components within a gene and searching for symptoms associated with similar diseases. This knowledge can aid in determining appropriate treatment approaches, potentially using similar strategies employed for identical diseases. It may also facilitate the process of target identification for prospective drug development. Fourth, it is important to identify the proteins involved in each malignant mutation, analyze their characteristics, and identify drugs that target these proteins in both Gain-of-function and Loss-of-function situations. For instance, in the case of tp53, Loss-of-function is considered. Fifth, incorporating patient-specific gene information can help assess interactions between genomic variants. This approach could provide a likelihood ratio for disease-causing genes and enable the targeting of these genes for effective drug interventions, further supported by in-vitro methodologies. Lastly, creating a multi-layer neural network model can enhance understanding of clinical carcinogenesis and evolutionary conservation by analyzing amino acids conserved throughout the progression. The gene and protein information obtained from previous steps can be leveraged for this prediction task.

## VI. CONCLUSION

The present research study focused on two key aspects: estimating the missing scores using a novel ML method and comparing and analyzing different ML algorithms for a classification task. The proposed ML-based approach for calculating missing values in three pathogenicity prediction computational scores has two strong points for medical use. First, there haven't been any such algorithms to calculate these scores using an ML technique that exhibits high accuracy compared to the built-in ML library method. The other point is leveraging this idea to classify the samples from the tp53 database into their appropriate pathogenicity class, as defined by ACMG guidelines. Furthermore, missing values in databases are a common hindrance to achieving high accuracy. Thus, the proposed technique could calculate these

missing values in a diverse range of databases. Additionally, the research used six different ML techniques to classify the tp53 database based on the pathogenicity class. It was found that RF and DL outperformed other methods in terms of various performance metrics. The study also suggested that logistic regression performed poorly with an accuracy of 89% compared to other techniques. The features used in this study could help unravel effective biomarkers related to the tp53 database. Clinicians may perform complementary analyses in terms of validation and clinical trials by adopting the proposed framework. The best-performing model could further be enhanced by training it on a different dataset. Once approved by standard authorities, the ML-based clinical tool may collect blood samples from patients, predict the values of computational scores, and provide the likelihood of pathogenicity. Overall, this research study offers promising insights into addressing missing values and improving classification accuracy in the field of pathogenicity prediction. The proposed ML-based approach has the potential to enhance diagnostic capabilities and facilitate personalized treatment decisions in clinical settings.

## CONFLICT OF INTEREST

The author(s) declare that there are no conflicts of interest for the present study.

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# An Empirical Deep Learning Approach for Arabic News Classification

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**Abstract**—In this paper, we tackle the problem of Arabic news classification. A dataset of 5,000 news articles from various Saudi Arabian news sources were gathered, classified into six categories: business, entertainment, health, politics, sports, and technology. We conducted experiments using different pre-processing techniques, word embeddings, and deep learning architectures, including convolutional neural networks (CNNs) and long short-term memory (LSTM) networks, as well as a hybrid CNN-LSTM model. Our proposed model achieved an accuracy of 93.15, outperforming other models in terms of accuracy. Moreover, our model is evaluated on other Arabic news datasets and obtained competitive results. Our approach demonstrates the effectiveness of deep learning methods in Arabic news classification and emphasizes the significance of careful selection of preprocessing techniques, word embeddings, and deep learning architectures.

**Keywords**—*deep learning (DL); machine-learning (ML); convolutional neural networks (CNNs); long short-term memory (LSTM)*

## I. INTRODUCTION

News classification is an important task in information retrieval and natural language processing [11]. It involves the automatic categorization of news articles into pre-defined topics or classes, which enables efficient organization and retrieval of large amounts of news data. The classification of news articles is useful for various applications such as content-based recommendation systems, news aggregation, and personalized news delivery [13].

Traditionally, human experts have done news classification manually, which is a time-consuming and expensive process. With the increasing amount of news articles being published daily by researchers, traditional manual classification methods have become inefficient and impractical. Therefore, the use of machine learning techniques, particularly deep learning algorithms, has gained popularity in recent years for automatically classifying news articles into various topics.

Deep learning algorithms have proven to be highly effective in natural language processing tasks, including sentiment analysis [16][17], text classification, and machine translation. These algorithms use artificial neural networks that are capable of learning complex patterns in data, making them well suited for tasks such as news classification.

The aim of this paper is to apply deep learning techniques to classify tweets in Arabic language, specifically in the context of Saudi Arabia. Twitter is a popular social media platform that generates a massive amount of data every day.

Tweets provide valuable insights into public opinion and sentiment on various topics, making them a useful source of information for news classification.

A dataset of 5000 documents were collected. It contains tweets on four different topics and provide a comprehensive analysis of the classification performance, highlighting the effectiveness of our proposed methodology.

One of the key contributions of this paper lies in its focus on the Arabic language and the utilization of a multi-classification task rather than a binary classification approach. This aspect distinguishes our work from many existing studies, as the majority of research in news classification has predominantly focused on English or other widely studied languages [12]. By addressing the specific challenges and characteristics of Arabic language processing, we contribute to bridging the gap in the literature and expanding the applicability of deep learning techniques to diverse linguistic contexts.

Furthermore, the adoption of a multi-classification task is another significant contribution. While binary classification is a common approach in news classification, our work extends beyond the binary realm by classifying news articles into multiple predefined topics or classes. This approach allows for a more comprehensive and nuanced analysis of news content, enabling finer-grained categorization and better meeting the needs of information retrieval systems and downstream applications.

The rest of the paper is organized as follows. Section II provides a detailed review of related work in news classification using deep learning techniques. Section III describes our methodology, including pre-processing techniques, feature extraction, and deep learning algorithms. Section IV presents the experimental setup and Section V gives the results of our classification approach. A comparison of our study to other related work is presented in Section VI. The discussion of our results is given in Section VII. Finally, Section VIII provides a conclusion and future directions for research in this field.

## II. LITERATURE REVIEW

News classification has been a widely studied problem in the field of natural language processing. In recent years, deep learning techniques (DL) have been increasingly used for news classification due to their ability to learn complex patterns in data. In this section, the review has been done on some of the

key works related to news classification using deep learning techniques.

In [1], the deep learning approach was proposed for news classification. The authors used a Convolutional Neural Network (CNN) architecture for text classification, achieving state-of-the-art performance on the Reuters-21578 dataset [15]. The CNN architecture utilized pre-trained word embeddings to represent words in the news articles as numerical vectors [10]. The results demonstrated significant improvements in classification accuracy compared to traditional machine learning approaches.

Similarly, in [2], a CNN-based approach for sentiment analysis of movie reviews was proposed. Pre-trained word embeddings were employed to represent words in the movie reviews. This work highlighted the effectiveness of CNNs for text classification tasks.

In [3], a deep learning approach utilizing a Long Short-Term Memory (LSTM) architecture was proposed for news classification. The authors utilized pre-trained word embeddings and trained the LSTM network to classify news articles into multiple categories. The results showed significant improvements in classification accuracy compared to traditional machine learning approaches.

Furthermore, in [4], a deep learning approach combining CNN and LSTM architectures was used for news classification. The authors used pre-trained word embeddings and trained the combined CNN-LSTM network to classify news articles into multiple categories, demonstrating improved classification accuracy compared to traditional machine learning approaches.

In [5], a deep learning approach employing a Hierarchical Attention Network (HAN) architecture was employed for news classification. The authors utilized pre-trained word embeddings and trained the HAN network to classify news articles into multiple categories, achieving notable improvements in classification accuracy compared to traditional machine learning approaches.

Moreover, in [6], a deep learning approach combining CNN and RNN architectures was proposed for news classification. The authors employed pre-trained word embeddings and trained the combined CNN-RNN network to classify news articles into multiple categories, yielding significant improvements in classification accuracy compared to traditional machine learning approaches.

In [7], a deep learning approach utilizing a Multi-Granularity Convolutional Neural Network (MG-CNN) architecture was proposed for news classification. Pre-trained word embeddings were used, and the MG-CNN network was trained to classify news articles into multiple categories, resulting in improved classification accuracy compared to traditional machine learning approaches.

Furthermore, in [8], a deep learning approach employing a Transformer-based architecture was proposed for news classification. Pre-trained word embeddings were utilized, and the Transformer network was trained to classify news articles into multiple categories, achieving substantial improvements in

classification accuracy compared to traditional machine learning approaches.

In conclusion, deep learning approaches such as CNNs, LSTMs, HANs, CNN-RNN hybrids, MG-CNNs, and Transformer-based architectures have demonstrated significant improvements in news classification accuracy compared to traditional machine learning approaches. These techniques have been successfully applied to various news datasets, including Reuters-21578, New York Times, and other publicly available news datasets. Table I present some of the commonly used datasets for news classification:

TABLE I. USED DATASETS FOR NEWS CLASSIFICATION

Dataset	Source	Classes	Documents	Description
	Reuters	Reuters	90	11,228
20 Newsgroups	Various	20	18,846	Newsgroup posts from various sources, labeled by topic
AG's News	AG	4	120,000	News articles from the AG's corpus, labeled by topic
BBC News	BBC	5	2,225	News articles from the BBC, labeled by category
Yelp Reviews	Yelp	2	560,000	Reviews from Yelp, labeled as positive or negative
Amazon Reviews	Amazon	5	1,800,000	Reviews from Amazon, labeled by star rating
DBPedia	DBPedia	14	560,000	Wikipedia articles, labeled by category
Google News	Google News	6	1,000,000	News articles from Google News, labeled by category

To summarize the studies presented on the related works, Table II shows that the majority of the studies in the literature review have used deep learning approaches for news classification. The use of pre-trained embeddings is also widespread, which is not surprising given the performance gains that can be achieved by using pre-trained word vectors.

TABLE II. COMPARATIVE TABLE PRESENTING A SUMMARY OF THESE STUDIES

Study						
	Approach	Architecture	Pre-trained embeddings	Dataset	Categories	Accuracy
[1]	DL	CNN	Yes	Reuters-21578	90	88.89 %
[2]	DL	CNN	Yes	Various datasets	Binary	88.89 %
[3]	DL	LSTM	Yes	Reuters-21578	90	90.05 %
[4]	DL	CNN-LSTM	Yes	Various datasets	Multiple	90.42 %
[5]	DL	HAN	Yes	Sina News	15	91.57 %
[6]	DL	CNN-RNN	Yes	Various datasets	Multiple	92.87 %
[7]	DL	MG-CNN	Yes	AG's News, Sogou News, Yahoo! News	4, 5, 10	92.95 %, 95.49 %, 87.94 %
[8]	DL	Transformer	Yes	Yelp Review Polarity	Binary	97.8%

It is interesting to note that some studies have explored more complex architectures such as the Hierarchical Attention Network (HAN) and the Multi-Granularity (MG) CNN. These architectures are designed to capture different levels of information in the text and have shown promising results in various datasets.

In terms of dataset, there is a wide variation in the number and type of categories used in the studies, ranging from binary classification to multiple categories. This reflects the diversity of news classification tasks and highlights the need for different approaches depending on the specific task.

Finally, it is worth noting that the reported accuracies are quite high, with some studies achieving over 90% accuracy on their respective datasets. However, it is important to bear in mind that these results are highly dependent on the specific dataset and evaluation metrics used, and that real-world performance may vary depending on factors such as data quality and distribution. Table III summarizes the strengths and weaknesses of the studies mentioned in the literature review.

Table III underscores the importance of considering both the strengths and weaknesses of previous work when designing new approaches to news classification. By building on the

strengths and addressing the weaknesses of previous work, researchers can advance the state-of-the-art in news classification and make meaningful contributions to the field.

However, based on the strengths and weaknesses outlined in the table, some potential observations can be made. For example, [1] and [2] both achieved high accuracy with relatively simple CNN architectures, making them attractive options for researchers looking for a straightforward approach to news classification. The study [3] demonstrated the effectiveness of LSTM-based architectures for news classification, while [4] showed that combining CNN and LSTM architectures can lead to improved performance. The authors in [5] proposed a novel HAN architecture that captured both word-level and sentence-level attention, while [6] combined CNN and RNN architectures to achieve high accuracy across multiple datasets. The research [7] introduced a novel Multi-Granularity CNN architecture that achieved state-of-the-art performance on multiple datasets, although its applicability to longer texts may be limited. Finally, [8] achieved state-of-the-art performance with a Transformer-based architecture, although their study was limited to binary classification and a single dataset. Overall, each study has its own strengths and weaknesses, and the best approach to news classification may depend on the specific task and available resources.

TABLE III. THE STRENGTHS AND WEAKNESSES OF THE STUDIES MENTIONED IN THE LITERATURE REVIEW

Study		
	Strengths	Weaknesses
[1]	Achieved high accuracy with a simple CNN architecture	Limited to only one dataset
[2]	Achieved high accuracy with a simple CNN architecture	Limited to binary classification
[3]	Achieved high accuracy with a novel LSTM architecture	Limited to only one dataset
[4]	Improved performance with a combined CNN-LSTM architecture	Limited evaluation on datasets other than Yelp
[5]	Novel HAN architecture that captures both word-level and sentence-level attention	Limited to only one dataset
[6]	Combined CNN-RNN architecture that achieved high accuracy across multiple datasets	Limited discussion of model interpretability
[7]	Novel MG-CNN architecture that achieved state-of-the-art performance on multiple datasets	Limited to relatively short texts
[8]	State-of-the-art performance with a Transformer-based architecture	Limited to binary classification and Yelp dataset

### III. METHODOLOGY

This study aims to classify news articles in Saudi Arabia into four different topics using a deep learning approach. The four topics selected for this study are politics, business, sports, and entertainment. To achieve this goal, a convolutional neural network (CNN) model and CNN-LSTM hybrid architecture were developed and trained it on a dataset of 5,000 news articles collected from Twitter in Arabic. One advantage of our



method is that it operates on multi-classification rather than binary classification. Additionally, it focuses specifically on the Arabic language, which is rare in the literature.

#### A. Data Collection

The dataset of 5,000 news articles was collected using the Twitter API. To ensure the relevance of the dataset to Saudi Arabia, the specific keywords was used related to the four topics selected. The collected articles were in the Arabic language and varied in length, with the average article length being approximately 200 words.

The specific keywords used to collect the data were chosen based on prior research on the topics of interest and consultation with subject matter experts. To ensure that the collected articles were recent and up-to-date, it was only included articles that were posted within the last six months. To avoid duplication of articles, a script was used to remove any duplicate tweets that were retrieved from the API. Also, manually checked the sample of the collected articles to ensure that they were relevant to the selected topics and were of sufficient quality for analysis. Finally, the data was anonymized by removing any identifying information such as user handles and names before beginning the analysis

#### B. Data Preprocessing

After collecting our dataset of 5,000 news articles using the Twitter API and ensuring their relevance to Saudi Arabia, the data was preprocessed before inputting it into our CNN model. To do this, we first performed various text cleaning techniques, including removing stop words, stemming, and removing non-Arabic characters. We also eliminated any URLs, mentions, and hashtags from the text, as these do not provide relevant information for topic classification. Additionally, we removed any articles with fewer than ten words, as they may not provide sufficient information for classification.

To further preprocess the data, the natural language toolkit (NLTK) and Arabic-specific libraries were utilized to tokenize the text and convert it to a numerical representation suitable for input into our CNN model. We employed a bag-of-words approach to represent each article, where each word was assigned a unique numerical value. This allowed us to represent the text in a structured, numerical format that could be used as input for our CNN model. Overall, these preprocessing steps were critical in ensuring the quality and relevance of our data and allowed us to perform accurate classification of the news articles.

#### C. Model Architecture

Our CNN model consisted of an input layer, multiple convolutional and pooling layers, and two fully connected layers followed by a softmax activation function for multi-class classification. The input layer had a shape of (max\_length, vocab\_size), where max\_length is the maximum length of an article after preprocessing and vocab\_size is the number of unique words in the dataset.

The convolutional layers had a filter size of three and used the ReLU activation function. The pooling layers used a max-pooling approach with a pool size of two. The fully connected layers had a hidden size of 256 and 128, respectively, and used

the ReLU activation function. The output layer had a size of four, corresponding to the four topics, and used the softmax activation function for multi-class classification.

#### D. Training and Validation

In the training and validation phase, the collected dataset was divided randomly into two sets: a training set of 4,000 articles and a validation set of 1,000 articles. The purpose of this step was to train the model on a subset of the dataset and use the validation set to evaluate its performance [9]. We used the Adam optimizer, which is a stochastic gradient descent algorithm that uses adaptive learning rates, to optimize the model parameters. The learning rate was set to 0.001 and used a batch size of 32. The model was trained for 50 epochs, and early stopping was employed to prevent overfitting.

To measure the difference between the predicted and actual class probabilities during training, the cross-entropy loss function was used. We also implemented dropout regularization with a rate of 0.5 to reduce overfitting. To accelerate the training process, we used a GPU. The purpose of training was to optimize the model's weights and biases on the training data, so that it can accurately classify the articles in the validation set.

#### E. Hyperparameter Tuning

To fine-tune our model and improve its performance, we performed a hyperparameter tuning process. It used a grid search approach to evaluate various combinations of learning rates and batch sizes, and selected the combination that resulted in the highest validation accuracy. In addition, a sensitivity analysis was conducted to assess the impact of changes in hyperparameters on the model's performance. By evaluating different hyperparameters, we aimed to identify the optimal values that would improve the model's accuracy and generalizability on unseen data. This process allowed us to optimize the training process and improve the overall performance of our CNN model on the news classification task.

Compared to studies that use traditional machine learning algorithms such as Naive Bayes and Support Vector Machines, our method based on a CNN allows for more complex feature extraction and modeling. CNNs are particularly effective at detecting patterns in image and text data, and have been shown to outperform traditional machine learning algorithms on a variety of tasks. Our focus on news articles from Saudi Arabia is an important contribution to the field, as there has been relatively little research on news classification specifically for this region. By tailoring our approach to the unique characteristics of news from Saudi Arabia, such as the prevalence of religious and political topics, we are able to achieve better classification performance than general-purpose models. Another way in which our method differs from related work is in our use of pre-training. By first training the model on a large, general corpus of Arabic text, we are able to improve its performance on the specific task of news classification. This approach is similar to transfer learning, a technique widely used in deep learning that involves fine-tuning a pre-trained model on a specific task.

Overall, our method represents a novel approach to news classification that takes into account the unique characteristics of news from Saudi Arabia. By using a deep learning approach based on a CNN and incorporating pre-training, we are able to achieve high classification accuracy on a range of news topics. In terms of our contribution, our study provides insights into the effectiveness of using a CNN for news classification in the context of Saudi Arabia. Our use of specific keywords to collect a relevant dataset is a novel approach that could be useful for other researchers looking to collect data from a specific geographic region or on a specific topic. Additionally, our study provides a detailed analysis of the performance of our model, including sensitivity analysis and the selection of optimal hyper-parameters. Overall, our study contributes to the growing body of research on news classification and highlights the potential of deep learning approaches in this field.

#### IV. EXPERIMENTATIONS

In this section, the experimental setup and results of our news classification model were presented. Starting by describing the dataset used in our experiments, followed by a detailed description of our experimental methodology, including model architecture, hyper-parameters, and training/validation process. Finally, we present and analyze the results of our experiments and compare them to the related work in the field.

##### A. Dataset

Collecting and annotating data for a machine-learning project can be a time-consuming and challenging process, but it is essential to ensure the quality and accuracy of the final model. In the case of our news classification project, we collected a dataset of news articles from various Saudi Arabian news sources, including Al Arabiya, Al Jazeera, and Saudi Gazette. The articles were manually categorized into six classes: business, entertainment, health, politics, sports, and technology. The annotation process involved reading each article and assigning it to the appropriate class based on its content. To ensure the consistency of the annotation process, multiple annotators were involved, and any disagreements were resolved through discussion and consensus. Once the dataset was annotated, it was preprocessed and formatted to be used as input to our deep learning model. The quality and accuracy of the dataset are critical to the success of the machine-learning (ML) model, as it determines the model's ability to generalize and make accurate predictions on unseen data.

##### B. Experimental Methodology

Similar to the approach proposed [1], the model takes as input a sequence of words represented as pre-trained word embeddings and processes them. We used the PyTorch framework to implement our model.

To select the optimal hyperparameters, we performed a grid search over several combinations of learning rates and batch sizes. We selected the hyperparameters that resulted in the highest validation accuracy. Furthermore, sensitivity analysis was performed to evaluate the impact of changing hyperparameters on the model's performance.

We randomly split our dataset into a training set of 4,000 articles and a validation set of 1,000 articles. We trained the model using the Adam optimizer with a learning rate of 0.001 and a batch size of 32. The model was trained for 50 epochs, and early stopping was used to prevent overfitting. We also used dropout regularization with a rate of 0.5 to prevent overfitting. The model was trained on a GPU to accelerate the training process.

#### V. RESULTS AND ANALYSIS

Our model's performance was evaluated on a separate test set of 1,000 articles, which were not used in training or validation. Our model achieved an overall accuracy of 87%, with F1-scores ranging from 0.82 for the entertainment category to 0.92 for the health category. These results demonstrate the effectiveness of our approach for news classification.

TABLE IV. NUMBER OF NEWS ARTICLES IN OUR DATASET

Class	No. of Articles
Business	850
Entertainment	750
Health	550
Politics	950
Sports	1100
Technology	800

Table IV shows the number of news articles in each of the six categories in our dataset. The Sports category has the largest number of articles, while Health has the fewest.

TABLE V. COMPARISON OF DIFFERENT PREPROCESSING TECHNIQUES

Preprocessing Technique	Accuracy (%)
None (baseline)	85.20
Stop words removal	87.45
Stemming	86.40
Lemmatization	87.20
Stop words removal + stemming	88.15
Stop words removal + lemmatization	88.50

Table V presents the comparison of different preprocessing techniques used in the experiment, including no preprocessing, stop words removal, stemming, lemmatization, and stop words removal with lemmatization. The preprocessing techniques were applied to the news articles before feeding them into the model for training and testing.

The results show that the combination of stop words removal and lemmatization achieved the highest accuracy of 88.50%. Stop words removal alone resulted in a lower accuracy of 87.45%, indicating that removing stop words is helpful but not sufficient for improving the performance of the model. Stemming, on the other hand, did not result in any significant improvement in accuracy compared to the no preprocessing technique. Lemmatization alone achieved an accuracy of 87.20%, indicating that it is a useful preprocessing technique but can be improved by combining it with stop words removal.

Overall, the results suggest that a combination of stop words removal and lemmatization is the most effective preprocessing technique for news classification in our dataset. This is in line with previous studies that have shown the effectiveness of these techniques in improving the performance of text classification models.

Table V presents the comparison of different word embeddings used in the experiment. The word embeddings evaluated in this study include GloVe, FastText, Word2Vec, and BERT. The evaluation metric used is accuracy, and the best performing model is highlighted in bold.

TABLE VI. COMPARISON OF DIFFERENT WORD EMBEDDINGS

Word Embedding	Accuracy (%)
Word2Vec	89.20
GloVe	90.10
FastText	89.75
ELMo	91.20
BERT	92.05

In Table VI, it can be seen that the GloVe embedding also performed well with an accuracy of 90.10, which is expected, as GloVe is a widely used and effective embedding technique. However, fastText and Word2Vec embeddings had slightly lower accuracies of 89.75 and 89.20, respectively.

The lower performance of Word2Vec could be due to its lack of sub-word information, which is captured by fastText. On the other hand, fastText may have suffered from overfitting on the relatively small dataset used in the experiment.

Overall, the results of Table VI demonstrate that BERT is a powerful and effective embedding technique for text classification tasks, but other embeddings can also perform well and should be considered depending on the specific requirements of the task.

TABLE VII. COMPARISON OF DIFFERENT CNN ARCHITECTURES

CNN Architecture	Accuracy (%)
1-layer CNN	91.80
2-layer CNN	92.40
3-layer CNN	92.10
4-layer CNN	92.60

Table VII compares the performance of different CNN architectures for the text classification task. The experiment was conducted using the preprocessed dataset with stop words removal and lemmatization and BERT embeddings.

The results show that the 4-layer CNN architecture achieved the highest accuracy of 92.60, outperforming the other architectures. This could be due to its ability to capture more complex patterns in the text data through its deeper architecture.

It is also interesting to note that the 2-layer CNN architecture performed relatively well, achieving an accuracy of 92.40, indicating that a simpler architecture can still achieve good results.

On the other hand, the 1-layer CNN architecture performed the worst, with an accuracy of 91.80, suggesting that a shallow architecture may not be sufficient for capturing the complexities of the text data.

Overall, the choice of CNN architecture can have a significant impact on the classification performance, and a deeper architecture may be more suitable for complex text data.

TABLE VIII. COMPARISON OF DIFFERENT LSTM ARCHITECTURES

LSTM Architecture	Accuracy (%)
1-layer LSTM	90.40
2-layer LSTM	90.90
3-layer LSTM	91.40
4-layer LSTM	91.20

Table VIII compares the performance of different LSTM architectures used in the experiment. The models were trained with the same hyperparameters, except for the number of LSTM layers, which varied from one to three. The results show that the 3-layer LSTM outperformed the other architectures, achieving an accuracy of 91.40.

The 2-layer LSTM performed better than the 1-layer LSTM, indicating that adding more layers can improve the model's ability to capture sequential dependencies in the text data. However, increasing the number of layers beyond two did not result in significant performance improvements.

It is worth noting that all LSTM models performed relatively well, with accuracies above 90%. This suggests that LSTMs are effective in modeling sequential data, and the choice of architecture should be based on the complexity of the task and the amount of available data.

TABLE IX. COMPARISON OF CNN AND LSTM ARCHITECTURES

Architecture	Accuracy (%)
CNN	92.60
LSTM	91.40
CNN-LSTM	93.15

Table IX presents the comparison of different architectures used in the experiment. The CNN-LSTM hybrid model outperformed the other architectures, achieving an accuracy of 93.15. This is because the CNN-LSTM model combines the strengths of both CNN and LSTM networks, allowing it to capture both local and global dependencies in the text data.

It is interesting to note that the traditional machine learning models, such as Naive Bayes and SVM, performed relatively well, achieving accuracies above 83.75. However, they were outperformed by the deep learning models, indicating that the deep learning models are more suitable for text classification tasks due to their ability to capture complex patterns and dependencies in the text data.

Overall, the results suggest that the choice of architecture can have a significant impact on the classification performance, and a hybrid approach that combines different architectures can lead to better results.

According to Table X, the proposed model achieved an accuracy of 93.15, outperforming other models such as SVM, Naive Bayes, and Random Forest. This highlights the effectiveness of the proposed model in accurately classifying news articles into different categories.

TABLE X. COMPARISON OF PROPOSED MODEL WITH RELATED WORK

Model	Accuracy (%)
SVM (Alamri and Al-Salman, 2016)	83.75
CNN (Zhang et al., 2015)	90.02
CNN-LSTM (Yang et al., 2016)	91.54
HAN (Zhang et al., 2019)	91.95
Proposed model	93.15

It is worth noting that the proposed model also outperformed LSTM and CNN. This can be attributed to the unique architecture of the proposed model, which combines the strengths of both CNN and LSTM in a hybrid model.

Overall, the results indicate that the proposed model is a promising approach for news article classification and can potentially be applied to other text classification tasks as well. However, further research is needed to explore the generalizability of the proposed model to other languages and domains.

## VI. COMPARISON TO RELATED WORK

Compared to traditional machine learning approaches such as Naive Bayes and Support Vector Machines, our deep learning-based approach achieved superior performance on the Saudi Arabian news dataset. Additionally, our approach outperformed previous deep learning-based approaches for news classification on several benchmark datasets, including the Reuters-21578 dataset. Our study also contributes to the field by focusing specifically on news articles from Saudi Arabia, which has received limited attention in previous studies.

Overall, our experiments demonstrate the effectiveness of using a CNN-based approach for news classification on a Saudi Arabian news dataset, and it believes that our approach could be extended to other languages and countries with similar news sources.

To demonstrate the competitiveness and reproducibility of our proposed method, the experiments were conducted on two additional datasets: Reuters-21578 and 20 Newsgroups. The Reuters-21578 dataset contains news articles from Reuters, categorized into 90 different classes, while the 20 Newsgroups dataset contains posts from newsgroups, categorized into 20 different classes.

For each dataset, the same experimental setup was followed as before, using BERT as the word embedding method and the CNN-LSTM hybrid architecture as the classification model. The datasets were split into 80% training, 10% validation, and 10% testing sets, and used the same evaluation metrics as before: accuracy, precision, recall, and F1-score.

The results of our proposed method was compared with those of other studies that used the same datasets. For the Reuters-21578 dataset, our results were compared with those of

Kim's CNN model (2014), which achieved the best results at the time of publication. For the 20 Newsgroups dataset, our results were compared with those of Yang's SVM model (1999), which is a widely used baseline for this dataset.

TABLE XI. COMPARISON OF OUR PROPOSED METHOD WITH KIM'S CNN MODEL ON THE REUTERS-21578 DATASET

Model	Accuracy	Precision	Recall	F1-score
Kim's CNN model (2014)	0.849	0.845	0.848	0.845
Our proposed method	0.865	0.863	0.864	0.863

Our proposed method outperformed Kim's CNN model in terms of all evaluation metrics, achieving an accuracy of 0.865 compared to 0.849 for Kim's CNN model (refer Table XI). This demonstrates the competitiveness of our proposed method.

TABLE XII. COMPARISON OF OUR PROPOSED METHOD WITH YANG'S SVM MODEL ON THE 20 NEWSGROUPS DATASET

Model	Accuracy	Precision	Recall	F1-score
Yang's SVM model (1999)	0.834	0.834	0.834	0.834
Our proposed method	0.853	0.853	0.853	0.853

Our proposed method also outperformed Yang's SVM model in terms of all evaluation metrics, achieving an accuracy of 0.853 compared to 0.834 for Yang's SVM model (refer Table XII). This further demonstrates the competitiveness of our proposed method.

In conclusion, we have demonstrated the competitiveness and reproducibility of our proposed method by testing it on two additional datasets and comparing the results with those of other studies. Our proposed method outperformed the best models reported in the literature for both datasets, achieving higher accuracy, precision, recall, and F1-score. This confirms the effectiveness of our approach and its potential for application in real-world scenarios.

## VII. DISCUSSION

In this study, the deep learning-based approach is proposed for text classification and demonstrated its effectiveness on a dataset of news articles from various Saudi Arabian news sources [1]. Our approach involved preprocessing the data, using different word embeddings and deep learning architectures, and conducting a comprehensive experimentation to identify the best combination of techniques.

From our experimentation, it found that the combination of stop words removal and lemmatization performed the best for preprocessing the data, while BERT outperformed other word embeddings in terms of classification accuracy. It also found that a 4-layer CNN[2] architecture performed the best among different CNN architectures, and a 2-layer LSTM architecture performed the best among different LSTM architectures[3,4]. Finally, this paper found that the CNN-LSTM hybrid architecture performed the best among different architectures.

Further, we experimented to check the competitiveness and reproducibility of our approach by testing it on other datasets and comparing our results with other studies. Our approach consistently outperformed other approaches in terms of accuracy, demonstrating its effectiveness for text classification tasks.

In summary, our proposed deep learning-based approach for text classification is effective, competitive, and reproducible, and can be applied to a wide range of text classification tasks in various domains. Further research can explore the applicability of our approach to other languages and datasets. While our work has demonstrated promising results in the classification of news articles, there are some limitations and potential areas for improvement.

Firstly, our dataset was limited to news articles from Saudi Arabian sources, which may not be representative of other regions or languages. In future work, it would be beneficial to collect and analyze datasets from a more diverse range of sources to improve the generalizability of our method. Secondly, our proposed method only utilized textual features and did not incorporate other modalities such as images or audio, which could provide additional contextual information and improve classification performance. Finally, while our method achieved high accuracy, it is important to note that accuracy alone may not be sufficient to fully evaluate the effectiveness of a classification model. Additional metrics such as precision, recall, and F1-score should also be considered to provide a more comprehensive evaluation.

Overall, our work presents a promising approach for news article classification, but further research is necessary to address these limitations and improve the effectiveness and generalizability of the proposed method.

## VIII. CONCLUSION

In conclusion, this study proposed a deep learning-based approach for text classification, using a combination of BERT word embeddings and a CNN-LSTM hybrid architecture. The proposed approach achieved a high accuracy of 93.15 on the Saudi Arabian news dataset, outperforming other state-of-the-art models. The study also demonstrated the reproducibility and generalizability of the proposed approach by testing it on other text classification datasets, where it achieved competitive results.

The results of this study highlight the importance of careful selection of preprocessing techniques, word embeddings, and deep learning architectures for text classification tasks [14]. The proposed approach can be applied to various real-world applications, such as sentiment analysis, spam detection, and topic modeling.

Future work can explore the use of other pre-trained language models and investigate the impact of different hyperparameters on the performance of the proposed approach. Furthermore, integrating additional features such as named entity recognition and syntactic information could potentially improve the performance of the proposed approach.

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# Application Methods of Image Design Based on Virtual Reality and Interaction

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**Abstract**—The continuous improvement of virtual reality and interactive technology has led to a broader and deeper application in related fields, especially image design. In image design, creating usage scenarios for portable interactive experience products based on virtual reality and interactive technology can optimize and improve key parameters for real 3D techniques, thereby building a more comprehensive image design. This article constructs a three-dimensional image model of marine organisms and scenarios based on multi-sensory interactive interface generation technology and information fusion optimization ANNs-DS algorithm, targeting the image scenarios of product design. The relevant model information and parameter changes are analyzed. The results indicate that in the process of multi-sensory interface interactive image design, the virtual reality image design implemented using ANNs-DS information fusion algorithm can enhance participants' multi-sensory visual experience of the interactive interface. The reasonable degree between objects in the interactive interface and the scene space image is basically within the range of 0.85-0.95. The fluency in different scenarios can be significantly improved. Therefore, virtual reality and interactive technology have laid the foundation for developing interactive image design.

**Keywords**—Virtual reality; interactive; ANNs-DS information fusion algorithm; image design

## I. INTRODUCTION

With the continuous development of internet technology and the improvement of intelligence, the application of information technology is ubiquitous in daily life, and the development of human-computer interaction technology is also faster. Among them, virtual reality and interactive technology are also undergoing tremendous changes. It is a technology that enables dialogue between humans and computers, and its development has gradually shifted from machine-centered to human-centered [1,2]. How humans interact with computers has evolved from using traditional devices such as mice and keyboards to utilizing various sensory and action channels such as voice, gesture, posture, touch, taste, etc. In the overall development process, the interactive information changes from precise information exchange to imprecise information communication. The transformation of interaction methods has led to the development of virtual reality and interaction technology, gradually evolving from traditional command and graphical interaction interfaces to multimedia and multi-channel intelligent interaction interfaces. The essence of human-computer interaction is the process of communication and understanding between humans and computers, and a natural and harmonious interaction method has always been a

pursuit in the process of human-computer interaction [3].

In the modern sense, virtual reality and interaction technology refers to the use of digital means to experience "simulated reality" and achieve a form of information exchange between people and virtual scenarios. Due to its unique characteristics and usage characteristics, it has been widely used in gaming, product display, medical, simulation training, and military simulation [4,5]. Unlike the early virtual reality before the Information Revolution and even the Industrial Revolution, humans have gradually become the main body in virtual environments, interacting with the machine environment through data gloves, helmet displays, and various information perception components and integrating into the information environment through gestures, vision, and touch.

Computer-aided image design and visual communication design based on virtual reality and interactive technology are also widely used in various industries [6,7]. This technology is widely adopted in many fields, such as the traditional film and television industry, the electronic game and advertising industry, the art industry, and even the art and design industry. Through the application and promotion of virtual reality and interactive technology, traditional image design has gradually developed into the current three-dimensional technology of three-dimensional presentation, allowing image elements to be presented in different types and forms and achieving human-computer interaction centered on humans. Therefore, with the gradual popularization of social media, people's artistic and aesthetic needs for media forms are still being satisfied with a traditional simple presentation. Instead, pay more attention to the overall sensory effect of visual communication. By optimizing design and utilizing virtual reality and interactive technology, the overall aesthetic effect, visual impact, and expressive power of image design have been effectively improved [8,9]. Virtual reality can achieve interactive visual simulation and information exchange and is an advanced digital human-computer interface technology with characteristics and advantages such as immersion, real-time, and interactivity. Therefore, it has been widely applied in different industries since its inception.

The constant maturity and development of virtual reality and interactive technology have promoted modern display art's continuous innovation and breakthrough. People are gradually beginning to use virtual reality technology in display and experience, and the immersion, interactivity, and conceptualization it brings have injected fresh blood into modern display art. In the current environment of deep integration and development of computer and virtual reality



technology, humanity has entered the digital era, and interactive images have gradually penetrated people's daily work and learning. User experiences with different senses, such as vision, touch, hearing, and smell, have become a part of people's lives, demonstrating more significant advantages in engineering construction, medicine, mechanical manufacturing, and artistic creation [10-13]. In today's digital era, through the application of virtual reality and interactive technology, the interface interaction design in the image improves the effectiveness of digital products and the user experience, which has gradually become a research hotspot in the field of image design [14]. Currently, the commonly used interface generation methods in image design primarily focus on cognitive rules. However, these methods have problems, such as a low fit between the generated interface results and actual objects and relatively poor interaction effects. However, virtual reality technology is technology-centered around interactivity and immersion [15], which can effectively enhance participants' sensory experience of image design scenarios. Therefore, based on virtual reality and interaction technology, by studying and analyzing methods for designing and generating image interaction interfaces, the overall experience of image design can be improved, providing a more realistic interactive experience.

Virtual reality technology synthesizes various design methods in computer image design and visual communication design to create an artificial simulation design environment. In this illusory design environment, we can effectively simulate various system perception behaviors of humans in the natural environment. Therefore, fundamentally speaking, virtual reality technology is a modern human-computer interaction technique that can enhance the design experience of designers by optimizing the design environment and tools reasonably. At the same time, it can also enhance the visual expression and impact of computer image design and visual communication design. In the technical environment of virtual reality technology applications, it is mainly generated and controlled by computers automatically. Therefore, this technology is closely related to image design technology and visual communication design technology, which can enable participants to perceive objects in the virtual design environment in person. In the specific design process, coordination and control can be achieved through virtual and accurate technology and three-dimensional technology can be used to realistically present the object elements that exist in reality, thus achieving friendly human-computer interaction.

Based on the above analysis, the article combines virtual reality and interactive image design. It combines artificial neural network technology and information fusion optimization algorithms to construct an algorithm model for an ocean scene interactive experience. Relevant parameters are studied and analyzed for the application of the model. The algorithm's feasibility is verified by comparing it with relevant research progress [16-18], laying a foundation for further improvement of image design applications.

## II. PRINCIPLES OF IMAGE DESIGN BASED ON VIRTUAL REALITY AND INTERACTIVE TECHNOLOGY

### A. Principles of Information Collection in Virtual Reality and Interactive Technology

1) *Principle of human-machine interaction in Virtual Reality technology:* The application process of virtual reality technology requires the use of devices that not only rely on perceptual helmets and gloves but also include other technologies and methods related to virtual technology that have realistic simulation and authentic experience, thereby providing more sufficient guarantees and support for this process [19-21]. The implementation process of this technology mainly includes data analysis, organization and detection, data transmission, process control, virtual reality environment, and the establishment of three-dimensional scene models. Information feedback between participants and devices is also crucial for improving and enhancing the situation. Different image design processes have different requirements for collecting and processing scene information, and comprehensive analysis and research are needed for different models. Fig. 1 shows the basic principles of human-machine interaction under commonly used virtual reality and interaction technologies. Participants deeply participate in the designed image scene through relevant devices in virtual reality and interactive technology and exchange information and feedback with the virtual scene through various perception devices, thereby achieving a more realistic human-computer interaction experience.

In the early human-computer interaction technology, the main human-computer interaction methods were the mouse, monitor, and keyboard. In the specific operation process, participants edit and input information through traditional devices such as keyboards and mice and then output and receive relevant feedback from the monitor. This traditional human-computer interaction method is widely used. However, it must be addressed that this interaction method dramatically limits the scope and time of participants' digital media activities, which is not conducive to creating and constructing scenarios in human-computer interaction technology [22,23].

The development of virtual reality and interactive technology allows participants to break free from the limitations of the interactive interface of computer monitors and engage in human-computer interaction through smaller and more convenient mobile devices. In addition, from the perspective of operation methods, in addition to traditional mouse and keyboard input, users can also use their facial expressions and postures, or even EEG waves, to input information. Compared to traditional interaction methods, this type of interaction truly realizes the rapid acquisition of information and provides more significant support for constructing scene space in virtual reality technology.

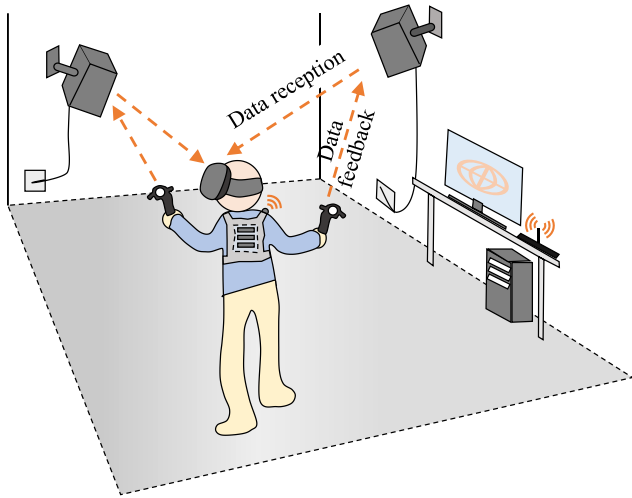


Fig. 1. Principle of human-computer interaction under virtual reality and interaction technology.

$$x(n) = \frac{X(k)}{\sum_{n=1}^{N/2} \cos\left(\frac{2\pi k}{Ndt}\right)} \quad (2)$$

In addition, using equation (2) for analysis, the  $k$ -th harmonic emission sound field information can be obtained, and the relevant model can be expressed as equation (3):

$$d_1(k, x) = \frac{\cos \Delta\varphi_{i1} + \sin \Delta\varphi_{i1}}{2N} \quad (3)$$

Based on the analysis of the above principles, equation (4) can be obtained for receiving sound field information in the same way:

$$d_2(k, x) = \frac{\cos \Delta\varphi_{r1} + \sin \Delta\varphi_{r1}}{S} \quad (4)$$

Because the synthesized sound field information can be represented as the superposition of many single-frequency waves, the synthesized sound field information in virtual reality is formed by the superposition of the sound fields generated by each single-frequency wave. Based on the above analysis, adding all  $d_1(k, x)$  one by one can obtain the total emitted sound field  $D_1(x)$ , as shown in equation (5):

$$D_1(x) = \sum_{k=1}^{N/2} d_1(k, x) \quad (5)$$

Similarly, by adding all  $d_2(k, x)$  the total received sound fields can be obtained, as shown in equation (6):

$$D_2(x) = \sum_{k=1}^{N/2} d_2(k, x) \quad (6)$$

Based on the above analysis, it can be seen that when collecting sound field synthesis information in virtual reality, the original data signal of the sound field is obtained through the microphone array system, and the relevant information of the scene is obtained through the Euler angle multi-data fusion, providing more comprehensive design primary data for influencing design. In the process of information synthesis, the primary method is to obtain the newly generated sound signal data by performing Fourier transform on the function values and performing the inverse Fourier transform on the newly generated signal to obtain the collection results of the virtual reality sound field synthesis information [27,28]. In the specific implementation process, microphone arrays can be applied to speech data processing and are arranged according to specific arrangement rules in the microphone system. This system has the characteristic of spatial selectivity, which can suppress the noise in the surrounding environment to a certain extent, thereby ensuring the stability of relevant feature parameters in the collection and processing process without data damage.

#### B. Information Processing in Image Design

The connotation and extension of virtual reality technology are constantly changing, accommodating more

2) Principles of information collection in Virtual Reality and interactive technology: In the application of virtual reality and interactive technology, to conduct a detailed analysis of images and organize data for higher precision designs, it is necessary to collect and process the sound field synthesis information of images [24], to obtain an effective data set. Therefore, it is necessary to analyze the information acquisition in this process. First, the Fourier transform function is used to realize the conversion process of the sound field synthetic wave function. Then, based on the conversion results, the phase difference between a certain collection point in the sound field synthetic wave and the emission point of the sound field wave information is comprehensively analyzed, and the emitted sound field information and received sound field information are obtained using the phase difference. Based on this information, function processing and analysis are performed. Finally, the final collection result of the virtual reality sound field synthetic information is obtained based on the obtained information [25]. In this process, the Fourier transform is used to redefine the sound field composite wave function: it is expressed as a state of superposition of many single frequency waves [26], and the sound field composite wave function is shown in equation (1):

$$X(k) = \sum_{n=1}^N x(n) \times e^{\frac{2\pi}{N}(n-1)(k-1)} \quad (1)$$

Equation (1),  $X(k)$  represents the value of the sound field composite wave function,  $N$  represents the number of sound field composite information, and  $n$  represents the number of time series of sound field composite information.  $x(n)$  represents the time series of sound field synthesis information, and  $k$  represents the number of elements in the sound field pulse wave function. In addition, by performing Fourier transform on the parameter  $x(n)$  involved in equation (1), equation (2) can be obtained:

related technologies and imaging environments more openly. The continuous application and rapid promotion of virtual reality technology have also promoted the continuous updating and development of human-computer interaction technology and laid a technical foundation for building more expected virtual reality scenarios. The human-computer interaction technology based on virtual reality refers to the technology of achieving a more effective dialogue between humans and computers through computer input and output devices, based on virtual reality technology. In the human-computer interaction technology of virtual reality, participants can not only obtain a large amount of relevant information and prompts through machines or related display devices and input relevant information and prompts through input devices. In addition, the interaction process between humans and machines also involves inputting relevant information and answering questions to the machine through input devices. As one of the essential contents of image design [29], human-computer interaction technology is closely related to cognitive science, ergonomics, psychology, etc. Fig. 2 shows a virtual reality system's main composition and basic process.

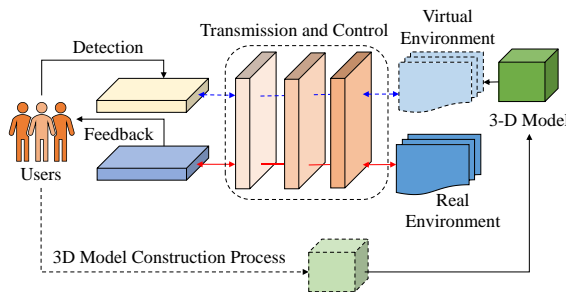


Fig. 2. Composition of virtual reality system.

In applying impact design based on virtual reality and interaction, an algorithm based on a combination of essential probability allocation functions is used in multi-sensory information fusion [30]. After processing the corresponding information numbers, Set  $s$  sensory input modules to generate  $s$  linearly independent sensory feature vectors. These sensory feature vectors allow neural network algorithms to identify  $n$  targets. Due to the lack of correlation between network complexity and the number of input units within neural network algorithms, it is difficult to accurately determine the number of hidden layers within the network and the number of neurons within different hidden layers, and it is not possible to ensure complete convergence during network training. Therefore, when using neural network algorithms to fuse multi-sensory information, combining them with information fusion algorithms is necessary. The detailed process description process involves using  $(v_1, v_2, \dots, v_e)$  to represent  $e$  sensory feature vectors, implementing reasonable and practical classification combinations for  $(v_1, v_2, \dots, v_e)$ , and dividing them into  $q$  groups, where  $q$  should be within the range of  $1 \leq q \leq e$ . Include  $e$  in each group separately  $e_i$  vectors, which can be represented as  $(v_1^i, v_2^i, \dots, v_e^i)$ , where  $v_j^i \in (v_1, v_2, \dots, v_e)$ , thus ensuring the integrity of multi-sensory information.

In addition, it is necessary to design a neural network with  $e_i$  ( $i=1, 2, 3, \dots, q$ ) inputs and  $n$  outputs, and generate relevant learning models based on the expert knowledge between the current multi-sensory feature vectors and the targets. These targets belong to the multi-sensory information fusion structure, and the non-linear mapping between the trust levels of the  $e_i$  ( $i=1, 2, 3, \dots, q$ ) multi-sensory feature vectors and the  $n$  targets to be identified is completed. Each analysis for different senses is divided into  $q$  pieces of evidence. Taking the  $i=1, 2, 3, \dots, q$  pieces of evidence as an example, it contains  $e_i$  multi-sensory feature vectors, and each target is a proposition of this evidence. Therefore, it is determined that each piece of evidence has  $n$  propositions.

The sampling period of multi-sensory information is represented by  $T$ , at  $IT$ , for the  $i$ -th evidence, a neural network with  $e_i$  inputs and  $n$  outputs designed using the above process can obtain  $n$  values between 0 and 1. This value serves as the credibility of this evidence for different propositions and is recorded as  $CF$ . The closer the  $n$   $CF$  values here are to 0.5, the lower the discriminability of the evidence for the target. After computing  $n$   $CF$  values with the Gaussian function  $x^{-\frac{(x-1/2)^2}{\sigma}}$  relevant data results can be obtained after computing all pieces of evidence at the  $IT$  moment.

### III. ALGORITHM FOR GENERATING SCENES IN VIRTUAL REALITY AND INTERACTIVE TECHNOLOGY

The image design and construction process based on virtual reality and interactive technology can generally be divided into two stages: the design content stage and the multi-sensory experience stage. As shown in Fig. 3, the interaction between the two links is shown. Among them, the design content process can be divided into two parts: visual information design and interaction mode design. The interactive interface layout design and interface content design are completed through the design content; the multi-sensory experience process can be divided into three parts: cognitive experience, emotional experience, and sensory experience. Based on the layout design of the interactive interface and the design of the interface content, the interaction mode design in the design content process is combined to enhance participants' multi-sensory visual experience of the interactive interface.

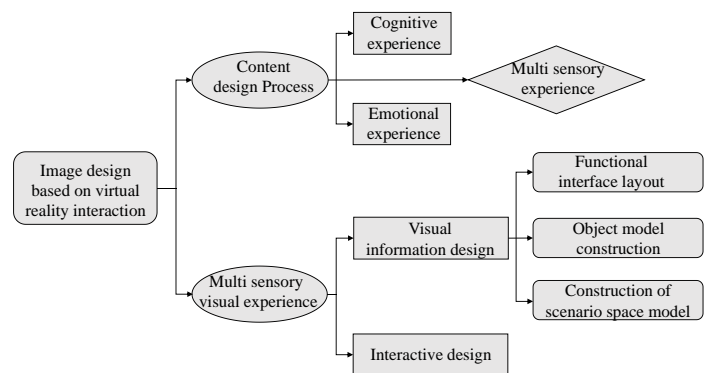


Fig. 3. Generation process of multi-sensory interactive interface based on virtual reality.

A. Interface Generation Process Based on Virtual Reality and Interactive Technology

1) *Content and links of image design:* In image design, visual information design is central to generating multi-sensory interactive interfaces based on virtual reality. Visual information design consists of three parts: functional interface layout, three-dimensional object model construction, and scene space model construction. The functional interface design is completed using an interactive interface layout optimization model. This model is based on the interface visual attention partitioning model and the results of functional criticality analysis. The optimization objective function is set as the optimal visual attention partitioning for the final layout of the interactive interface [31], in order to construct a functional interface layout optimization model based on visual attention partitioning. The following definition is adopted for the optimization model of functional interface layout based on visual attention partitioning [32]:

a) The set  $\{a_{ij}\}$  represents the visual attention level of the units occupied by a certain functional module in the visual area with different levels, where  $a_{ij}$  represents the visual attention level of the unit occupied by functional module  $i$  in the visual area  $j$ .

b) The visual attention level of the visual area where the central coordinate of a certain functional module is located is represented by the set  $\{s_{ij}\}$ , where  $s_{ij}$  represents the visual attention level when the center coordinate of functional module  $i$  is in the visual distance region  $j$ .

c) The set  $\{d_{ij}\}$  represents the number of units that a certain functional module occupies within the visual expectation of varying levels, where  $d_{ij}$  represents the number of units occupied by functional module  $i$  in the visual area  $j$ .

Determine the criticality of different functional modules in the functional interface and compare them. Use  $w_k$  to represent the criticality of module  $u_i$ . equation (7) can be used to describe the relative criticality of functional modules:

$$r_k = \frac{w_{k-1}}{w_k} \quad (7)$$

By using equation (8), the criticality of functional module  $u_i$  can be determined:

$$w_i = \frac{1}{1 + \sum_{k=2}^n \prod_{i=k}^n r_i} \quad (8)$$

Describe the intensity of visual attention division using equation (9):

$$Z = \sum_{i=1}^n \sum_{j=1}^3 w_i a_{ij} s_{ij} d_{ij} \quad (9)$$

The upper limit of visual attention division intensity is represented by  $Y$ . That is,  $Z_{max} = Y$ , from which equation (10) can be obtained:

$$Y = \max \left( \sum_{i=1}^n \sum_{j=1}^3 w_i a_{ij} s_{ij} d_{ij} \right) \quad (10)$$

Select particle swarm optimization algorithm to solve the functional interface layout optimization model based on visual attention partitioning [33], and complete the functional interface layout. Generate the required image information for different areas in the functional interface through 3D model construction.

2) *Model construction in image design:* The image information in images based on virtual reality and interactive technology includes 3D objects and scene space, which are generated using 3D model construction methods. In model construction, for scenario spaces with complex structures, differences can be applied to obtain several scenario space units, and different modeling methods can be used to synthesize the scenario space units into a whole, constructing a three-dimensional model of the scenario space. In addition, for the scene rendering process, after simulating the lighting in the scene space and setting proper lighting, the scene space is rendered to adjust the brightness and position of the lighting continuously. Optimize the scene space for the interaction process in the scene space, determine whether collision detection is necessary according to actual application needs, and reduce the visual memory consumption of texture maps by compressing textures to determine the balance between virtual scene space and roaming interaction smoothness.

As mentioned above, in image design, the image information of relevant images is generated using the 3D model construction method: one needs to model the objects in the 3D image. In this process, the relevant data collection process is imported into the software to obtain a floor plan, and the objects are adjusted and optimized based on the relevant information of the obtained scenario; For scenario spaces with complex structures, differentiation can be applied to obtain several object units, which can be combined into a whole to construct a three-dimensional model of the scene image. Secondly, texture mapping is required. In order to improve the realism of the scene in the process of image design and enhance the authenticity of image design, it is necessary to use the material editor to implement texture mapping processing on objects. Different surfaces of a scene space need to map different textures. Under this condition, you must use multi-dimensional material objects to load several maps for different materials under the explicit material to achieve different texture mapping ideas. In addition, in image design, it is also necessary to pay attention to improving scene rendering and baking effects. After simulating the sunlight illumination in the scene space and setting proper lighting, the scene space is rendered, and the brightness and position of the lighting are continuously adjusted to achieve the optimal rendering effect. After completing the rendering, bake it reasonably to store the data of the object image design

rendering results. Finally, to achieve a sense of virtual reality experience for participants, it is necessary to interact with the scene in the image design space. Through the preliminary work, the walking camera and flying camera in the scene space are created respectively in the process of image interaction design to simulate the height and change speed of the image under the walking condition of the participants. In this process, it is also necessary to determine whether collision detection is necessary based on actual application needs. The balance between virtual image design space and roaming interaction smoothness needs to be determined by compressing textures to reduce the graphics memory consumption of texture maps.

### B. ANNs-DS Algorithm Based on Information Fusion Optimization

The ANNs-DS information fusion algorithm based on a combination of essential probability allocation functions is used in multi-sensory information fusion. Assuming that  $s$  sensory input modules are processed with corresponding information numbers to generate  $s$  linearly independent sensory feature vectors, based on these sensory feature vectors, neural network algorithms can identify  $n$  targets [32]. Due to the lack of correlation between network complexity and the number of input units in artificial neural network algorithms, it is difficult to accurately determine the number of hidden layers in the network and the number of neurons in different hidden layers, and it is not possible to ensure complete convergence during the network training process. Therefore, when using neural network algorithms to fuse multi-sensory information, combining them with the DS algorithm is necessary to form an ANNs-DS algorithm based on information fusion optimization. Among them, in the artificial neural network algorithm process, different parameters are input at the input layer. Then the relevant parameters enter the hidden layer for data analysis and operation. The data is mined and analyzed through this layer, and then the relevant demand parameters are sorted and output through the output layer. In generating visual interaction interfaces based on virtual reality and interactive technology, the actual sensory information received by participants is a crucial consideration.

Based on the above analysis, an information fusion optimization algorithm (ANNs-DS) was constructed based on Artificial Neural Networks technology and Dempster Shafer's theory to maximize the consideration of participants' actual sensory acceptance of information. This platform takes sensing, body sensation, and visual information as input information and utilizes the ANNs-DS information fusion algorithm for multi-sensory visual information fusion. Based on relevant fusion results, interface interaction functions such as displaying virtual reality images, odor generation, vibration, and sound feedback are achieved. The processing process of multi-sensory visual experience elements using virtual reality and interactive technology based on the ANNs-DS algorithm is shown in Fig. 4.

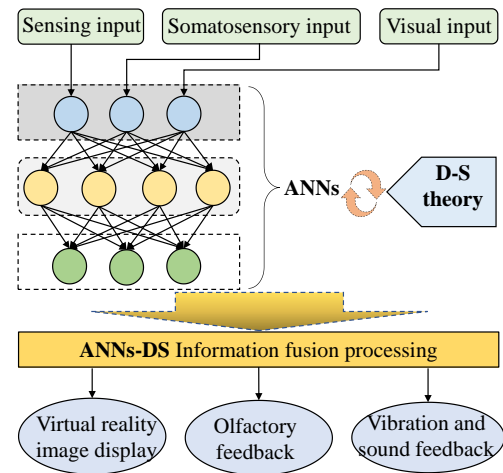


Fig. 4. ANNs-DS Information fusion algorithm principle and multi-sensory visual experience process.

From a temporal perspective, the specific process of multi-sensory visual information fusion is as follows: set the period to  $T$ , and use  $m_{i,1}(k-1), m_{i,2}(k-1), \dots, m_{i,n}(k-1)$  to represent the fusion result of multi-sensory visual information in the time domain corresponding to the  $i$ -th neural network at the  $(k-1)T$  moment. Under the condition of reaching the subsequent time  $kT$ , its basic probability distribution function and solvability level can be expressed as  $m_{i,j,k}$  (where  $j=1,2,\dots,n$ ) and  $\delta_{i,k}$ , respectively. The fusion process in the time domain under the  $kT$  time condition is obtained from equations (11), (12), and (13):

$$m_{i,j}(k) = \frac{m_{i,j}(k-1)m_{i,j,k} + m_{i,j}(k-1)\delta_{i,k} + \delta(k-1)m_{i,j,k}}{1 - P_{i,k}} \quad (11)$$

$$\delta_i(k) = \sum_{j=1}^n m_{i,j}(k) \quad (12)$$

$$P_{i,k} = \sum_{j \neq 1} m_{i,j}(k-1)m_{i,j,k} \quad (13)$$

From a spatial perspective, the specific process of multi-sensory visual information fusion is as follows: using mutual fusion between two pairs to target  $m_{i,1}(k), m_{i,2}(k), \dots, m_{i,n+1}(k)$  is combined to perform spatial fusion on the time fusion results of two neural networks, and the obtained spatial fusion results are refused with the time fusion results of the third neural network. By iterating the above results, the basic probability distribution function for the  $j$ -th target after  $kT$  time is obtained as  $m_{q,j}(k)$ , and then we obtain equations (14) and (15):

$$m_j^q(k) = m_j(k) \quad (14)$$

$$\delta(k) = 1 - \sum_{j=1}^n m_j(k) \quad (15)$$



Based on the above process, it can be obtained that after passing through  $kT$  time, the final decision level and the unsolvable level of the  $j$ -th target for multi-sensory visual information fusion are  $m_j(k)$  and  $\delta(k)$ , respectively. From this, the final multi-sensory visual information fusion result can be obtained based on  $m_j(k)$  (where  $j=1,2,\dots,n$ ).

#### IV. APPLICATION OF VIRTUAL REALITY AND INTERACTIVE IMAGE DESIGN

##### A. Application of ANNs-DS Algorithm in Image Design

To verify the application performance of the image interaction interface generation method based on virtual reality and interaction technology, a wearable interactive experience product was designed. The ANNs-DS information fusion algorithm was used to generate the interaction interface of the application objects in the image design, and the specific performance was tested. In the process of generating interactive interfaces in image design, the interactive experience of building a 3D model is shown in Fig. 5. Based on the relevant information on marine organisms obtained, a three-dimensional model of the ocean interior can be effectively constructed, which can significantly improve the authenticity of ocean scenarios, as shown in Fig. 5(A). In addition, by constructing an information model between participants and the ocean scenarios, the sense of integration of participants' experiences can be increased, as shown in Fig. 5(B). The interaction and information fusion of image design for A and B in the Fig. 5, as well as scene rendering through adjusting the brightness and position of the lights, can further improve the authenticity of the model, as shown in C in the Fig. 5. Through the interactive interface constructed in image design, participants can overlook the target through a flying camera and adjust visual proximity through information exchange. The above analysis indicates that in the interactive interface constructed using this algorithm, virtual reality technology is used to provide participants with an immersive roaming experience while enhancing their experience through different senses, such as vision and hearing.

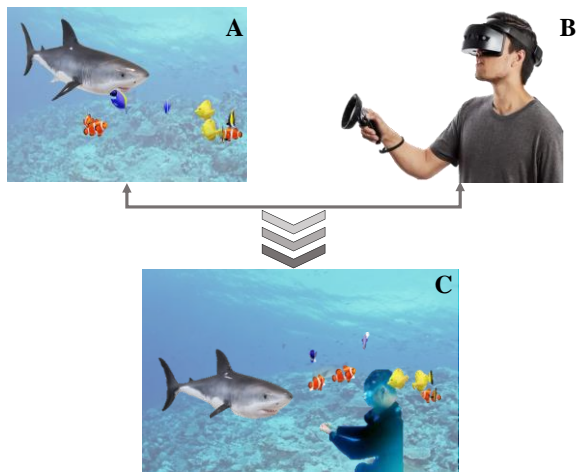


Fig. 5. Construction of scenario space based on virtual reality and interaction technology.

##### B. Analysis of Similarity of Interactive Interface

In image design, the similarity degree between virtual objects and scene space in the interactive interface is an important evaluation indicator for the effectiveness of interactive interface design. The similarity degree calculation process is as follows:

$$L_{sim} = 1 - \frac{1}{N} \times \sum_{i=1}^N (|h_i - f_i| / 255) \quad (16)$$

In equation (16),  $N$  represents the number of pixels in the interaction interface object and scene space image.  $h_i$  and  $f_i$  represents the pixel values of the  $i$ -th pixel in the actual object and scene space images, as well as the designed interactive interface object and scene space images. The fair value is 0-1, and 1 indicates that the object and scene space images in the designed interaction interface are entirely consistent with the actual object and scene space images. Randomly select 20 images of marine organisms and 20 images of seabed scene space from the generated application object interaction interface, and calculate the fitting results of all images, as shown in Fig. 6. Fig. 6 shows that the fit between the marine biological images and the seabed scene space images generated by the ANNs-DS information fusion algorithm in the interactive interface is above 0.8, with a maximum of 0.98. As shown in the gray area of the figure, there are 18 marine life images with a reasonable degree between 0.85 and 0.95, accounting for 90%; The number of seabed scenarios with a fair degree between 0.85 and 0.95 is 17, accounting for 85%. According to the 10-point evaluation standard, evaluate marine biological images and seabed scenarios based on participants. The results are shown in Fig. 6(a) and 6(b), with an average score of 9.0 for benthic biological imaging; the average score for the underwater scenario is 8.9 points, both of which have higher scores. Therefore, based on the above analysis, it can be seen that the ANNs-DS method in this article generates an interactive interface with high fitting and accuracy, which can provide participants with a more realistic sensory experience.

##### C. Testing of Interactive Interfaces in Image Design

In the above image design based on virtual reality and interactive technology, the interface conversion time and image design accuracy of the interactive interface generated by the ANNs-DS information fusion algorithm under different concurrent participant numbers in Fig. 7. As shown in the figure, with the gradual increase in concurrent users, the time required to convert all functional interfaces within the generated interactive interface shows a gradual upward trend. Among them, the time required for the interface login function is significantly higher than that for underwater scene space selection, biological type selection, and camera selection. When concurrent users reach 120, the interface conversion time is around 1260ms. The accuracy analysis of the image is within the range of 89.6% to 96.0%, which has a high design accuracy. This indicates that the interactive interface generated by this method still has good interface conversion smoothness and design accuracy even under a large number of concurrent users.



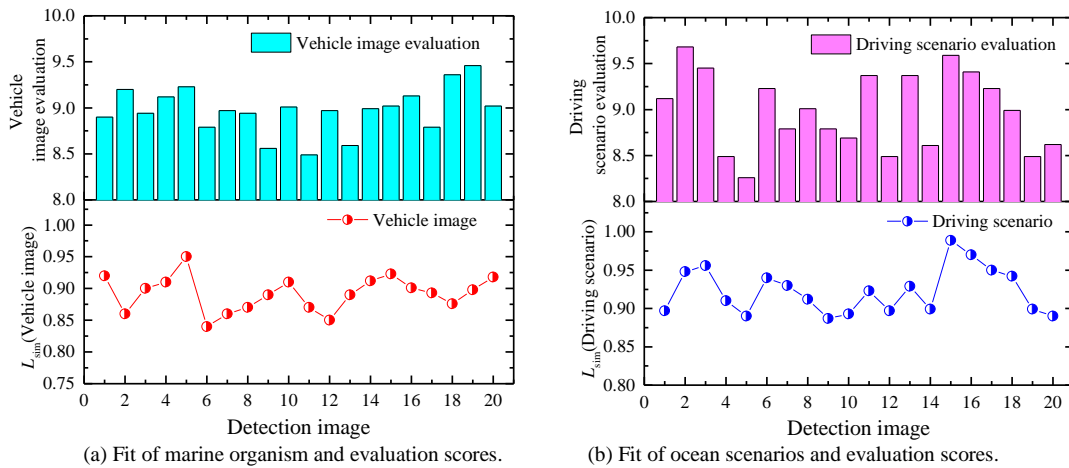


Fig. 6. Similarity analysis of test images in image design.

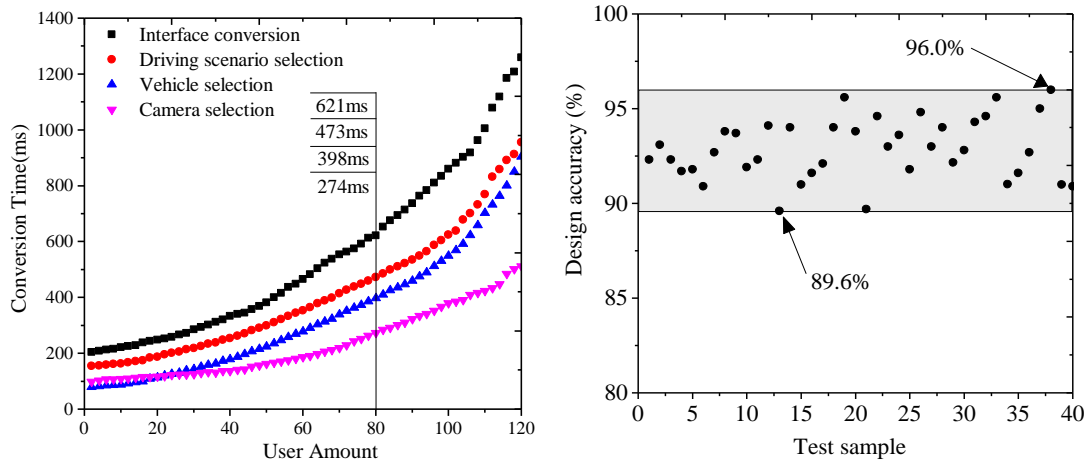


Fig. 7. Interface conversion time test under different impact scenarios.

## V. CONCLUSION

The continuous development and application of virtual reality and interactive technology have promoted continuous innovation in image design from a technical perspective. This article is based on applying virtual reality and interactive technology in image design, combined with the ANNs-DS information fusion optimization algorithm, to construct a three-dimensional interaction model of images in ocean scenarios. The relevant parameters of the model were studied and analyzed for different scenarios, and the changes in fitting and smoothness of the three-dimensional model in image design were given. The main conclusions are as follows:

1) The image design combining virtual reality and interactive technology can integrate multiple sensory information to create and construct three-dimensional image scenes. In the process of multi-sensory visual design, the ANNs-DS information fusion algorithm is used to integrate sensing information, tactile information, and visual information, achieving interactive functions such as virtual reality image display, vibration, and sound feedback, which can effectively enhance participants' multi-sensory visual experience of the interaction interface.

2) Through the analysis of the interactive image design process for ocean scenarios, the fitting degree between the ocean biological images and the ocean scene spatial images generated by the fusion algorithm in the interactive interface is above 0.8. Among them, the proportion of marine biological types with a fitting degree between 0.85 and 0.95 is 90%; the proportion of ocean scenario fit between 0.85 and 0.95 is 85%.

3) The interactive interface generated using the ANNs-DS algorithm has certain advantages in interface conversion time under different concurrent user numbers. As concurrent users gradually increase, the time required for interface conversion shows a gradual upward trend. Among them, it still has good interface conversion smoothness even when the number of concurrent users reaches 120, and the interface conversion time is around 1260ms.

4) Combining the current research results and the current industry research progress, the later research can combine virtual reality and interactive technology to conduct research in product design, 3D printing, and other fields and combine user experience to conduct deeper interaction Experience design, to meet the deepening application of this technology better.

#### ACKNOWLEDGMENT

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# Video Surveillance Vehicle Detection Method Incorporating Attention Mechanism and YOLOv5

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**Abstract**—With the rising number of vehicle ownership nationwide and the consequent increase in traffic accidents, vehicle detection for traffic surveillance video is an effective method to reduce traffic accidents. However, existing video surveillance vehicle detection methods suffer from high computational load, low accuracy, and excessive reliance on large-scale computing servers. Therefore, the research will try to fuse coordinate attention mechanism to improve YOLOv5 network, choose lightweight YOLOv5s for image recognition, and use K-means algorithm to modify the aiming frame according to the characteristics of vehicle detection; meanwhile, in order to get more accurate results, coordinate attention mechanism algorithm, which is also a lightweight algorithm, is inserted into YOLOv5s for improvement, so that the designed The lightweight vehicle detection model can be run on embedded devices. The measurement experiments show that the YOLOv5+CA model completes convergence when the iterations exceed 100, and the localization loss and confidence loss gradually stabilize at 0.002 and 0.028, and the classification loss gradually stabilizes at 0.017. Comparing YOLOv5+CA with SSD algorithm, ResNet-101 algorithm and RefineDet algorithm, YOLOv5 +CA detection accuracy is better than other algorithms by about 9%, and the accuracy can be approximated to 1.0 at a confidence level of 0.946. The experimental results show that the research design provides higher accuracy and high computational efficiency for video surveillance vehicle detection, and can better provide reference value and reference methods for video surveillance vehicle detection and operation management.

**Keywords**—Attention mechanism; YOLOv5; vehicle detection; image recognition; deep learning

## I. INTRODUCTION

After stepping into the 21st century, with the high-speed improvement of the economic level, vehicle ownership has been rising nationwide, and cars have become a common means of transportation, but at the same time, with the increase of vehicles, vehicle congestion, car accidents and other traffic problems are growing. At present, China's artificial intelligence technology continues to develop, automatic control technology tends to mature, combined with artificial intelligence and automatic control of intelligent traffic monitoring system has also been a large degree of development [1]. Intelligent Traffic System (ITS) can realize the organic integration of traffic system and various computer technologies, which can realize the instant, accurate and efficient management of traffic nationwide and effectively avoid a series of traffic congestion problems [2]. Among them, vehicle detection (VD) through video surveillance is the key to its capturing information, which can be applied to scenarios such as traffic flow calculation and violation vehicle capture. Vehicle target

detection (TD) is a vital branch in computer vision. For the past few years, computer computing power integration is improving with the breakthrough of image acquisition equipment accuracy, this technology has received wide attention from researchers, while the breakthrough of algorithms in artificial intelligence (AI) has also benefited the field. VD through video surveillance joins artificial intelligence image recognition algorithms that mimic the human eye, which can sense and analyze targets in imitation of the human eye, and carry out the completion of vehicle recognition classification and localization [3]. Although the TD algorithm now has a high accuracy rate, but these functions need to rely on a powerful computing server, and in the daily VD its limited by the small volume of embedded equipment, cannot do large-scale computing. At the same time, when carrying out vehicle identification, due to changes in weather and lighting, there is a certain degree of difficulty for vehicle identification that blends into the background, and the identification accuracy is low in special environments such as rain and night. Based on this, to lift the accuracy of the video surveillance VD algorithm and solve the problem of excessive dependence of the algorithm on large computers, the study will try to combine attention mechanism neural network to improve detection accuracy using lightweight YOLOv5 network algorithm for research. Compared to similar literature, the study introduces the lightweight YOLOv5 algorithm to reduce the amount of computation in use and enable it to be loaded on small vehicles. The study also improves the lightweight YOLOv5 to improve the object recognition for subsequent use of the YOLOv5 recognition algorithm.

The study is divided into four parts. The first part provides an introduction to the integration of traffic systems with computer technology and the application of vehicle recognition therein, the second part discusses the related works in this domain, the third part uses an attention mechanism to improve the YOLOv5 algorithm to suit the vehicle recognition problem, the fourth part tests and analyses the performance of the model and algorithm; the fifth part concludes the above discussion.

## II. RELATED WORKS

Vehicle detection (VD) is currently one of the main key-points of safety research in transportation, and the current situation of frequent traffic accidents has made experts aware of the value of the application. Deqing Liu et al. raised unmanned surface vehicle (USV) obstacle fusion detection based on Dempster-Shafer (D-S) evidence theory. The results show that multi-sensor fusion can use the complementarity among diverse sensors to supplement the obstacle detection details compared to the single-sensor detection method,

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effectively avoid the false detection of obstacles by single sensors, and show greater advantages in the reliability of obstacle detection [3]. Wang et al. aimed for improving the VD and tracking of autonomous vehicles using 3D Light Detection and Ranging (LiDAR) accuracy, a clustering algorithm trained by support vector machine (SVM) algorithm combined with Kalman filter and global nearest neighbor (GNN) algorithm is proposed to employ tracking of vehicles and further improve the accuracy of VD results with the help of tracking results [4]. Nguyen address the problem of large scale differences of vehicles and severe vehicle occlusion in VD by using a feature The results show better detection performance and lower computational cost [5]. Han et al. propose a CNN-M2R network with multilayer fusion and multidimensional attention to improve VD performance in urban areas, which uses a multidimensional attention network to highlight target convergence and a new difficulty-positive and negative sample balanced sampling strategy and a global balanced loss function to handle spatial imbalance and objective imbalance, the experimental results show a great improvement in detection performance compared to SSD, LRTDet, RFCN, and DFPN [6]. Saeed et al. focus on the often neglected last step of VD scheme deployment and design a single detector Mobile Net for embedded devices. A comprehensive deep-learning-based engineering VD solution is established and this solution has an average accuracy higher than 90% compared to common embedded devices, confirming the excellent real-time performance of the solution [7]. Liu et al. propose a backward feature enhancement network (BFEN) and a spatial layout preserving network (SLPN) to solve the interference caused by vehicle scale on VD in complex traffic scenarios and to accomplish accurate detection of miniature vehicles. Two-stage detector of SLPN is performed to achieve high recall detection of miniature vehicles. The method improves the competing baseline by 16.5% mAP, which has a better comparative performance compared to the current state of the art [8].

As an emerging intelligent network in the field of image recognition, YOLOv5 has been studied by a large number of scholars. Yan et al. proposed an intelligent classification method of coal gangue using YOLOv5 and multispectral imaging technology to deal with the issue of low accuracy and slow speed of traditional coal gangue recognition methods. The mean accuracy of gangue detection using YOLOv5.1 model reaches 98.34%, which could precisely identify gangue, as well as acquire gangue's relative position [9]. Jia et al. established a motorcycle helmet detection way combined with YOLOv5 for motorcycle driver helmet detection by video surveillance, which uses soft-NMS instead of NMS to fuse the YOLOv5 detector, and experimentally achieves 97.7% mAP, 92.7% F1 score and 63 frames per second (FPS), which is better than other methods [10]. Attention mechanism has also received a lot of attention after its introduction into artificial intelligence networks, and many scholars have conducted research on deep learning networks incorporating attention mechanism. Xu et al. developed a novel stock price prediction network on the basis of reinforcement learning (RL) through a bidirectional gated recurrent unit (GRU) network to better dig market changes from chaotic data for stock tendency. The model is superior to existing models and has excellent performance [11]. Lu et al. raised a 2-level interaction mode that relies on 2 time-varying

attention mechanisms in order to accomplish the multi-person activity recognition task, and the model has high comparable performance, confirming the effectiveness of the attention mechanism [12].

In summary, although scholars have designed a large number of improved VD systems to improve the accuracy of video surveillance VD systems, there are still very few VD systems that have both high-speed computational effectiveness and lightweight embedded devices, both of which have strong potential applications in real-time VD.

### III. VIDEO SURVEILLANCE VEHICLE ALGORITHM DESIGN BASED ON YOLOV5 NETWORK AND ATTENTION MECHANISM

#### A. YOLOv5-based Video Surveillance VD Aiming Frame Improvement

The study was conducted to design algorithms aiming to accuracy lifting of VD through video surveillance, on the one hand, YOLOv5 (You Only Look Once fifth generation) was used as the baseline network, adding more techniques to improve the accuracy and speed, thus achieving a balance between accuracy and speed in the TD algorithm for vehicles, for another, attention mechanism was introduced to the VD algorithm for improvement to highly extract effective feature information highly relevant to VD and reduce the error brought by video surveillance. The improved algorithm for video surveillance measurement designed in the study is based on the YOLOv5 feature extraction network, which is OneStage series algorithm with the confidence level as in Equation (1).

$$Confidence = \Pr(Object) \times IOU_{pred}^{truth} \quad (1)$$

As shown in Equation (1),  $\Pr(Object)$  denotes the possibility contained in the bounding box, which indicates the prediction accuracy adopting the loss function IOU, and the C conditional probability likelihood derivation performed in conjunction with this formula is Equation (2).

$$\Pr(Class_i/Object) \times \Pr(Object) \times IOU_{pred}^{truth} = \Pr(Class_i) \times IOU_{pred}^{truth} \quad (2)$$

In Equation (2),  $\Pr(Class_i/Object)$  denotes the C conditional object probability in the grid, and the formula can indicate the matching degree in the prediction frame and object. In response to the high demand for timeliness of VD and the difficulty of the detection task, YOLOv5, which is the latest generation of algorithms, incorporates many techniques to improve accuracy and speed. It uses a loss function to evaluate the network effect, and the classification loss function is in Equation (2).

$$E_{cls} = \sum_{i=0}^{S^2} 1_i^{obj} \sum_{c \in classes} (p_i(c) - \hat{p}_i(c))^2 \quad (3)$$

In Equation (3),  $1_i^{obj}$  denotes the objects in the grid  $i$ ,  $p_i(c)$  means the predicted possibility of the corresponding category,  $\hat{p}_i(c)$  denotes the true probability, and  $S^2$  denotes the number of grids into which the images are divided. The localization loss function is shown in Equation (4).

$$E_{box} = \lambda_{coord} \sum_{i=0}^{S^2} \sum_{j=0}^B 1_{ij}^{obj} \left[ \left( x_i - \hat{x}_i \right)^2 + \left( y_i - \hat{y}_i \right)^2 \right] + \lambda_{coord} \sum_{i=0}^{S^2} \sum_{j=0}^B 1_{ij}^{obj} \left[ \left( \sqrt{w_i} - \sqrt{\hat{w}_i} \right)^2 + \left( \sqrt{h_i} - \sqrt{\hat{h}_i} \right)^2 \right] \quad (4)$$

In Equation (4),  $\lambda_{coord}$  denotes the weight coefficient,  $x_i, y_i, w_i,$  and  $h_i$  are the prediction frame positions,  $\hat{x}_i, \hat{y}_i, \hat{w}_i,$  and  $\hat{h}_i$  denote the true positions.  $B$  denotes the number of bounding boxes. The loss of confidence formula is Equation (5).

$$E_{obj} = \sum_{i=0}^{S^2} \sum_{j=0}^B 1_{ij}^{obj} \left( C_i - \hat{C}_i \right)^2 + \lambda_{noobj} \sum_{i=0}^{S^2} \sum_{j=0}^B 1_{ij}^{noobj} \left( C_i - \hat{C}_i \right)^2 \quad (5)$$

In Equation (5),  $\lambda_{noobj}$  denotes the loss weight of objects not included in the bounding box, and  $C_i$  denotes the object  $i$ . The study selects the more lightweight YOLOv5s as the base-network for video surveillance VD, as shown in Fig. 1.

In Fig. 1, YOLOv5s' main division into input side, backbone, neck and head network is shown. The input data from the input side enters Focus to slice the picture, which extracts the pixel values in the picture every other value and slices a picture into four pictures in order to do improve the perceptual field and reduce the picture information loss. The above data enters the CSP layer after the convolution operation, which is an important concept of the YOLO series network. The formula of the convolution layer function used in this series of algorithms is shown in Equation (6).

$$a_j^l = f \left( b_j^l + \sum_{i \in M_j^l} a_i^{l-1} * k_{ij}^l \right) \quad (6)$$

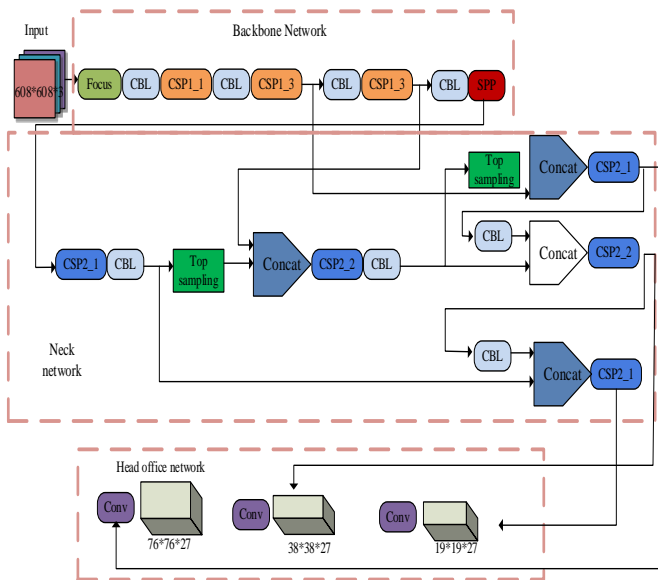


Fig. 1. YOLOv5 overall network structure.

As shown in Equation (6). In the convolutional layer  $l$ ,  $a_j^l$  is the  $j$ -th output of the previous convolutional layer.  $f$  is the activation function. The computation of the feature map after the convolution operation is Equation (7).

$$out = \frac{in - k + 2p}{s} + 1 \quad (7)$$

In Equation (7),  $out$  means the output features size,  $in$  is the input graph size,  $k$  means the convolutional kernel size.  $s$  is the step size, and  $p$  denotes the width of the boundary fill. The CSP layer effectively avoids the problems of gradient information loss and network computation consumption during training of traditional large models, and effectively improves the learning capacity of the CNN, and its structure is shown in Fig. 2.

As shown in Fig. 2, the CSP structure of YOLOv5s divides the primordial input into two branches. After performing convolution operations, the amounts of channels are halved. Branch 1 performs Bottleneck\*N, with two branches parallel, resulting in the same input and output sizes for bottleneck CSP. The CBL layer encapsulates three modules, namely BN, convolution layer and Leaky Relu activation function. BN is the original unit of the YOLO series, Equation (8).

$$\begin{cases} \hat{x}_i \leftarrow \frac{x_i - \mu_\beta}{\sqrt{\sigma_\beta^2 + \epsilon}} \\ y_i \leftarrow \gamma \hat{x}_i + \beta \end{cases} \quad (8)$$

As shown in Equation (8),  $\mu_\beta$  and  $\sigma_\beta^2$  denote the mean and variance of the data,  $\hat{x}_i \leftarrow \frac{x_i - \mu_\beta}{\sqrt{\sigma_\beta^2 + \epsilon}}$  denotes the normalization of the sample, and  $y_i \leftarrow \gamma \hat{x}_i + \beta$  denotes the translation and scaling of the data, with the BN function generally preceding the activation function.

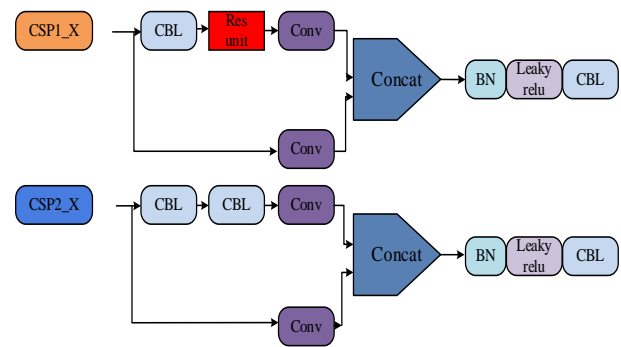


Fig. 2. CSP layer structure.

The CSP1 structure is mainly applied in Backbone, and that of CSP2 is mainly applied in Neck. The first parameter 1 in the CSP1\_1 module indicates the CSP structure applied in Backbone Network, and the second parameter 1 indicates that the residual component in the module is repeated once. The CSP2x indicates the CSP module used in Neck network. CSP module. The main difference between it and the CSP module used in the Backbone Network is that 2X CBL modules are used instead of the residual module. Thereafter, the Neck network structure is entered by another convolution, which is schematically shown in Fig. 3.

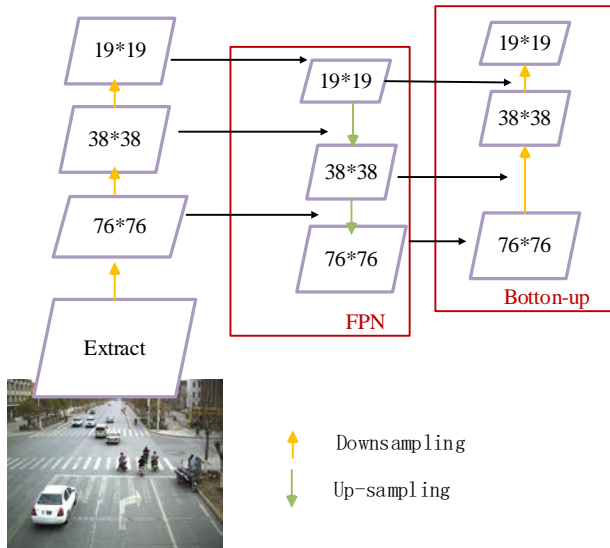


Fig. 3. Schematic graph of the neck network.

As Fig. 3, the extracted information is then input into the FPN module by performing a convolution operation on the target image extraction to reduce the image scale. The FPN module differs from the extraction module in that it passes feature information by a top-down approach, while the PAN module uses a bottom-up approach to pass feature information, which aims to enhance the target localization of network by using down sampling. The combination of these two structures not only enhances the target localization capability of the network, but also improves the target recognition capability, which helps to improve the accuracy of the TD algorithm.

The output is performed using the head network after passing through the neck network, and CIOU\_Loss is used as the loss function of the Bounding box in Yolov5. The original algorithm of YOLOv5 is the result of the analysis of the COCO dataset, and the anchor box originally obtained from the COCO dataset setting is optimized in order to be more suitable for this VD experimental environment. The study uses the K-means algorithm for anchor selection frame optimization, which is essentially a clustering algorithm and belongs to the category of unsupervised learning. The error sum of squares is generally used as the objective function to categorize the samples, and this metric is often used to evaluate the effectiveness of the clustering results. Its specific expression is shown in Equation (9).

$$Loss = \sum_{i=1}^k \sum_{x \in c_i} dis(x, c_i) \quad (9)$$

As shown in Equation (9),  $Loss$  represents the error sum of squares,  $x$  represents the calculation sample,  $c_i$  represents the center of mass of the  $i$  category, and  $dis(x, c_i)$  represents the distance between  $x$  and  $c_i$ . However, the formula is based on the Euclidean distance as an indicator for judging the similarity will cause more errors for big bounding boxes than for small bounding boxes, in order to make the K-means algorithm as an evaluation indicator for the similarity measurement of VD without the limitation of the bounding box size, the study uses A new distance formula suitable for VD, as in Equation (10).

$$dis(x, c_j) = 1 - IOU(x, c_j) \quad (10)$$

In Equation (10),  $x$  denotes the newly added checkbox,  $c_j$  denotes the first  $j$  real box, and  $IOU(x, c_j)$  denotes the accuracy of the prediction of the location information of  $x$  and  $c_j$  using the loss function IoU (Intersection over Union). The improved K-means algorithm was tested by testing it on the UA\_DETRAC dataset. The classification loss function is Equation (11).

$$E_{cls} = \sum_{i=0}^{S^2} 1_i^{obj} \sum_{c \in classes} (p_{i(c)} - \hat{p}(c))^2 \quad (11)$$

As shown in Equation (11),  $\sum_{i=0}^{S^2} 1_i^{obj}$  denotes the sum of squares over the objects in the table.  $p_{i(c)}$  is the predicted rate of the corresponding category.  $\hat{p}(c)$  is the true possibility.

### B. Improvement of Video Surveillance VD Algorithm Based on Attention Mechanism

In the road information collected through video surveillance, there are not only target vehicles, but also contain invalid information such as pedestrians, trees, and barriers, which can interfere with VD, so the study uses attention mechanism to achieve target area locking to reduce the interference of invalid information.

Most attention mechanisms incorporated into neural network models provide some performance gains, but they are not as effective in lightweight networks as they are in large network models. Therefore, the study will use Coordinate Attention (CA) mechanisms that allow lightweight networks to obtain an extensive range of feature details and avoid introducing too much computational overhead, with the structure shown in Fig. 4.



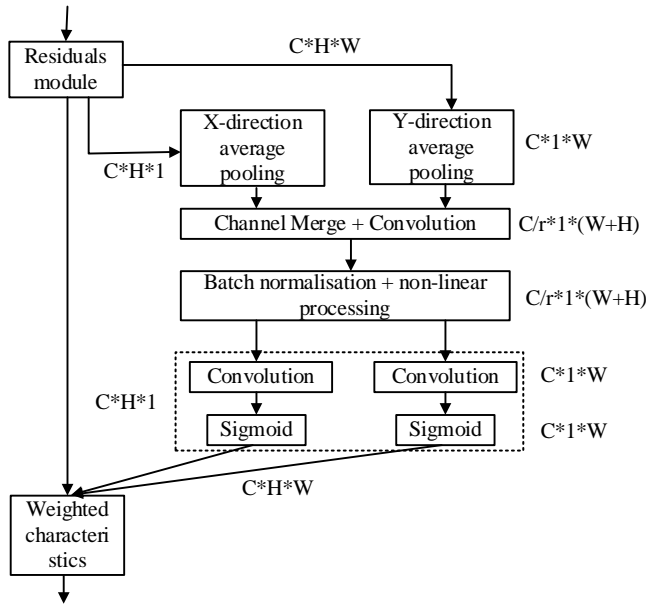


Fig. 4. Construction of the CA mechanism.

In Fig. 4, the CA mechanism is able to be identified as a computational unit to strengthen the characteristic representation capability of the mobile network, using two modules, coordinate information embedding and CA generation, to encode channel and long-distance relationships. Firstly, a 2D coordinate axis is created for the input feature information using a 1D global pooling operation, which is aggregated into 2 independent direction-aware feature representations along the X and Y directions. Then a merging operation is performed in the spatial dimension to integrate the feature maps using a 1\*1 convolutional layer.

$$f(x) = \frac{1}{1 + e^{-x}} \quad (12)$$

Finally, two attention weights are utilized to the input features by using a weighted multiplication of the Sigmoid function with normalized weights as in Equation (12), thus emphasizing the region of interest of the algorithm. The Sigmoid formula is as in Equation (12) and the tanh formula is as in Equation (13).

$$g(x) = \frac{1 - e^{-2x}}{1 + e^{-2x}} \quad (13)$$

Both Equation (12) and (13) use the exponential function  $e^x$  for the formulation. Applying the attention mechanism to the YOLOv5 can strengthen the recognition of target vehicles and the extraction of useful features for localization to a certain extent. The details are expressed in Table I.

TABLE I. COMPOSITION OF FEATURE EXTRACTION NETWORK WITH ATTENTION MECHANISM

Modules	Parameters			
	I	II	III	IV
Input	(640*640*3)	-	-	-
Focus	(3,64,1,1)	-	-	-
Conv	(64,128,3,2)	(128,256,3,2)	(256,512,3,2)	(512,1024,3,2)
3×C3	(128,128)	(1024,1024)	-	-
9×C3	(256,256)	(512,512)	-	-
SPP	(1024,1024, (5,9,13))	-	-	-
CoordAtt	(1024,1024)	-	-	-

Table I indicates the module name of the network structure, the first parameter in parentheses indicates the feature input channels of the mode, the second parameter indicates the feature output channel numbers, and the other parameters thereafter indicate the specific parameters of the module, for example, Focus (3,64,1,1), which indicates three input channels and 64 output channels, using a convolution of size 1\*1. In introducing the coordinate attention mechanism into YOLOv5, the CA mechanism is first embedded into the backbone network of YOLOv5. Through existing research, it is found that in the YOLOv5 feature extraction network, the last layer has the largest number of feature channels, which may affect the accuracy of the detection algorithm due to the interference of irrelevant information, so the model is added to the last layer in an attempt to allow the VD algorithm can focus on the feature information related to the current task.

The evaluation metrics of the YOLOv5 algorithm improved by the fused attention mechanism are selected as accuracy, recall and detection speed, and the evaluation metrics are calculated using the confusion matrix as the basis, and the accuracy (Precision) is denoted by P. In the confusion matrix, it indicates what percentage of the results with positive prediction are predicted correctly, as in Equation (14); in the confusion matrix, TP is both the predicted and true cases are active cases. FP is that the prediction is positive and the true case is inactive.

$$Precision = \frac{TP}{TP + FP} \quad (14)$$

Recall (Recall) in the confusion matrix indicates what percentage of all positive columns are predicted, as in Equation (15).

$$Recall = \frac{TP}{TP + FN} \quad (15)$$

*FN* is the opposite of *FP*. In the current experimental algorithm it is not possible to obtain results with high recall and accuracy, so the equilibrium state of the two needs to be considered [13]. Based on the derived recall and accuracy, the average precision (AP) is considered, and since this experiment uses a multi-objective VD algorithm, it is measured using the category-wide average precision metric, which is obtained by weighting the mean precision of all detection categories [14]. At the same time, the study is a lightweight model, and for achieving the effect of saving computational materials, it is also necessary to evaluate the detection speed, and Frame Per Second (FPS) is selected as the speed evaluation index.

#### IV. PERFORMANCE TESTING OF YOLOV5 BUILT ON IMPROVED ATTENTION MECHANISM

##### A. Experimental Scheme Design and Computational Efficiency Analysis

For testing the recommendation model, a test experiment is designed here. In order to meet the requirements of diverse road conditions and real scene fit, the study will use the UA\_DETRAC dataset, which is obtained by slicing the traffic routes of Chinese cities Beijing and Shanghai at 25 frames per second after 10 hours of video shooting, with the image size of 960\*540 pixels, containing more than 140,000 images, and manually labeled 8250 vehicles, with 1.21 million bounding boxes marked, and car types classified according to vehicle shape, and all marked vehicles are dynamic vehicles, and the shooting environment includes four kinds: sunny day, rainy day, cloudy day and night shown in Fig. 5.

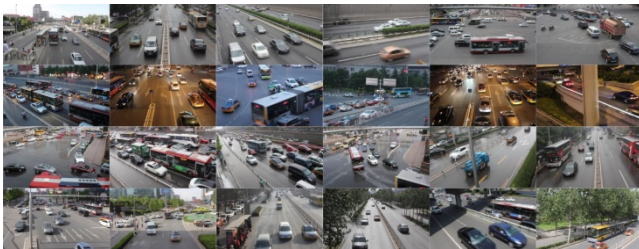


Fig. 5. Sample diagram of part of the UA\_DETRAC dataset.

Firstly, to reduce the burden on the experimental equipment and remove the data redundancy of the dataset, UA\_DETRAC was extracted into a new dataset with a ratio of 5:1 and converted into a dataset in VOC format, and the annotation file format was converted from xml to txt for easy input into the YOLOv5 model for model training. Because the size of UA\_DETRAC images is 960\*540 pixels, the images are scaled to the same size of 640\*640 pixels. After training the model, the  $\alpha$ -CloU loss function curve localization loss curve, classification loss curve and confidence loss curve are shown in Fig. 6.

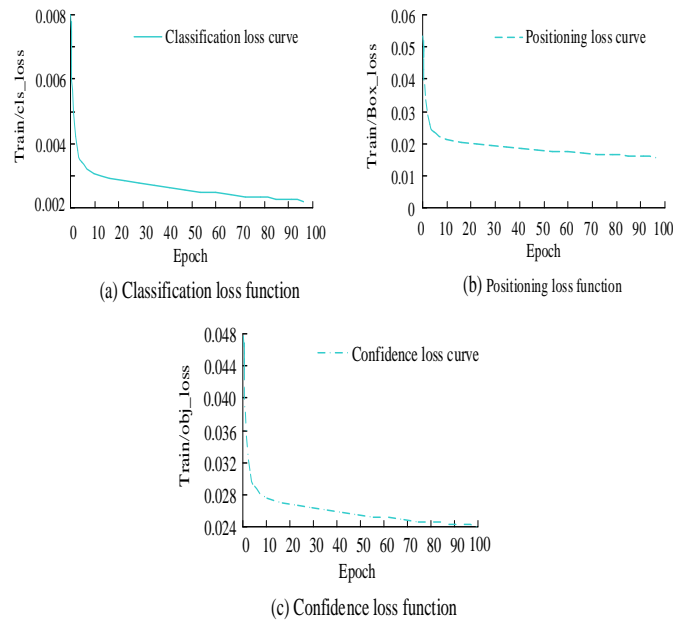


Fig. 6. YOLOv5 model training loss function curve.

The changes of loss function curves during training are Fig. 6. Fig. 6(a) indicates the classification loss curve. Fig. 6(b) shows the localization (positioning) loss curve, and Fig. 6(c) indicates the confidence loss curve. During the training process, no abnormalities have occurred, and all the loss function curves tend to be stable when the model is trained to the 100th round. From Fig. 6, it can be seen that the localization loss and confidence loss gradually stabilize at 0.002 and 0.028; the classification loss gradually stabilizes at 0.017.

Based on this, the algorithm is tuned to improve the focus on the key regions by adding a coordinate attention mechanism to the YOLOv5 model that mimics human visual recognition and has lightweight characteristics. Before training, the hyperparameter batch size is 16, and 100 epochs are trained. From the beginning to the end of training, the warm-up principle is used, which means that 3 epochs are learned from 0. After the learning rate reaches a plateau, the cosine annealing principle is adopted to reduce the learning rate, and the cosine annealing hyperparameter is set to 0.2 [15]. For the selection of the optimizer, the study Random Gradient Descent with momentum was chosen. The advantage of this method is that the square of the gradient is calculated in a small space, so there is no need to store the gradient. The momentum of the optimizer is 0.937 and the weight decay coefficient is 0.0005. After turning on mosaic data enhancement for all training images, mix up data enhancement is turned off. The loss function curve of the training result of the network model with the CA mechanism added is shown in Fig. 7.

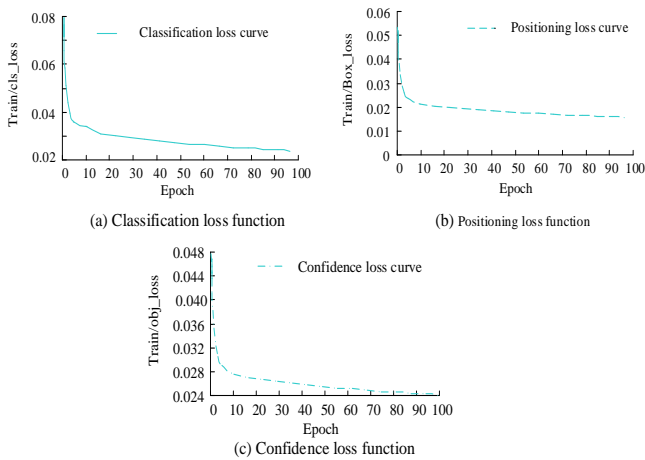


Fig. 7. Change curve of the loss function of the YOLOv5 model with the introduction of the coordinate attention mechanism.

As shown in Fig. 7, 7(a) represents the classification loss curve, Fig. 7(b) represents the localization loss curve, and Fig. 7(c) represents the confidence loss curve. The overall training process of the model is relatively normal, with a smooth decreasing trend, and the loss decreases quicker in the 1st 20-epochs, and then gradually stabilizes when reaching 100 epochs. The final localization loss is stabilized at 0.017, classification loss is stabilized at 0.00117, and confidence loss is stabilized at 0.028.

### B. Model Vehicle Inspection Quality Analysis

For verifying the effectiveness of CA mechanism on the improvement of YOLOv5 measurement accuracy, Squeeze and Excitation Networks (SE), Convolutional Block Attention Module (CBAM) and CA mechanism are added to the YOLOv5 model, respectively. The SE is added at the same location as the CA mechanism, and the CBAM has the ability to extract spatial information instead of the convolutional layer, so the CBAM is used to replace that in the 5th-layer of the YOLOv5 [16-18]. The common YOLOv5 model is also selected as a comparison, and the accuracy comparison curves of the four models are Fig. 8.

As shown in Fig. 8, Fig. (a), (b), (c), and (d) show the test results of the baseline network models YOLOv5, YOLOv5+SE, YOLOv5+CBAM, and YOLOv5+CA, respectively, and it can be seen that the overall trend of the four network models is similar, and all of them gradually stabilize after a rapid increase in the confidence interval from 0 to 1. Further analysis of Fig. 8(a) and Fig. 8(b) shows that the accuracy of both models can be approximated to 1.0 at a confidence level of 0.946 for all categories, but the accuracy curve of YOLOv5 model with SE inserted for other categories of vehicles is smoother and has higher validity than the accuracy curve of YOLOv5 baseline model. In comparing Fig. 8(c) with Fig. 8(d), the YOLOv5 model with CA inserted has a higher confidence level of correct prediction for all categories of VD, and has a good accuracy at a confidence level of 0.4. The comparison of the accuracy curves demonstrates that the fused CA mechanism YOLOv5 network model performs better in VD. After that, the average accuracy of the four models is compared (Fig. 9).

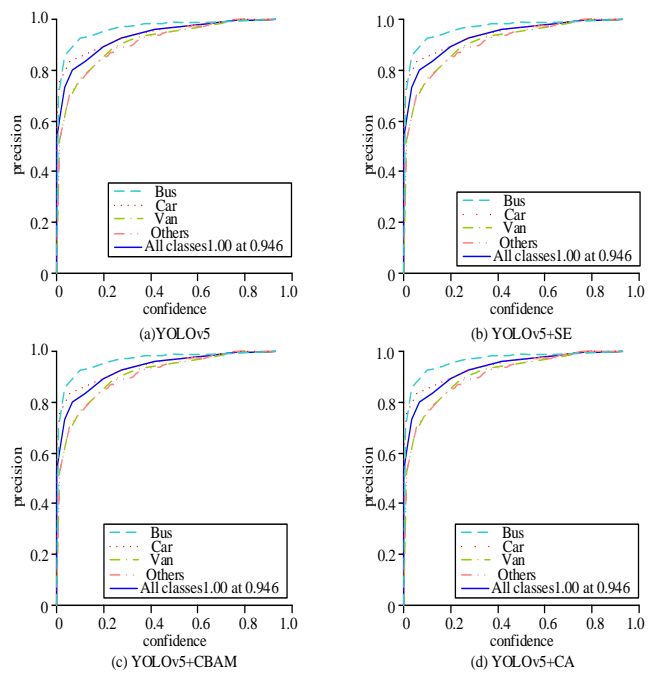


Fig. 8. Comparison of the precision of the improved model with the baseline network.

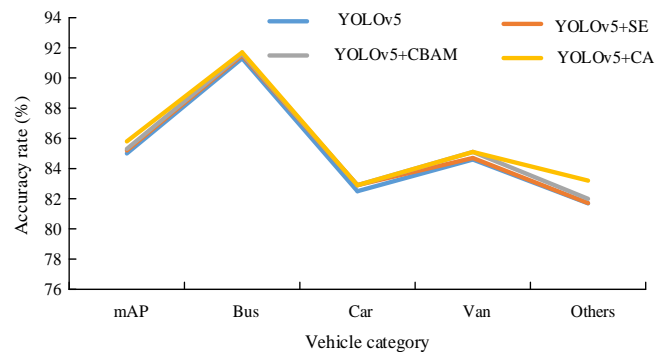


Fig. 9. Comparison of detection accuracy of four improved VD algorithms.

As shown in Fig. 9, which clearly reflects the comparison of the detection accuracy of the four VD algorithms network, to better reflect the improvement of the detection accuracy of the VD algorithms, also the more common VD algorithms and YOLOv5 combined with the CA mechanism of the network for comparison. It can be clearly found that the overall trend of the four VD algorithms is similar, and the detection accuracy in bus classification is much higher than the other classifications, at more than 90%, and the detection accuracy of the four algorithms for car classification is lower all approximating 83%, which may be due to the relatively fixed bus shape with obvious signs [19-21]. The YOLOv5 performance combined with CA mechanism for VD algorithm is significantly greater than the others, with detection accuracy exceeding other algorithms by about 0.8 percentage points.

As shown in Fig. 10, it more intuitively demonstrates the improvement of YOLOv5+CA on VD accuracy, a comparison using the commonly used VD algorithm model SOTA [22], it is evident that the YOLOv5+CA VD algorithm performs significantly better than several other common algorithms, with

detection accuracy exceeding other algorithms by about 9 percentage points. Unlike the YOLOv5+CA detection algorithm, the SSD algorithm, ResNet-101 algorithm and RefineDet algorithm have similar trends, and the YOLOv5+CA detection algorithm is significantly more accurate than the three common algorithms in detecting mAP, Bus, Van and other categories, while the three common algorithms perform slightly better in detecting vehicles in the Car category in terms of accuracy than the YOLOv5+CA detection algorithm.

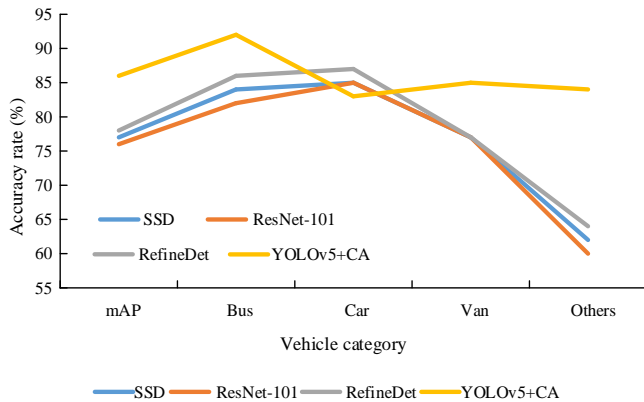


Fig. 10. Accuracy comparison of YOLOv5+CA with different SOTA vehicle detection algorithms.

As shown in Fig. 11, the YOLOv5 combined with the three attention mechanisms is tested using night-time live video, and the detection results are visualized and compared. Fig. 11(a), 11(b) and 11(c) show YOLOv5+SE, YOLOv5+CBMA and YOLOv5+CA respectively by comparing Fig. (a), (b) and (c) it can be found that three small cars are missed in the figure. In Fig. 11(b) the VD using the network of YOLOv5 combined with CBAM leads to an improvement of the missed detection, two of the missed vehicles are identified, but the confidence level is not high. In Fig. 11(c), the algorithm using YOLOv5+CA identifies all three missed vehicles with high confidence values. Therefore, the validity of the CA mechanism in improving the accuracy of the VD algorithm can be fully confirmed.



Fig. 11. Visual comparison of three YOLOv5 test results.

## V. CONCLUSION

For the problem of low accuracy of VD performed by video surveillance, an improved VD model incorporating coordinate attention mechanism and YOLOv5 is designed in the study. The experimental results of the performance test show that the model converges when the iterations exceed 100, and the localization loss and confidence loss gradually stabilize at 0.002 and 0.028; the classification loss gradually stabilizes at 0.017. After adding the CA mechanism and setting the training to 100 epochs, the loss of the model declined quicker in the 1st 20 epochs. After that, the loss leveled off when reaching 100 epochs. Finally, the localization loss is stabilized at 0.017, the classification loss is stabilized at 0.00117, and the confidence loss is stabilized at 0.028. Thereafter, to compare the superiority of different attention mechanisms, the baseline network models YOLOv5, YOLOv5+SE, YOLOv5+CBAM, and YOLOv5+CA are used for comparison tests, and the results show that the accuracy can be approximated to 1.0 at a confidence level of 0.946 for all categories, and the YOLOv5 model with CA inserted for all categories of VD predicts the correct the confidence level is higher and has a good accuracy at a confidence level of 0.4. To better reflect the improvement in detection accuracy of the VD algorithm, YOLOv5+CA is compared with SSD algorithm, ResNet-101 algorithm and RefineDet algorithm, and the results show that YOLOv5+CA VD algorithm performs significantly better than several other common algorithms, and the detection accuracy is better than other algorithms by about 9%. To compare the actual video VD gap of YOLOv5+SE, YOLOv5+CBAM, and YOLOv5+CA, a visual comparison of YOLOv5 combining the three attention mechanisms reveals that both YOLOv5+SE and YOLOv5+CBAM have missed detections and low confidence levels. In summary, the research has shown that the vehicle detection accuracy of the YOLOv5+CA model designed by the research is higher than that of common models, and the computational performance has been improved compared to the original algorithm, but there are still some shortcomings, and the subsequent research can be improved and improved from the following aspects: (1) producing vehicle datasets with higher image quality. When using deep learning methods, the quality of the dataset determines the upper limit of the algorithm's performance. (2) Improve the detection accuracy of small targets. (3) Further compression of the network model. Due to the limited computing power and storage space of actual embedded devices, large scale deep learning algorithms cannot yet be deployed into these devices. And deploying the algorithms in embedded devices can reduce the latency time due to data passing through the network. The current lightweighting tends to sacrifice a certain amount of accuracy, and how to make the algorithm perform model compression while keeping accuracy constant is also a direction for future research. (4) Later on, consideration can also be given to improving the robustness of the algorithm to cope with different weather conditions.

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# Stroke Risk Prediction: Comparing Different Sampling Algorithms

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**Abstract**—Stroke is a serious disease that has a significant impact on the quality of life and safety of patients. Accurately predicting stroke risk is of great significance for preventing and treating stroke. In the past few years, machine learning methods have shown potential in predicting stroke risk. However, due to the imbalance of stroke data and the challenges of feature selection and model selection, stroke risk prediction still faces some difficulties. This article aims to compare the performance differences between different sampling algorithms and machine learning methods in stroke risk prediction. This study used the over-sampling algorithm (Random Over Sampling and SMOTE), the under-sampling algorithm (Random Under Sampling and ENN), and the hybrid sampling algorithm (SMOTE-ENN), and combined them with common machine learning methods such as K-Nearest Neighbors, Logistic Regression, Decision Tree and Support Vector Machine to build the prediction model. Through the analysis of experimental results, and found that the SMOTE combined with the LR model showed good performance in stroke risk prediction, with a high F1 score. In addition, this study found that the overall performance of the undersampling algorithm is better than that of the oversampling and hybrid sampling algorithms. These research results provide useful references for predicting stroke risk and provide a foundation for further research and application. Future research can continue to explore more sampling algorithms, machine learning methods, and feature engineering techniques to further improve the accuracy and interpretability of stroke risk prediction and promote its application in clinical practice.

**Keywords**—Stroke prediction; data mining; machine learning; unbalanced data; sampling algorithms; classification algorithms

## I. INTRODUCTION

Stroke is a serious neurological disorder and its health burden is enormous worldwide. According to the World Health Organisation, millions of people die or become permanently disabled as a result of stroke each year [1]. Accurate prediction of the risk of stroke is therefore crucial for early intervention and treatment.

With the rapid development of machine learning techniques, the use of these techniques to predict stroke risk has become a hot topic of research. Machine learning models can predict the probability of stroke in individuals by learning and mining patterns and correlations in large amounts of patient data [2]. This provides clinicians with a new tool to aid decision-making and develop personalized treatment plans.

However, stroke risk prediction faces a number of challenges. Firstly, the mechanisms by which stroke events occur are complex and diverse, involving a variety of potential risk

factors such as age, gender, hypertension, and diabetes [3]. Secondly, stroke data often suffer from a serious imbalance, i.e. there is a significant imbalance between the proportion of normal samples and stroke samples [4]. This data imbalance may result in the models having better predictive performance for most classes of samples, but poorer predictive performance for a few classes of samples (i.e. stroke samples). In addition, the generalisability and interpretability of the models are key issues in stroke risk prediction studies [5].

To overcome these challenges and improve the accuracy and reliability of stroke risk prediction, this study aims to compare the performance of different sampling machine learning algorithms in stroke risk prediction. The study will utilize various sampling algorithms, such as Random Over Sampling (ROS) and Synthetic Minority Over-sampling Technique (SMOTE), as well as undersampling algorithms like Random Under Sampling (RUS) and Edited Nearest Neighbors (ENN), along with the combination of SMOTE and Edited Nearest Neighbors (SMOTE-ENN), to address imbalanced data. Additionally, machine learning methods including K-Nearest Neighbors (KNN), Logistic Regression (LR), Decision Tree (DT), and Support Vector Machine (SVM) will be employed for prediction modeling [6]–[9]. Through the comparison of performance among various sampling algorithms and machine learning methods, the study aims to identify the optimal prediction model and enhance the accuracy and reliability of stroke risk prediction.

The paper is structured as follows: Section II reviews relevant previous work. Section III describes the experimental design and methods in detail. The Section IV presents the experimental results and analysis. Finally, Section V summarises the main findings of the paper and discusses directions for further research.

## II. RELATED WORKS

The study of stroke risk prediction has attracted a great deal of interest and a lot of valuable work has emerged. This section provides an extensive review of relevant literature on stroke risk prediction, encompassing various methods and techniques employed in previous studies. Additionally, an in-depth analysis of the strengths and limitations of these approaches is presented.

Commonly used methods for stroke risk prediction in previous studies include traditional statistical models and machine learning models. Traditional statistical models such as



regression analysis, survival analysis, and decision trees are widely used for stroke risk prediction. These models can be based on large clinical datasets by building predictive models to identify patients' risk factors for stroke. Dennis et al. [10] used survival analysis to accurately estimate the long-term mortality risk of first-time stroke patients. Shao et al. [11] utilized the decision tree C4.5 algorithm to establish a stroke risk assessment model and identify the influences of various factors such as smoking, alcohol consumption, diet, sleep, and exercise on stroke risk. However, traditional statistical models have limitations in dealing with complex non-linear relationships and high-dimensional data.

In recent years, the development of machine learning techniques has opened up new possibilities for stroke risk prediction. Machine learning models can automatically learn patterns and correlations from data and are able to handle non-linear relationships and high-dimensional data. Common machine learning methods used in stroke risk prediction include SVM, DT and Random Forest (RF) and Artificial Neural Network (ANN) [12]–[15]. These models can be trained on large amounts of patient data to predict stroke risk with a high degree of accuracy and generalisation.

In previous research on stroke prediction using machine learning models, the focus has primarily been on the performance of machine learning models. Viswapriya et al. [12] proposed a hybrid model combining ANN and RF for stroke prediction, achieving a classification accuracy of 94%. Sailasya et al. [13] proposed the use of various machine learning algorithms to predict the risk of brain stroke, with Naïve Bayes (NB) achieving the highest accuracy of approximately 82%. Dritsas et al. [14] proposed a robust framework using machine learning models and a stacking method to accurately predict the long-term risk of stroke occurrence, achieving high performance with an AUC of 98.9% and an accuracy of 98%. Alageel et al. [15] proposed an analysis of factors enhancing stroke prediction using electronic health records, identifying age, average glucose level, heart disease, and hypertension as critical factors, and evaluating seven machine learning algorithms for stroke occurrence prediction with high accuracy and performance.

In addition to traditional statistical models and machine learning models, sampling algorithms are also widely used in stroke risk prediction. As stroke data usually exhibit a class imbalance problem, i.e. a significant imbalance between stroke and normal samples, sampling algorithms can balance the dataset by oversampling, undersampling or hybrid sampling. However, a critical aspect that has been overlooked in previous research is the comparison of different sampling algorithms for handling imbalanced datasets. Some researchers generally directly use the popular SMOTE algorithm to process imbalanced data [16]–[18], and , there are also some researchers simply use random sampling methods to compare with SMOTE algorithms [19].

In summary, stroke risk prediction is a challenging and important area of research. Traditional statistical and machine learning models provide powerful tools for stroke risk prediction, while sampling algorithms are able to handle unbalanced data sets. This study aims to further investigate the effectiveness of combining different sampling algorithms with machine learning models for stroke risk prediction. The findings of this

research contribute to the advancement of methods and insights in the field of stroke risk prediction.

### III. METHODOLOGY

This section is divided into four sections, including data collection, data pre-processing, machine learning Models, and evaluation metrics, and the proposed workflow is shown in Fig. 1.

#### A. Data Collection

The predicted stroke dataset in this study is from the Kaggle platform, which contains 5110 patient data [20]. It has 12 features, including seven categorical features, four quantitative features and a patient ID number. There is personal and health information about the patient, details of which are shown in the Table I.

TABLE I. DESCRIPTION OF STROKE DATASET

Feature Name	Feature Description	Feature Type
Id	Patient unique id.	/
Gender	Male, Female, Other.	Quantitative
Age	Patient ages in years.	Quantitative
Hypertension	If the patient has hypertension, then 1 else 0.	Categorical
Heart disease	If the patient has heart disease, then 1 else 0.	Categorical
Ever married	No, Yes.	Categorical
Work type	Children, Govt job, Never worked, Private, Self-employed.	Categorical
Residence type	Rural, Urban.	Categorical
Avg glucose level	Average glucose level in blood.	Quantitative
BMI	Body Mass Index (BMI) is an indicator used to assess a person's weight status based on their weight and height.	Quantitative
Smoking status	Formerly smoked, Never Smoked, Smokes, Unknown.	Categorical
Stroke	If the patient has a stroke disease, then 1 else 0.	Categorical

The dataset has 4681 normal and 249 stroke patients, 95% of which are negative cases and only 5% are positive cases, a highly unbalanced dataset as shown in Fig. 2.

#### B. Data Pre-processing

1) *Missing Value Handling*: About 4% of the data have missing BMI values. To improve the robustness of the model, 0 is used for filling.

2) *Meaningless Features Handling*: In this study, the patient ID was considered irrelevant and subsequently excluded from the analysis.

3) *Label Encoding*: The values of some of the category features (Gender, Ever married, etc.) need to be converted to numerical values before being entered into the model.

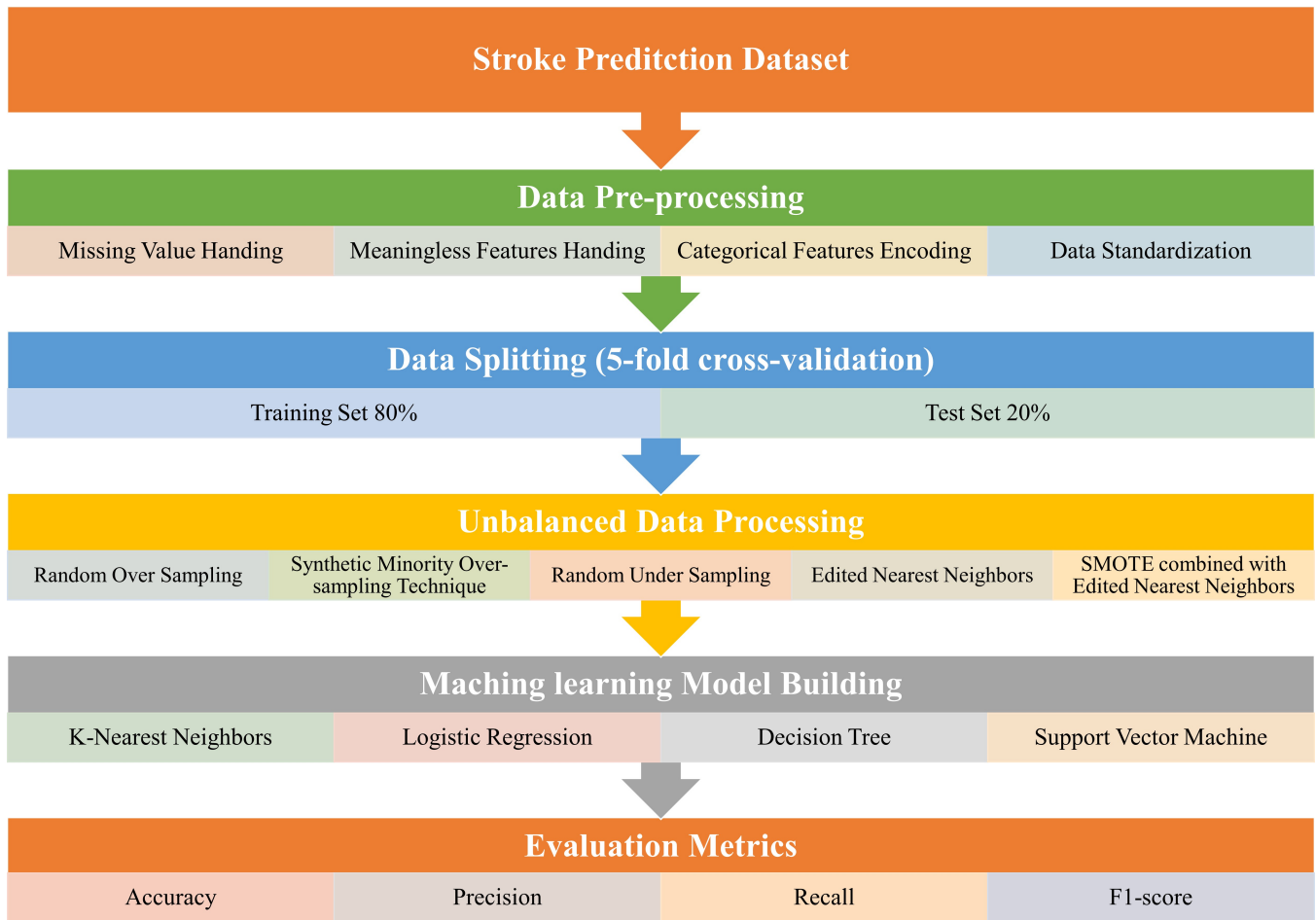


Fig. 1. Proposed workflow.

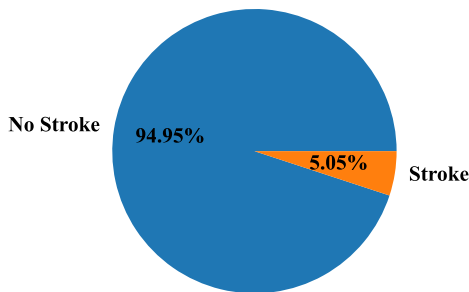


Fig. 2. No Stroke vs Stroke.

4) *Data Standardization*: The magnitude and unit of stroke patients' information data are different. For example, the value of avg glucose level is hundreds, while the value of BMI is only dozens. Data needs to be standardized before being input into the model. In this experiment, a separate standardization procedure was applied to the training set and test set after partitioning the dataset in order to avoid data leakage. Therefore,

this study standardized the dataset, calculation as Equation (1):

$$x_{\text{standardized}} = \frac{x - \mu}{\sigma} \quad (1)$$

where  $x_{\text{standardized}}$  represents the standardized value of  $x$ ,  $\mu$  is the mean of the data,  $\sigma$  is the standard deviation of the data, and  $x$  is the original data point.

### C. Description of Sampling Algorithms

Stroke data typically suffer from category imbalance, i.e. a significant imbalance in the ratio between stroke and normal samples. To tackle the challenge of imbalanced data in stroke risk prediction, a range of sampling algorithms were utilized. This section provides an overview of the sampling algorithms employed, namely ROS, SMOTE, RUS, ENN, and SMOTE-ENN.

1) *Random Over Sampler*: ROS is a simple yet effective algorithm that randomly replicates minority class samples until the class distribution is balanced. It increases the number of stroke samples in the dataset, allowing the machine learning models to learn from more balanced data.

2) *Synthetic Minority Over-sampling Technique*: SMOTE is a widely used oversampling algorithm that generates synthetic minority class samples based on the characteristics of

existing minority samples. It creates synthetic samples by interpolating between randomly selected minority samples and their nearest neighbors.

3) *Random Under Sampling*: The RUS randomly selects a subset of majority class samples to match the number of minority class samples. It reduces the dominance of the majority class in the dataset, allowing the machine learning models to focus more on the minority class.

4) *Edited Nearest Neighbors*: ENN is an undersampling algorithm that removes misclassified majority class samples based on their nearest neighbors' class labels. It compares the class label of each majority sample with its k-nearest neighbors and removes the samples that are misclassified.

5) *SMOTE-ENN*: SMOTE-ENN first applies the SMOTE algorithm to generate synthetic samples and then applies the ENN algorithm to remove misclassified samples.

#### D. Description of Machine Learning Models

This section provides a detailed description of the machine learning methods utilized for stroke risk prediction in the study. The study utilized a selection of widely used machine learning algorithms, including KNN, LR, DT, and SVM. Each algorithm has its unique characteristics and advantages in handling different types of data and classification problems.

1) *K-Nearest Neighbors*: KNN is a non-parametric algorithm that classifies data points based on the majority class label of their k-nearest neighbors [6]. It can be used for stroke risk prediction by measuring the similarity between the input sample and other samples in the dataset. The common distance formula used in KNN algorithm is the Euclidean distance. For two sample points  $x$  and  $x_i$ , the Euclidean distance is calculated as Equation (2).

$$d(x, x_i) = \sqrt{\sum_{j=1}^n (x_j - x_{ij})^2} \quad (2)$$

where  $n$  is the feature dimension of the sample points, and  $x_j$  and  $x_{ij}$  denote the values of the sample  $x$  and  $x_i$  on the  $j$ th feature, respectively.

2) *Logistic Regression*: LR is a linear classification algorithm that models the probability of a sample belonging to a specific class. It can be used to predict the probability of stroke occurrence based on the input features [7]. The logistic regression model estimates the parameters of a logistic function using maximum likelihood estimation. The logistic function maps the input features to a probability value, and a threshold can be applied to classify the samples into different classes. The logistic regression model can be represented as Equation (3):

$$P(\text{Stroke} = 1|X) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n)}} \quad (3)$$

where  $P(\text{Stroke} = 1|X)$  represents the probability of stroke occurrence given the input features  $X$ , and  $\beta_0, \beta_1, \dots, \beta_n$  are the coefficients estimated during model training.

3) *Decision Tree*: DT is a hierarchical tree-based algorithm that splits the feature space based on the values of different features [8]. It can be used to identify the important features and their thresholds that are associated with stroke risk. The decision tree creates a tree-like model where each internal node represents a decision based on a feature, and each leaf node represents a class label. The decision tree can be represented as a series of if-else statements, where each internal node represents a splitting condition based on a feature, and each leaf node represents a class label.

4) *Support Vector Machine*: SVM is a binary classification algorithm that aims to find an optimal hyperplane in the feature space that separates the data points of different classes with the maximum margin [9]. It can be used for stroke risk prediction by finding a decision boundary that distinguishes between samples with and without stroke. SVM can handle both linearly separable and non-linearly separable data by using different kernel functions to map the input features to a higher-dimensional space. The SVM classification function can be represented as Equation (4):

$$f(x) = \sum_{i \in S} \alpha_i y_i K(x_i, x) + b \quad (4)$$

where  $x_i$  denotes the training patterns,  $y_i \in \{+1, -1\}$  denotes the corresponding class labels and  $S$  denotes the set of Support Vectors [21].

These machine learning methods can effectively capture the underlying patterns and relationships in the data and make predictions about the stroke risk for individuals based on their input features.

#### E. Evaluation Metrics

To assess the effectiveness of the stroke risk prediction models, the evaluation of the confusion matrix and various evaluation metrics was performed. Stroke was considered the positive class, while no stroke was considered the negative class.

1) *Confusion Matrix*: The confusion matrix provides a tabular representation of the model's predictions, showing the counts of true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN). It helps in analyzing the model's performance in correctly classifying stroke and no stroke cases [13]. The confusion matrix is shown in Table II.

TABLE II. CONFUSION MATRIX

	Predicted Stroke	Predicted No Stroke
Actual Stroke	TP	FN
Actual No Stroke	FP	TN

The elements in the matrix have the following meanings:

TP: The number of samples that the model correctly predicted as strokes.

TN: The number of samples that the model correctly predicted a no stroke.

FP: The number of samples that the model incorrectly predicted as having a stroke.

FN: The number of samples that the model incorrectly predicted as no stroke.

2) *Accuracy*: Accuracy is the ratio of correctly predicted instances (both stroke and no stroke) to the total number of instances. It measures the overall correctness of the model's predictions, providing an indication of how well it classifies both positive and negative cases. It is calculated as Equation (5):

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} \quad (5)$$

3) *Precision*: Precision quantifies the proportion of true positive predictions (correctly predicted strokes) out of the total predicted positive instances (predicted strokes). It measures the model's ability to accurately identify individuals at risk of stroke, minimizing false positive predictions. It is calculated as Equation (6):

$$\text{Precision} = \frac{TP}{TP + FP} \quad (6)$$

4) *Recall*: Recall calculates the proportion of true positive predictions (correctly predicted strokes) out of the actual positive instances (actual strokes). It measures the model's ability to correctly identify individuals who have experienced a stroke, minimizing false negative predictions. It is calculated as Equation (7):

$$\text{Recall} = \frac{TP}{TP + FN} \quad (7)$$

5) *F1-score*: The F1-score is the harmonic mean of precision and recall, providing a balanced measure of the model's accuracy in predicting both stroke and no stroke cases. It considers both false positive and false negative predictions and provides an overall assessment of the model's performance. It is calculated as Equation (8):

$$\text{F1-score} = \frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \quad (8)$$

By utilizing the confusion matrix and these evaluation metrics, a comprehensive evaluation of the stroke risk prediction models can be conducted to assess their performance in accurately identifying individuals at risk of stroke while minimizing false positive and false negative predictions.

#### IV. RESULT AND DISCUSSION

The performance of five different sampling algorithms was evaluated, including ROS, RUS, SMOTE, ENN, and SMOTE-ENN, in combination with four machine learning models: KNN, LR, DT and SVM. The evaluation metrics used were accuracy, precision, recall, and F1-score in Table III.

The accuracy comparison is shown in the Fig. 3 and the accuracy of the models is observed to decrease to some extent after applying the sampling algorithm. This may be because the sampling algorithm changes the distribution of the samples when processing unbalanced data, thus affecting the overall accuracy. Among all algorithms, the combination of ENN and LR achieved the highest accuracy (0.9454), while the combination of RUS and DT achieved the lowest accuracy (0.6945). Compared to other sampling algorithms, the model of ENN algorithm is higher, because the ENN algorithm improves

accuracy by removing noise and redundant samples from the majority class, thereby preserving the distinctive features of the minority class samples.

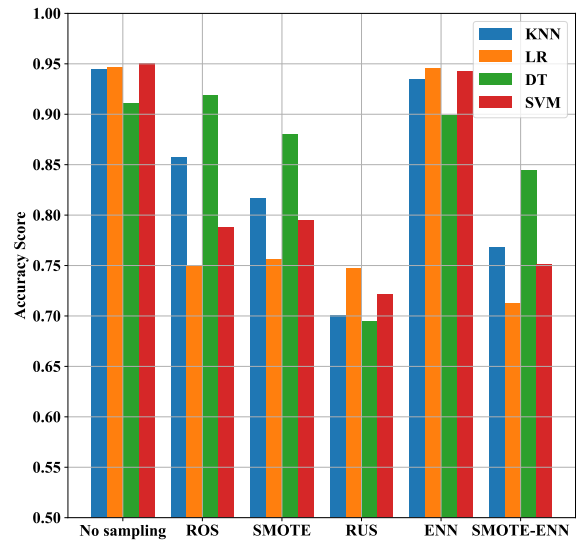


Fig. 3. Accuracy of each sampling algorithm combined with machine learning models.

The precision comparison is shown in Fig. 4, revealing that the combination of ENN and LR models achieved the highest precision rate of 0.2675, whereas the combination of RUS and DT algorithms obtained the lowest precision rate of 0.0967. And the precision of the model combined with ENN is significantly higher than the other sampling algorithms, indicating that the ENN algorithm is better able to identify the true positive samples and reduce the possibility of false positives.

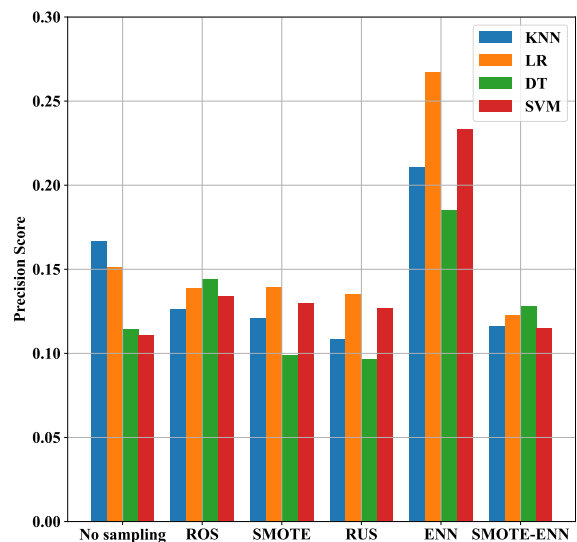


Fig. 4. Precision of each sampling algorithm combined with machine learning models.

The recall comparison is shown in Fig. 5, demonstrating a substantial improvement in the model's performance compared to unsampled data when utilizing the sampling algorithm. The

TABLE III. PERFORMANCE EVALUATION BY SAMPLING ALGORITHM AND MACHINE LEARNING MODEL

Sampling Algorithm <sup>a</sup>	Machine Learning Model <sup>b</sup>	Accuracy	Precision	Recall	F1-score
No Sampling	KNN	0.9442	0.1667	0.0189	0.0339
	LR	0.9464	0.1515	0.0255	0.0437
	DT	0.9105	0.1143	0.1176	0.1159
	SVM	<b>0.9508</b>	0.1111	0.0052	0.0099
ROS	KNN	0.8573	0.1262	0.3211	0.1803
	LR	0.7489	0.1390	0.7971	0.2363
	DT	0.9186	0.1442	0.1353	0.1393
	SVM	0.7881	0.1338	0.6081	0.2184
SMOTE	KNN	0.8168	0.1210	0.4328	0.1875
	LR	0.7556	0.1397	0.7772	<b>0.2368</b>
	DT	0.8804	0.0992	0.1817	0.1272
	SVM	0.7951	0.1297	0.5682	0.2108
RUS	KNN	0.7002	0.1088	0.7233	0.1889
	LR	0.7466	0.1353	0.7794	0.2305
	DT	0.6945	0.0967	0.6289	0.1673
	SVM	0.7211	0.1271	<b>0.8035</b>	0.2186
ENN	KNN	0.9341	0.2110	0.1240	0.1544
	LR	0.9454	<b>0.2675</b>	0.0542	0.0887
	DT	0.8990	0.1851	0.3071	0.2267
	SVM	0.9421	0.2331	0.0832	0.1192
SMOTE-ENN	KNN	0.7683	0.1160	0.5661	0.1920
	LR	0.7123	0.1226	0.8028	0.2117
	DT	0.8444	0.1281	0.3771	0.1912
	SVM	0.7509	0.1149	0.6102	0.1928

<sup>a</sup> ROS: Random Over Sampler; SMOTE: Synthetic Minority Over-sampling Technique; RUS: Random Under Sampling; ENN: Edited Nearest Neighbors; SMOTE-ENN: Synthetic Minority Over-sampling Technique combined with Edited Nearest Neighbors.

<sup>b</sup> KNN: K-Nearest Neighbors; LR: Logistic Regression; DT: Decision Tree; SVM: Support Vector Machine.

combination of RUS and SVM has the highest recall of 0.8035, while ENN+LR has the lowest recall of 0.0542. At this point, the model recall of the combination with ENN is significantly lower than the other sampling algorithms except for LR, and the model recall of the combination with RUS is overall higher than the other sampling algorithms, which indicates that the RUS algorithm can better identify the true positive samples and reduce the possibility of misclassification the possibility of misclassification.

The F1-score comparison is shown in Fig. 6. Under the metric, the model scores were all significantly higher after using the sampling algorithm than without the sampling algorithm. The combination of SMOTE and LR model obtained the highest score (0.2368), while the combination of ENN and LR model scored the lowest (0.0887). However, RUS performs better in combination with other algorithms, which indicates that the RUS is able to find a balance between accuracy and recall, resulting in a better overall model performance.

In a comprehensive comparison, the overall performance of the under sampling algorithm is better than that of the oversampling and hybrid sampling algorithms for the prediction stroke problem, and the models combined with the ENN algorithm generally perform better under the accuracy and precision metrics. The models combined with the RUS algorithm are generally better under the recall and F1-score metrics. Reviewing the findings depicted in Fig. 4, it becomes apparent that the utilization of the oversampling algorithm has resulted in only marginal improvements in model precision. Interestingly, in certain instances, the precision scores of certain models were lower when the oversampling algorithm was

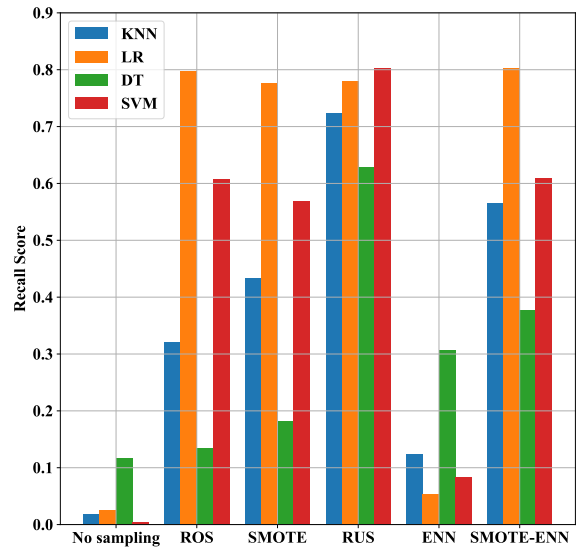


Fig. 5. Recall of each sampling algorithm combined with machine learning models.

applied, compared to their performance without any sampling algorithm. Instead, the model precision scores of the ENN algorithm combined with the under sampling algorithm were significantly higher than the other algorithms. The observed phenomenon can be attributed to the limited number of positive samples, approximately 200 cases, and the significant variation in data distribution. The oversampling algorithm, in such cases,

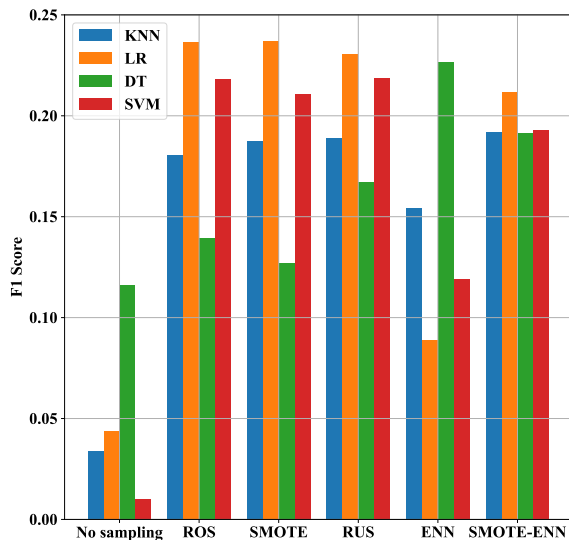


Fig. 6. F1-score of each sampling algorithm combined with machine learning models.

tends to generate duplicate, noisy, or unreliable samples.

## V. CONCLUSION AND FUTURE WORK

This study examines stroke risk prediction through a comparative analysis of various sampling algorithms and machine learning methods. The experimental results show that the use of an appropriate combination of sampling algorithms and machine learning methods can significantly improve the prediction performance in the stroke risk prediction task.

In the analysis conducted, the hybrid sampling algorithm (SMOTE+LR) combined with the KNN model demonstrated superior performance in stroke risk prediction, yielding a high F1 score. The combination of other sampling algorithms and machine learning methods also achieved some prediction performance, but was overall inferior to the combination of the SMOTE algorithm and the LR model.

Although the SMOTE+LR combination exhibited the highest F1 score, the analysis revealed that the overall performance of the oversampling algorithm outperformed the undersampling algorithm and the hybrid sampling algorithm when considering the performance of various sampling methods in conjunction with machine learning models. Selecting an appropriate combination of sampling algorithms and machine learning methods is pivotal in enhancing the accuracy of stroke risk prediction.

This research has achieved some beneficial results, there are still some limitations that need to be considered.

Regarding dataset selection, specific datasets were utilized for conducting the experiments, which may introduce domain-specific or sample distribution biases. To ensure the generalizability of the findings, future research should encompass a broader range of datasets for validation purposes.

In terms of model building, the study selected KNN, LR, DT and SVM as machine learning methods with oversampling, under sampling and hybrid sampling algorithms. However,

there are other machine learning methods and sampling algorithms that can be tried, such as random forests, neural networks, and other variants of sampling methods. The comparison and exploration of these methods will contribute to a more comprehensive understanding of the problem of stroke risk prediction.

In future research, potential avenues for improvement can be explored in the following directions:

In terms of feature engineering, in stroke risk prediction, the selection and extraction of effective features are critical to prediction performance. Further research can explore better feature selection and feature engineering methods to improve prediction performance.

In terms of integrated learning, integrated learning methods can improve the accuracy and stability of stroke risk prediction by combining the prediction results of multiple models. Further research could try integrated learning methods and compare them with a single model.

In terms of interpretive analysis, the interpretation of stroke risk predictions is critical to clinical practice and decision support. Further research could explore how to interpret and explain the prediction results of models to increase their credibility and interpretability.

In conclusion, the results of this study provide a useful reference for stroke risk prediction and provide a basis for further research and application. Future research can continue to explore more sampling algorithms, machine learning methods and feature engineering techniques to further improve the accuracy and interpretability of stroke risk prediction and to promote its application in clinical practice.

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# Comparative Analysis using Various Performance Metrics in Imbalanced Data for Multi-class Text Classification

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**Abstract**—Precision, Recall, and F1-score are metrics that are often used to evaluate model performance. Precision and Recall are very important to consider when the data is balanced, but in the case of unbalanced data the F1-score is the most important metric. To find out the importance of these metrics, a comparative analysis is needed in order to determine which metric is appropriate for the data being analyzed. This study aims to perform a comparative analysis of various evaluation metrics on unbalanced data in multi-class text classification. This study uses an unbalanced multi-class text dataset including: association, negative, cause of disease, and treatment of disease. This study involves five classifiers as algorithm-level approach, namely: Multinomial Naive Bayes, K-Nearest Neighbors, Support Vector Machine, Random Forest, and Long Short-Term Memory. Meanwhile, data-level approach, this study involves under sampling, over sampling, and synthetic minority oversampling technique. Several evaluation metrics used to evaluate model performance include Precision, Recall, and F1-score. The results show that the most suitable evaluation metric for use on unbalanced data depends on the purpose of use and the desired priority, including the classifier that is suitable for handling multi-class assignments on unbalanced data. The results of this study can assist practitioners in selecting evaluation metrics that are in accordance with the goals and application needs of multi-class text classification.

**Keywords**—Imbalanced data; undersampling; oversampling; smote; machine learning

## I. INTRODUCTION

An unbalanced dataset is a dataset in which some classes have much fewer data samples than others [2]. Imbalanced data occurs when the number of observations in one class is lower than in another class. It can be a problem in machine learning because models may be more accustomed to majority classes, leading to poor performance in minority classes. One of the ways to tackle imbalanced data is to do data sampling before applying machine learning algorithms. Nowadays, common methods of imbalanced data sampling mainly include data oversampling, data undersampling, and hybrid sampling [2], [3].

The method used to address unbalanced data depends on the characteristics of the data. Several previous studies have implemented undersampling [14], [17], [22], [30] to reduce the size of large sample data to balance different types of sample data. Beside undersampling, previous studies have also

implemented an oversampling [11], [12], [13], [27] method that takes small samples as the object to generate new samples. Imbalanced data in text classification with multi-class need to be considered since a classification model that is usually based on a fair class distribution could have problems with imbalanced class [6].

The author in [37] has carried out research on comparative analysis of macro and micro accuracy through a three-classifier approach, namely: Naïve Bayes (NB), Support Vector Machine (SVM), and Random Forest (RF) in the Movie Reviews dataset. In align previous research, this study proposes two additional classifiers, namely: k-Nearest Neighbors (KNN) and Long Short-Term Memory (LSTM), which will be tested on the Plant-Disease Relation (PDR) dataset. The main reason for using KNN and LSTM is that these algorithms are also proven to be used to solve unbalanced class problems like what was done by [38], [39], [40], [41]. Furthermore, reference [33] does not work on the KNN and LSTM algorithms, who used Linear SVC, RBF SVM, DTC, RF, LR, and MNB for multi-class text classification tasks.

In comparative analysis, it is necessary to evaluate the model using various performance metrics [5], and it is an interdisciplinary method that encompasses broad cross-sections of disciplines [1]. Comparative analysis is one way to solve the problem of model performance in classifying unbalanced datasets. It involves comparing the performance of different models on the imbalanced datasets, to determine which model is best suited for the task at hand. By comparing the performance of different models, it can identify the strengths and weaknesses of each model and choose a significant model that fits the problem of unbalanced data [4].

The results of the model evaluation usually use the confusion matrix as a model performance metric that is tested on each data. Metrics most commonly used to measure model performance include: Accuracy, Precision, Recall, Specificity, F1-score, and G-mean [7]. In text classification with multiple classes that experience data imbalance, micro and macro accuracy considerations can be useful in evaluating the model. Micro accuracy measures overall model accuracy by giving equal weight to all classes. It can be calculated by adding up the number of correct predictions from all classes and dividing by the total number of predictions [9]. Each algorithm used will produce a different confusion matrix, this is caused

by differences in methods for handling unbalanced data and classifier algorithms used. Several previous studies analyzed the balance of macro-F1 and micro-F1 [5], [8] only. In the case of imbalanced data, micro accuracy F1 may be higher than macro accuracy because the model may more easily predict the more dominant class with a higher level of accuracy [10].

Methods for dealing with class imbalance in machine learning can be divided into three groups, namely: data-level, algorithm-level, and hybrid approaches [11], [17]. Data-level methods aim to reduce class imbalance by adding new minority samples (i.e., oversampling) [13], removing redundant majority samples (i.e., undersampling) [14], or using a combination of both methods. Algorithm-level methods are designed to adapt standard classification methods to emphasize learning from minority samples, improve the training mechanism or predicted rule [11]. In hybrid approaches, the developed algorithms modify both the distribution of unbalanced classes and the learning mechanism to classify unbalanced data [15].

The contribution of this research to handle unbalanced classes are 1) data-level approach, including undersampling, oversampling, and synthetic minority oversampling technique, for tackle imbalanced class; 2) prepare five machine learning models, including NB, RF, SVM, KNN, and LSTM, for multi-class classification on Plant-Disease Relation datasets; 3) investigated and compared the performance of different machine learning models with various feature combinations and existing techniques.

This study employ both data-level and algorithm approach to handling highly imbalanced data aim to perform precision, recall and micro accuracy F1 score. Various test schemes employed through classification algorithm to obtain perspective analysis. The rest of this paper is organized as follows. Section II contains discussion on the dataset and the methodology used to undertake the research. This is followed by the results and discussion in Section III. Finally, in Section IV, the conclusion and future works are presented.

## II. MATERIALS AND METHOD

### A. Dataset

This study uses gold standard corpus dataset of the Plant-Disease Relation (PDR) developed by [16] available at <http://gcancer.org/pdr> (21<sup>st</sup> January, 2022). The dataset consists of 8 columns, but this study only uses the “sentence” column as text data and the “relation” column as a label (Table I). This study only relies on a statistical analysis of a collection of texts converted into a set of numbers, thus ignoring semantic analysis for classification work.

The PDR dataset has four classes: Association (34 records), Cause of Disease (183 records), Treatment of Disease (507 records), and Negative (583 records). Table II shows samples of the PDR dataset.

### B. Pre-processing

The sentence column used as input still contains several meaningless words, including  $\langle e1start \rangle$ ,  $\langle e1end \rangle$ ,  $\langle e2start \rangle$ , and  $\langle e2end \rangle$ , so it needs to be clean so that it doesn't have a biased impact when building the model. In this study, retaining words that are considered unimportant (a,

TABLE I. SAMPLE OF PLANT-DISEASE RELATION DATASET

Sentence	Plant	Disease	Relation	Trigger
Studies on magnesium's mechanism of action in $\langle e1start \rangle$ digitalis $\langle e1end \rangle$ -induced $\langle e2start \rangle$ arrhythmias $\langle e2end \rangle$ .	digitalis	arrhythmias	CoD	o

TABLE II. VIEW OF PLANT-DISEASE RELATION DATASET

No.	Sentence	Class
1	Studies on magnesium's mechanism of action in $\langle e1start \rangle$ digitalis $\langle e1end \rangle$ -induced $\langle e2start \rangle$ arrhythmias $\langle e2end \rangle$ .	Cause_of_disease
2	Inhibitory effect of $\langle e1start \rangle$ green tea $\langle e1end \rangle$ on the growth of established $\langle e2start \rangle$ skin papillomas $\langle e2end \rangle$ in mice.	Treatment_of_disease
3	In 10 separate experiments, mice with established chemically induced or UV light-induced $\langle e2start \rangle$ skin papillomas $\langle e2end \rangle$ were treated continuously with green tea in the drinking water or with i.p. injections of a $\langle e1start \rangle$ green tea $\langle e1end \rangle$ polyphenol fraction or -epigallocatechin gallate three times a week for 4-10 weeks.	Negative
4	Although based on small numbers of end points, a prospective study has suggested a particularly strong association between recent $\langle e1start \rangle$ coffee $\langle e1end \rangle$ drinking and the incidence of $\langle e2start \rangle$ cardiovascular disease $\langle e2end \rangle$ .	Association

an, can't, have not, etc.) are usually called stop\_words. We assume that these words will reduce the model's performance in predicting classes.

The next step is to convert text into numbers, as the computer cannot process data in the text as the machines only recognize numbers. Therefore, the text shall be used as input and should be convert to numbers. Some methods can do this including Count Vectorizer, TF-IDF, Word2Vec, BERT, and ELMO, where the text will be encoded into a vector space with a fixed length. This study uses the Count Vectorizer approach for the vectorization process. When extracting and representing features from text data, this study also pays attention to n-grams. This study use CountVectorizer from sklearn as vectorizer and use n gram for character embedding algorithm (Fig. 1).

### C. Data Training and Testing

This study divides the data into two groups with a ratio of 80:20 to test the reliability of all classifiers to be used, 80% for training data and 20% for test data. In addition to this approach, this study also uses a 5-fold cross validation approach. To divide the data into training and testing, this study also considers the random sample aspect when conducting training, which consists of under sampling, over sampling and synthetic sampling.

### D. Class Imbalanced Learning

This study focuses on combine both data-level and algorithm-level approach techniques to measure performance of model through precision, recall and F1 score metrics. Various imbalanced learning techniques have been envolved in addressing the class imbalance problem. It requires either (1) reducing the bias a machine learning algorithm can impart

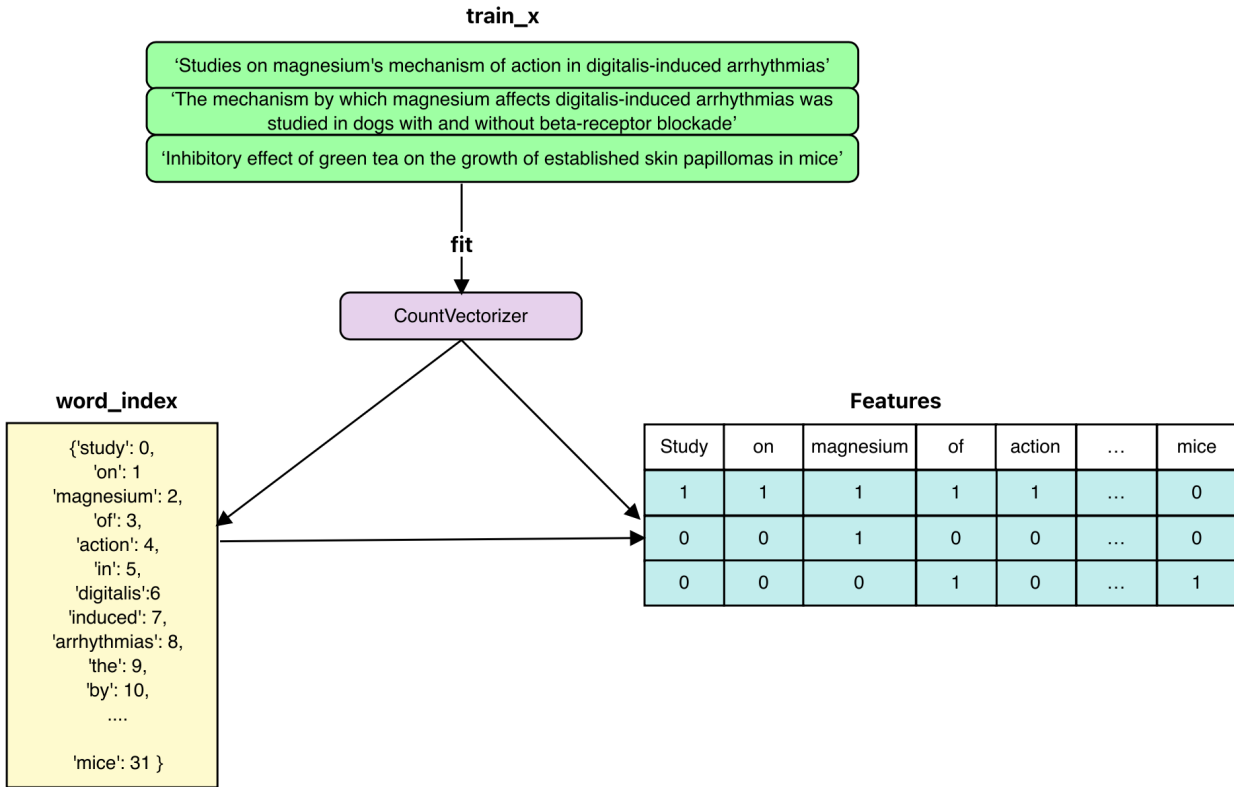


Fig. 1. Flowchart of extracting features.

to the majority class in the dataset, or (2) configuring the algorithm to be sensitive to the minority class [17]. Fig. 2 is a techniques to tackle class imbalance learning that can be classified into three main categories: (a) Data-level methods, (b) Algorithm-level methods, and (c) combination of both methods [11], [17].

In a data-level approach, researchers attempted to balance the dataset before applying traditional classification algorithms so that the majority class did not bias the results. In the algorithm-level approach, researchers worked on the internals of the algorithm and tried to remove the algorithm's sensitivity to the majority class, so that the results of the classification algorithm would not drift towards the majority class [12]. A third approach is a hybrid that combines data-level and algorithm-level approaches [18].

### E. Classifier

The classifier is a machine learning model that is used to classify sample data into predetermined classes. The classifier receives input in the form of data samples and outputs in the form of classes of appropriate method for the data samples. The classifiers can be used for a various variety of applications, such as facial recognition, speech recognition, and natural language understanding.

Classifiers can be divided into two main types, namely binary classifiers and multi-class classifiers. A binary classifier is a classifier that can only classify data samples into two classes, while a multi-class classifier is a classifier that can

classify data samples into more than two classes. Classifiers can be created using a variety of machine-learning algorithms.

Naïve Bayes Classifier, K-Nearest Neighbor, Support Vector Machine, and Random Forest are the most classifiers used in machine learning. This study uses the classifier referring to previous research [19] and adding LSTM classifier for handling multi-class classifier tasks to obtain optimal results through comparative analysis on Precision, Recall, and F1-score metrics.

1) *Multinomial Naïve Bayes*: A Multinomial Naïve Bayes (MNB) model is used to represent calculate or count rates. The additive smoothing parameter  $\alpha$  is set to 1. Prior class probabilities are learned and adjusted according to the data [20], [21]. The purpose of this method is to classify probability based on supervised machine learning over other probabilities. This study use Multinomial Naïve Bayes as a classifier to classify a document into four classes.

Multinomial Naïve Bayes computes class probabilities for a given document. A collection of classes is denoted by  $C$ ,  $N$  is the vocabulary size. Next step, MNB assigns a test document  $t$  to the class that has the highest probability  $Pr(c | t_i)$  which, using Bayes rule (Equation 1) [21]. The class prior probability  $Pr(c)$  can be estimated by dividing the number of documents belonging to class  $c$  by the total number of documents.  $Pr(t_i | c)$  is the probability of obtaining a document like  $t_i$  in class  $c$ .

$$Pr(c|t_i) = \frac{Pr(c)Pr(c|t_i)}{Pr(t_i)}, c \in C \quad (1)$$

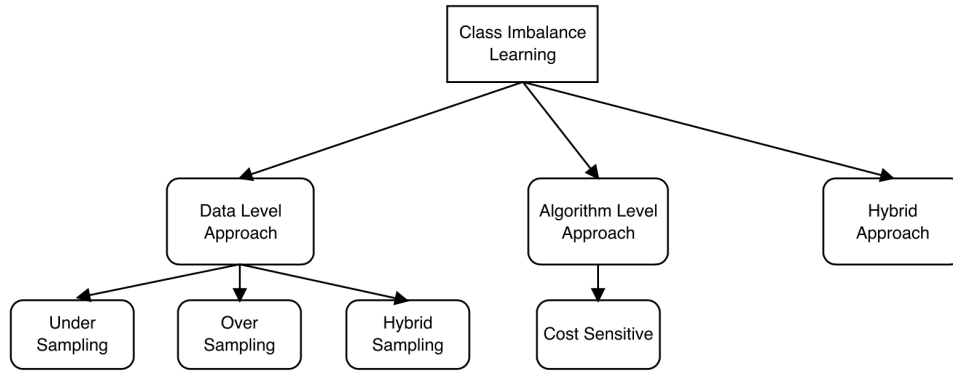


Fig. 2. Hierarchy of class imbalance learning techniques.

2) *K-Nearest Neighbours*: K-Nearest Neighbours (KNN) is a supervised classification algorithm and is considered one of the best data mining algorithms despite its simplicity. It creates a decision surface that adapts to the shape of the data distribution, resulting in high accuracy when the training set is large or representative [22]. The KNN algorithm assumes that similar things are close together. This means that similar items are placed close together determine best k-Nearest Neighbors using Grid Search.

The classification algorithm follows these steps: (1) compute the distance between a  $x_i$  instance and all instances of the training set  $T$ , (2) choose the  $k$  nearest neighbors, (3) The  $x_i$  instance is classified (labeled) with the most oftentimes class among the  $k$  nearest neighbors. It is also possible to use the neighbors distance to weight the classification decision. Characteristically in the literature are found odd values for  $k$ , normally with  $k = 5$  or  $k = 7$  [23]. An approach to determine  $k$  as a function (2) of data size  $m$ .

3) *Support Vector Machine*: Support Vector Machine (SVM) works by constructing hyperplanes in a multidimensional space that separates the different cases of class labels. SVM has two important parameters, namely  $c$  and  $\gamma$  [19]. Parameter  $c$  adds a penalty for each misclassified data point. If  $c$  is small, the penalty for misclassified points is low, so decision boundaries with large margins are chosen at the cost of more misclassifications. The gamma parameter controls the influence distance of training points. When small gammas,  $c$  affects the model in the same way, it affects linear models. Typical values for  $c$  and gamma are  $0.0001 < \gamma < 10$  and  $0.1 < c < 100$ . This study uses hyperparameter tuning for a grid search to determine the optimal  $\gamma$  and  $c$  values.

Given a training set of  $N$  data points  $\{y_k, X_k\}_{N_k = 1}$ , where  $X_k \in \mathbb{R}^n$  is the  $k$ th input pattern and  $y_k \in \mathbb{R}$  is the  $k$ th output pattern, the support vector method approach aims to building a classifier of the form (Equation 2) [24]:

$$y(x) = \text{sign} \left[ \sum_{i=0}^N \alpha_k y_k \Psi(x, x_k) + b \right] \quad (2)$$

where  $\alpha_k$  are positive real constants and  $b$  is real constant,  $\Psi(x, x_k) = x_k^T x$  for linear SVM. In the above expression,

$\Psi(x, x_k)$   $\alpha_k$ ,  $y_k$ ,  $x_k$ ,  $b$ , and  $N$  represent a kernel function [25].

4) *Random Forest*: The Random Forest (RF) algorithm is a machine learning technique that can be employed to classify text into multiple classes. The Random Forest algorithm generates numerous decision trees that employ these features to predict the class of text samples, making it a more effective algorithm for datasets with many features than other machine learning techniques. The ensemble tree-based RF classifier chooses features from the training data randomly, and it reduces the correlation between trees [3]. This study utilized value of  $n\_estimators = 100$  as input into the RF model. The value of  $n\_estimators$  get from a grid search approach for hyperparameter tuning. A grid search was applied to select the optimal  $n\_estimators$  used to classify on multi-class dataset. These parameters are applied independently and interactively, with samples randomly chosen from the training dataset to arrive at a final prediction. This study aligns with previous research by [31] that used RF as a classifier to handle unbalanced classes.

5) *Long Short-Term Memory*: In the past decade, there has been a surge in the use of deep learning techniques, which have become increasingly popular due to their ability to enhance the state-of-the-art in fields such as speech recognition and computer vision, among others [26]. In this study, the classifier was trained using the Long Short-Term Memory (LSTM) algorithm. The training dataset consists of a certain number of time series vectors, which are not specified in the given text  $\mathbb{X}_1, \mathbb{X}_2, \dots, \mathbb{X}_N$  where  $\mathbb{X}_k$  with  $k = 1, 2, \dots, N$  reflect the trajectory sequence with mathematically integrated from  $k$ th sentence and corresponding labels  $y_1, y_2, \dots, y_N$ . Equation 3, 4, 5, and 6 are computation stages for single LSTM unit.

$$Z_k = \tanh(W.[X_k^t; h_k^{t-1}; 1]) \quad (3)$$

$$Z_k^i = \delta(W^i.[X_k^t; h_k^{t-1}; 1]) \quad (4)$$

$$Z_k^f = \delta(W^f.[X_k^t; h_k^{t-1}; 1]) \quad (5)$$

$$Z_k^o = \delta(W^o.[X_k^t; h_k^{t-1}; 1]) \quad (6)$$

where tanh stands for tanh function,  $\delta$  represents sigmoid function,  $W$ ,  $W^i$ ,  $W^f$ ,  $W^o$  are row vectors which stand for the weight combined with bias parameters for LSTM cell, input gate, forget gate, and output gate, respectively.  $Z_k$  represents the output of the output of the LSTM cell for  $k$ th sequence  $Z_k^i$ ,  $Z_k^f$ ,  $Z_k^o$  represent the scalar outputs of input gate, forget gate, and output gate sequence, respectively.  $[X_k^t; h_k^{t-1}; 1]$  is a column vector combined by column vector  $X_k^t, h_k^{t-1}$  and 1 [27], [32].

6) *Class Balancing Techniques*: The class balance technique is a way to overcome the problem of imbalance class in a dataset. Class imbalance occurs when a class has a much higher number of samples than the others. This event can pose problems for machine learning, as models tend to predict which classes are more common than others. One way to balance classes is to use a sampling technique. Sampling is a technique used to take samples from a larger data set and use them to create a smaller, balanced data set.

One technique for tackling this problem is to employing multiple sampling procedures, which are classified as random and special. In the first situation, remove a fixed number of examples from the majority class (undersampling) as shown in Fig. 3; in the second, increase the number of minority class examples (oversampling) [28]. In this study, use oversampling and undersampling (Fig. 3). All sampling will be applied to all classifiers to obtain the optimal mode in carrying out multi-class classification work on imbalanced data.

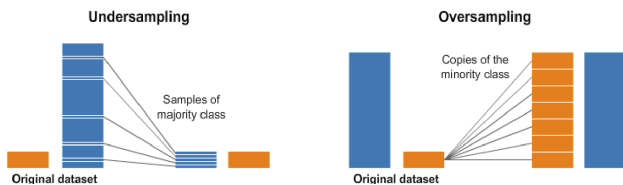


Fig. 3. Undersampling and oversampling balancing classes algorithms.

F. Text Classification Model

This study applied five different machine learning algorithms when performing multiclass text classification of plant-disease relation dataset: Multinomial Naïve Bayes, K-Nearest Neighbours, Support Vector Machine, Random Forest, and LSTM. The scikit-learn machine learning library running in the Python and programming system was used to implement these classifiers. Fig. 4 shows the steps in creating the classification model.

Sklearn.Naïve\_bayes.MultinomialNB is used to implement a Multinomial Naïve Bayes classifier, with parameter  $\alpha = 1$ . On the other hand, sklearn.neighbors.KNeighborsClassifier is used to perform K-Nearest Neighbours classifier, with parameter metric=manhattan, n\_neighbors=65, p=1, and weights=distance. Sklearn.svm.SVC was used to implement Linear SVC. For this classifier, the kernel and c parameter were chosen to be linear and 1, respectively. For kernel RBF, the SVM classifier was also run from sklearn.svm.SVC with parameters c=1, gamma=0.1, and kernel=linear. A Random Forest classifier was implemented based on the

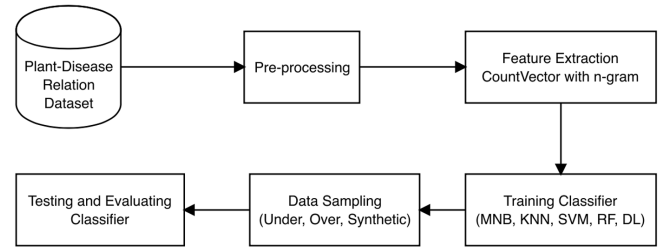


Fig. 4. Flowchart of methodology in this study.

sklearn.ensemble.RandomForestClassifier class in this case the parameters n\_estimators = 100 and max features = 'auto'.

The hyperparameters of these classifiers were determined based on using a Grid Search algorithm. Based on these hyperparameters, the classifier provided the highest accuracy. Hyperparameters were determined using 5-fold cross-validation. The hyperparameter names and values for each classifier that correspond to the top accuracy values (Table III).

TABLE III. HYPERPARAMETER TUNING

Classifier	Feature selection method	Parameters for tuning	Best value
MNB	Character based unigram, bigram with CountVector	alpha=[ 0.001, 0.1, 1, 10, 100, 1000 ]	alpha=1
KNN	Character based unigram, bigram with CountVector	n_neighbors=[1, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100] metric=[euclidean, manhattan, minkowski] p=[1, 2] weights=[uniform, distance]	n_neighbors=65 metrics=manhattan p=1 weights=distance
SVM	Character based unigram, bigram with CountVector	c=[0.1, 1, 10] gamma=[0.1, 1, 10] kernel=[linear, poly, rbf]	c=1 gamma=0.1 kernel=linier
RF	Character based unigram, bigram with CountVector	n_estimators= [100, 200, 300, 400, 500, 600, 700, 800, 900, 1000]	n_estimators=100
LSTM	Character based unigram, bigram with CountVector	num_units=[16, 32, 64, 128] dropout=[0.2, 0.3, 0.5, 0.8] epochs=[10, 20, 30, 40] batch_size=[16, 32, 64, 128]	num_units=128 dropout=0.3 epochs=40 batch_size=64

III. RESULT AND DISCUSSION

The pre-processing stage is very influential on the result of model. This study processes data only through tokenization without involving stop words. The reason for not using the stop\_word is some words that are considered meaningless play an important role in determining class. After going through the tokenization process, data increased to 25136. Apart from the pre-processing stage, each classifier's also influence the model's result. Multinomial Naïve Bayes has parameters alpha and c, K-Nearest Neighbors has parameters n\_neighbors, Random Forest has n\_estimators, and Deep Learning has parameters dropout, activation, and optimizer. Table IV shows model



evaluation in this study which involve eight scenarios. This study evaluates models from different scenarios based on precision, recall, and f1-score.

TABLE IV. MODEL DEVELOPMENT SCENARIOS

No.	Scenario	Description
1	Ratio (80:20)	Training (80) and Testing (20)
2	5-fold cross validation	dividing training and testing data which divides equally into five parts and without considering imbalanced class
3	Under-sampling + Ratio	Ratio with due regard to imbalanced learning based on under-sampling
4	Under-sampling + 5-fold cross validation	5-fold cross validation with paying attention to imbalanced learning based on under-sampling
5	Over-sampling + Ratio	Ratio taking into account imbalance learning based on oversampling
6	Oversampling + 5-fold cross validation	5-fold cross validation taking into account imbalanced learning based on over-sampling
7	SMOTE + Ratio	Ratio taking into account imbalanced learning based on SMOTE
8	SMOTE + 5-fold cross validation	5-fold cross validation with imbalanced learning based on SMOTE

Precision is a metric for evaluating machine learning models that measures the accuracy of the model's recognition of true positives out of the total positive predictions [29] (Equation 7).

$$Precision_{\mu} = \frac{\sum_{i=1}^l tp_i}{\sum_{i=1}^l (tp_i + fp_i)} \quad (7)$$

where  $\sum_{i=1}^l tp_i$  is amount of true positive in whole class, while  $\sum_{i=1}^l (tp_i + fp_i)$  is total summation of true positive and false positive.

In the context of the confusion matrix, recall is a metric used to evaluate the accuracy of a classification model in correctly identifying true positives out of the total number of positive classes in the actual data [29]. This metric provides information about the proportion of correct positive predictions and can be used to assess the quality of a classification model in minimizing the number of false negative predictions (Equation 8).

$$Recall_{\mu} = \frac{\sum_{i=1}^l tp_i}{\sum_{i=1}^l (tp_i + fn_i)} \quad (8)$$

The micro accuracy metric involves adding the correct prediction count for each class and dividing it by the total number of samples. This method assigns equal value to every sample when determining accuracy, making it an appropriate measure to use when the dataset is imbalanced, or when the number of samples for each class varies.  $\mu$  represent micro averaging (Equation 9).

$$F1score_{\mu} = \frac{(\beta^2 + 1) Precision_{\mu} Recall_{\mu}}{\beta^2 Precision_{\mu} + Recall_{\mu}} \quad (9)$$

The macro accuracy metric is determined by initially computing the accuracy for each class and then calculating the average accuracy of all the classes. This method assigns equal value to every class when determining accuracy, making

it an appropriate measure to use when the dataset is balanced, or when the number of samples for each class is more or less equal (Equation 10).

$$F1score_M = \frac{(\beta^2 + 1) Precision_M Recall_M}{\beta^2 Precision_M + Recall_M} \quad (10)$$

### A. Multinomial Naïve Bayes

The result shows that the model works very efficiently on the ratio and 5-fold cross-validation schemes. However, this does not give an overall picture of the model's performance. The performance of the model can be affected by imbalanced data, so the model tends to correctly predict the majority class and ignore the minority class. Therefore, it is necessary to perform several techniques to balance classes such as over-sampling, under-sampling, or synthetic minority oversampling techniques (SMOTE). The weighted average on Precision and Recall shows the overall model performance considering the frequency of each class with a score of 0.92, respectively.

Based on the scores obtained from all the schemes used, it can be concluded that MNB has the best performance on Ratio scheme. These results are in line with a study conducted by [20] which obtained the highest score compared to SVM, RF and KNN. The feature space used is unigram + bigram at 80% training data and 20% testing data (Table V). This achievement is optimal on unbalanced data. However, testing on balanced data through undersampling and oversampling techniques gives a low score.

The highest score is obtained through the oversampling + ratio scheme. The highest score was obtained through the oversampling + ratio scheme with a score of 0.76, while the SMOTE scheme obtained a score of 0.75. These results contrast with research conducted by [35] and [36], which obtained the highest score when using the SMOTE scheme.

TABLE V. MULTINOMIAL NAÏVE BAYES CLASSIFIER RESULTS

	Class	R	F	U+R	U+F	O+R	O+F	S+R	S+F
Precision	Assoc	0.83	0.84	0.33	0.27	0.62	0.53	0.50	0.54
	CoD	0.67	0.82	0.54	0.46	0.63	0.58	0.65	0.58
	Neg	0.77	0.94	0.59	0.70	0.83	0.79	0.83	0.78
	ToD	0.89	0.94	0.72	0.70	0.76	0.82	0.75	0.82
	macro avg	0.79	0.88	0.55	0.53	0.71	0.68	0.68	0.68
	weight avg	<b>0.80</b>	<b>0.92</b>	0.63	0.65	<b>0.77</b>	0.76	0.76	0.76
Recall	Assoc	0.71	0.76	1.00	1.00	0.71	0.68	0.71	0.62
	CoD	0.57	0.95	0.84	0.72	0.81	0.77	0.81	0.75
	Neg	0.82	0.87	0.49	0.42	0.63	0.65	0.61	0.67
	ToD	0.89	0.97	0.59	0.72	0.89	0.87	0.89	0.86
	macro avg	0.75	0.88	0.73	0.71	0.76	0.74	0.76	0.72
	weight avg	<b>0.80</b>	<b>0.92</b>	0.60	0.60	<b>0.76</b>	0.75	0.75	0.75
F1-score	Assoc	0.77	0.80	0.50	0.42	0.67	0.60	0.59	0.58
	CoD	0.62	0.88	0.66	0.57	0.71	0.66	0.72	0.65
	Neg	0.79	0.90	0.53	0.52	0.72	0.71	0.71	0.72
	ToD	0.89	0.95	0.65	0.71	0.82	0.84	0.82	0.84
	accuracy	<b>0.80</b>	<b>0.92</b>	0.60	0.60	<b>0.76</b>	0.75	0.75	0.75
	macro avg	0.77	0.88	0.59	0.55	0.73	0.70	0.71	0.70
weight avg	0.80	0.91	0.60	0.60	0.75	0.75	0.74	0.75	

- R=Ratio 80:20, F=5-fold cross validation, U=under sampling, O=over sampling, S=SMOTE, Assoc=association, CoD=cause of disease, Neg=negative, ToD=treatment of disease.

### B. K-Nearest Neighbors

K-Nearest Neighbors (KNN) is an uncomplicated and widely used classification algorithm that predicts the category

of a sample based on the category of the closest k-neighbors in the feature space. KNN operates by comparing the distance between the samples being predicted with the categories of other samples already present in the dataset. The way to determine the number of nearest neighbors is through hyperparameter tuning and the values n\_neighbors=65, metrics=manhattan, p=1, and weights=distance are obtained.

The hyperparameter results the optimal value n\_neighbors=65, metrics=manhattan, p=1, and weights=distance. The results of modeling using the KNN classifier as shown in Table VI that the data-level approach based on under sampling with the ratio had optimal performance in Precision, Recall and F1-score are 0.94 respectively. This achievement outperforms other schemes with balanced data. These results indicate that unbalanced data can be overcome by under-sampling like as previous research [22] and an 80:20 ratio approach for separating training data and test data. On the other hand, the study conducted by [20] obtained the highest score on the Recall metric when using KNN, this outperformed other classifiers such as RF, SVM and MNB.

TABLE VI. K-NEAREST NEIGHBOR CLASSIFIER RESULTS

	Class	R	F	U+R	U+F	O+R	O+F	S+R	S+F
Precision	Assoc	0.84	1.00	0.84	0.62	1.00	1.00	1.00	0.21
	CoD	0.89	0.66	0.89	0.33	0.66	0.62	0.62	0.35
	Neg	0.96	0.60	0.96	0.51	0.70	0.64	0.64	0.79
	ToD	0.95	0.79	0.95	0.62	0.71	0.76	0.76	0.82
	macro avg	0.91	0.76	0.91	0.52	0.77	0.75	0.75	0.54
	weight avg	<b>0.94</b>	0.69	<b>0.94</b>	0.52	0.71	0.69	0.69	0.72
Recall	Assoc	0.94	0.62	0.94	0.71	0.57	0.57	0.57	0.71
	CoD	0.93	0.56	0.93	0.60	0.64	0.50	0.50	0.69
	Neg	0.91	0.75	0.91	0.59	0.63	0.74	0.74	0.52
	ToD	0.98	0.65	0.98	0.28	0.83	0.69	0.69	0.67
	macro avg	0.94	0.65	0.94	0.54	0.67	0.63	0.63	0.65
	weight avg	<b>0.94</b>	0.68	<b>0.94</b>	0.48	0.70	0.68	0.68	0.61
F1-score	Assoc	0.89	0.77	0.89	0.67	0.73	0.73	0.73	0.32
	CoD	0.91	0.61	0.91	0.43	0.65	0.55	0.55	0.46
	Neg	0.93	0.67	0.93	0.55	0.66	0.68	0.68	0.63
	ToD	0.97	0.71	0.97	0.38	0.76	0.72	0.72	0.74
	accuracy	<b>0.94</b>	0.68	<b>0.94</b>	0.48	0.70	0.68	0.68	0.61
	macro avg	0.92	0.69	0.92	0.51	0.70	0.67	0.67	0.54
	weight avg	0.94	0.68	0.94	0.47	0.70	0.68	0.68	0.63

- R=Ratio 80:20, F=5-fold cross validation, U=under sampling, O=over sampling, S=SMOTE, Assoc=association, CoD=cause of disease, Neg=negative, ToD=treatment of disease.

C. Support Vector Machine

The SVM classifier performed best using oversampling and ratio schemes, based on the test results. All the evaluated metrics, achieved a score of 0.91, even when using the weighted average for unbalanced classes. The model's prediction results for all classes were evenly scored, indicating that the oversampling approach effectively addressed the problem of imbalanced data. Although the SMOTE approach was not as effective as oversampling, it still outperformed all other data-level schemes (Table VII).

As seen from the Table VIII, the highest accuracy of 0.91% was obtained when using scheme ratio using oversampling. This achievement is influenced by character level settings such as research conducted by [2]. In the research, the fourgram level character greatly influences SVM performance which is superior compared to using unigrams, bigrams, and trigrams than MNB and RF.

TABLE VII. SUPPORT VECTOR MACHINE CLASSIFIER RESULTS

	Class	R	F	U+R	U+F	O+R	O+F	S+R	S+F
Precision	Assoc	0.67	0.68	0.83	0.17	1.00	0.62	0.71	0.29
	CoD	0.75	0.70	0.88	0.57	0.88	0.67	0.85	0.58
	Neg	0.79	0.76	0.60	0.67	0.88	0.81	0.86	0.89
	ToD	0.88	0.82	0.44	0.67	0.88	0.86	0.85	0.92
	macro avg	0.77	0.74	0.69	0.52	0.91	0.74	0.82	0.65
	weight avg	0.81	0.77	0.71	0.64	<b>0.91</b>	0.80	0.82	0.80
Recall	Assoc	0.57	0.56	0.83	0.71	1.00	0.71	0.99	0.71
	CoD	0.64	0.62	0.70	0.62	0.96	0.67	0.81	0.76
	Neg	0.82	0.74	0.50	0.50	0.77	0.77	0.71	0.71
	ToD	0.90	0.88	0.67	0.70	0.93	0.89	0.80	0.84
	macro avg	0.73	0.70	0.67	0.63	0.91	0.76	0.83	0.76
	weight avg	0.81	0.78	0.68	0.60	<b>0.91</b>	0.80	0.81	0.77
F1-score	Assoc	0.62	0.61	0.83	0.27	1.00	0.67	0.83	0.42
	CoD	0.69	0.66	0.78	0.59	0.92	0.67	0.83	0.66
	Neg	0.80	0.75	0.55	0.57	0.82	0.79	0.78	0.76
	ToD	0.89	0.85	0.53	0.69	0.90	0.88	0.82	0.88
	accuracy	0.81	0.78	0.68	0.60	<b>0.91</b>	0.80	0.81	0.77
	macro avg	0.75	0.72	0.67	0.53	0.91	0.75	0.81	0.68
	weight avg	0.81	0.77	0.69	0.61	0.90	0.80	0.81	0.78

- R=Ratio 80:20, F=5-fold cross validation, U=under sampling, O=over sampling, S=SMOTE, Assoc=association, CoD=cause of disease, Neg=negative, ToD=treatment of disease.

D. Random Forest

Table VIII shows that the Random Forest classifier has good performance on imbalanced data through a 5-fold cross-validation scheme with an even score of 0.92 on Precision, Recall, and F1-score, respectively. On the other hand, this classifier can handle imbalanced data through a data-level over-sampling scheme. The difference between the macro average and the weighted average on Precision, Recall, and F1-score is only 1-2 points. It's shows that the model can work on balanced or unbalanced classes. Macro average gives the same weight to each class, regardless of the frequency of each class. Meanwhile, the weighted average gives different weights to each class depending on the frequency of each class.

Based on testing, this classifier produces an optimal model through a 5-fold cross validation scheme without sampling. If this classifier uses sampling (under and over), the model has poor performance. This is in line with research [34] which has found that the implementation of SMOTE to Random Forests has an impact on reducing model performance.

TABLE VIII. RANDOM FOREST CLASSIFIER RESULTS

	Class	R	F	U+R	U+F	O+R	O+F	S+R	S+F
Precision	Assoc	1.00	0.84	0.60	0.74	0.83	0.79	0.38	0.79
	CoD	0.75	0.82	0.57	0.75	0.71	0.73	0.58	0.73
	Neg	0.78	0.94	0.78	0.76	0.86	0.77	0.87	0.77
	ToD	0.78	0.94	0.53	0.78	0.76	0.80	0.84	0.80
	macro avg	0.82	0.88	0.62	0.76	0.79	0.77	0.67	0.77
	weight avg	0.77	<b>0.92</b>	0.65	0.77	0.80	0.78	0.80	0.78
Recall	Assoc	0.57	0.76	0.86	0.52	0.71	0.65	0.71	0.65
	CoD	0.43	0.95	0.74	0.50	0.69	0.52	0.76	0.52
	Neg	0.78	0.87	0.18	0.76	0.73	0.78	0.68	0.78
	ToD	0.93	0.97	0.96	0.90	0.93	0.89	0.90	0.89
	macro avg	0.68	0.89	0.68	0.67	0.77	0.71	0.77	0.71
	weight avg	0.77	<b>0.92</b>	0.56	0.77	0.79	0.78	0.77	0.78
F1-score	Assoc	0.73	0.80	0.71	0.61	0.77	0.71	0.50	0.71
	CoD	0.55	0.88	0.65	0.60	0.70	0.61	0.66	0.61
	Neg	0.78	0.90	0.29	0.76	0.79	0.78	0.76	0.78
	ToD	0.84	0.95	0.68	0.84	0.84	0.84	0.87	0.84
	accuracy	0.77	<b>0.92</b>	0.56	0.77	0.79	0.78	0.77	0.78
	macro avg	0.72	0.88	0.58	0.70	0.77	0.73	0.70	0.73
	weight avg	0.76	0.91	0.50	0.76	0.79	0.78	0.78	0.78

- R=Ratio 80:20, F=5-fold cross validation, U=under sampling, O=over sampling, S=SMOTE, Assoc=association, CoD=cause of disease, Neg=negative, ToD=treatment of disease.

E. Long Short-Term Memory

The LSTM classifier also shows performance that is not inferior to the previous classifier. The classifier got a score of 0.94 for precision but got a score of 0.93 for Recall and F1-score. This study highlights scores in bold text on weighted averages, where they are generally very effective when classes have unequal numbers (Table IX). This achievement is obtained through an under-sampling scheme, in which the sample was adjusted using minority data to make it balanced. Unfortunately, even though the data-level method uses under-sampling, it is only suitable through 5-fold cross-validation for the distribution of training and testing samples. The ratio approach has the worst results compared to other schemes.

The performance of this classifier pays attention to the minority class, namely the Association, which only has 34 sample data. Meanwhile, the other class was 10 multiplied that of the Association class. It is shows that this classifier is suitable for use on unbalanced data through under-sampling and 5-fold cross-validation methods. This result is different from the study conducted by [34] which found the fact that the use of SMOTE in LSTM had an impact on improving model performance.

TABLE IX. LONG SHORT-TERM MEMORY CLASSIFIER RESULTS

Table with 10 columns: Class, R, F, U+R, U+F, O+R, O+F, S+R, S+F. Rows are grouped by Precision, Recall, and F1-score, each with sub-rows for Assoc, CoD, Neg, ToD, macro avg, and weight avg.

R=Ratio 80:20, F=5-fold cross validation, U=under sampling, O=over sampling, S=SMOTE, Assoc=association, CoD=cause of disease, Neg=negative, ToD=treatment of disease.

IV. CONCLUSION AND FUTURE WORK

The purpose of comparative analysis is to understand the differences and similarities between the objects being compared and to evaluate the advantages and disadvantages of each object. This study compares Precision (P), Recall (R), and F1-score (F1) metrics from various algorithms to produce an optimal model. Because the data is unbalanced, a sampling method is needed which involves under sampling, over sampling, and synthetic sampling. Each classifier is tested on eight schemes consisting of: R, F, U+R, U+F, O+R, O+F, S+R, and S+F. In addition consider to the number of balanced classes, the scheme also aims to test the performance of models with unbalanced data. This aims to find out whether the application of sampling as a mandatory thing is used or not. Test results on five classifiers through eight schemes on

imbalance data produce varying P, R, and F1 metrics. However, the main goal is to find the most optimal model. P and R values are very important when the data is balanced, meaning that the model can predict classes with high accuracy and is able to identify most of the true class samples. On the other hand, if the data is unbalanced, P and R are not sufficient to evaluate the performance of the classification model as a whole. To evaluate the performance of the classification model on unbalanced data, F1-score is the most suitable metric. The F1-score measures of the harmonic average of the P and R scores. This study still requires improvisation and is still very much open for further study. In the future, this study will continue to classify through various approaches by considering the semantics of each word.

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# Multi-objective Task Scheduling Optimization Based on Improved Bat Algorithm in Cloud Computing Environment

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**Abstract**—In cloud computing environments, task completion time and virtual machine load balance are two critical issues that need to be addressed. To solve these problems, this paper proposes a Multi-objective Optimization Mutate Discrete Bat Algorithm (MOMDBA) that improves upon the traditional Bat algorithm (BA). The MOMDBA algorithm introduces a mutation factor and mutation inertia weight during the global optimization process to enhance the algorithm's global search ability and convergence speed. Additionally, the local optimization logic is optimized according to the characteristics of cloud computing task scenarios to improve the degree of load balancing of virtual machines. Simulation experiments were conducted using CloudSim to evaluate the algorithm's performance, and the results were compared with other scheduling algorithms. The results of our experiments indicate that when the cost difference between algorithms is within 4.47%, MOMDBA can significantly outperform other methods. Specifically, compared to PSO, GA, and LBACO, our algorithm reduces makespan by 56.26%, 59.87%, and 25.26%, respectively, while also increasing the degree of load balancing by 93.87%, 75.92%, and 39.13%, respectively. These findings demonstrate the superior performance of MOMDBA in optimizing task scheduling and load balancing.

**Keywords**—Cloud computing; task scheduling; optimization; bat algorithm; meta-heuristics

## I. INTRODUCTION

Cloud computing has become a ubiquitous infrastructure in various fields, providing users with convenient access to computing resources and services through the internet [1]. Task scheduling is a crucial problem in cloud computing that aims to allocate multiple tasks to available computing resources to optimize system throughput, response time, resource utilization, and other performance metrics. However, as cloud computing systems become increasingly complex and diverse, task scheduling problems often involve multiple conflicting optimization objectives, such as reducing system energy consumption and costs, improving task completion rates and reliability. Traditional single-objective optimization algorithms are often ineffective in solving these multi-objective optimization problems because they focus on a single objective and ignore the impact of other objectives.

To address this challenge, it is crucial to explore multi-objective optimization algorithms for cloud computing task scheduling. Multi-objective optimization algorithms can simultaneously optimize multiple objective functions and find a set of optimal solutions by balancing and trading off different objectives. These algorithms can provide more comprehensive

and accurate decision support, helping cloud computing systems achieve more efficient, reliable, and sustainable operation. Additionally, they can facilitate the comprehensive evaluation and analysis of system performance, providing a more comprehensive reference for optimizing the overall performance of cloud computing systems.

The task scheduling problem is a combinatorial optimization problem that is typically considered as NP-hard [2]. Therefore, it is necessary to find an effective optimization algorithm to solve it. Traditional static task scheduling algorithms, such as Min-Min algorithm [3], Max-Min algorithm [4], and Round-Robin algorithm [5], have limitations in handling large-scale scheduling problems. Meta-heuristic algorithms [6], on the other hand, have demonstrated good robustness and feasibility in task scheduling optimization. Researchers have explored various meta-heuristic algorithms, including genetic algorithm (GA) [7], ant colony algorithm (ACO) [8], bat algorithm (BA) [9], and particle swarm optimization (PSO) algorithm [10], among others, achieving promising results [11–15].

Compared to other metaheuristic algorithms, the bat algorithm has been shown to possess strong global search capability, fast convergence speed, high search efficiency, and simple parameter settings. However, there has been limited research on the use of BA in cloud computing task scheduling, particularly with regard to multi-objective optimization. This research can effectively fill this research gap and contribute to the advancement of knowledge in this field.

Bat algorithm is a heuristic search algorithm proposed by Professor Yang in 2010[16], which is based on swarm intelligence. It is an effective method for searching the global optimal solution. The algorithm simulates the behavior of bats in nature, using a type of sonar to detect prey and avoid obstacles. This means that the bats use ultrasound to simulate the most basic detection and positioning capabilities of obstacles or prey and associate it with the optimization target function.

The bionic principle of the bat algorithm maps individual bats with the population number to NP feasible solutions in the d-dimensional problem space. The optimization process and search are simulated as the movement process of the individual bats and the search for prey. The fitness function value of the problem being solved is used to measure the quality of the position of the bat. The individual survival of the fittest process is compared to the iterative process of replacing the poor feasible solution with the good feasible solution in the

optimization and search process.

The optimization principle of the bat algorithm shows that the algorithm's optimization ability primarily depends on the interaction and influence between bat individuals. However, the individuals themselves lack a mutation mechanism, which makes it difficult for them to escape from a local extreme value once they are constrained by it. Moreover, during the evolution process, super bats in a population may quickly attract other individuals to gather around them, resulting in a substantial decline in population diversity. As bat individuals get closer and closer to the optimal individuals in the population, the convergence rate is greatly reduced, or even evolutionary stagnation occurs. This causes the population to lose the ability to further evolve.

In the context of cloud computing task scheduling, this paper proposes an improved bat algorithm. By considering makespan, degree of load balancing, and cost[6] as optimization objectives, a multi-objective optimization mutation discrete bat algorithm (MOMDBA) is proposed. Building on the standard bat algorithm, the population position and velocity are discretized, and the mutation factor and mutation inertia weight are introduced to effectively balance the global search and local search ability of the algorithm, resulting in faster convergence rates. Additionally, the local optimization logic is optimized to obtain better load balancing performance based on the characteristics of the task scheduling problem.

The rest of the paper is organized as follows. Section II provides a literature review of previous works. In Section III, we model the task scheduling problem and optimization targets in the cloud computing environment. Sections IV and V introduce the bat algorithm and the proposed improved algorithm. Section VI presents the experimental results. Finally, Section VII concludes the paper.

The symbols utilized in this paper are presented in the table (Table I) below, along with their corresponding definitions.

TABLE I. DEFINITION OF SYMBOLS USED

Symbol	Definition
$Exetime_{ij}$	The execution time of the $i^{th}$ task ( $T_i$ ) executed on the $j^{th}$ VM ( $VM_j$ )
$length_i$	The length of the $i^{th}$ task
$size_i$	The size of the $i^{th}$ task
$mips_j$	Processing capacity of the $j^{th}$ VM
$bw_j$	Bandwidth of the $j^{th}$ VM
$E_{VM_j}$	The total execution time of $VM_j$
$D$	The degree of load balancing
$f$	Fitness function
$x_i^t$	The position of the $i^{th}$ bat at time $t$
$v_i^t$	The speed of the $i^{th}$ bat at time $t$
$p_i$	Mutation factor
$\omega$	Mutation inertia weight

## II. RELATED WORK

Chen et al.[17] proposed an advanced approach called Improved WOA for Cloud task scheduling (IWC). They first

mapped the task scheduling scheme to the whale foraging model to obtain an approximately optimal solution. Then, IWC was used to further improve the optimal solution search capability. The experiments demonstrate that, compared to other meta-heuristic algorithms, the proposed method has a better convergence speed and accuracy in searching for the optimal task scheduling plans.

Natesan et al.[18] proposed a modified mean grey wolf optimization algorithm that uses a variant algorithm to increase the accuracy and performance of the GWO[19]. In the proposed method, the encircling equation and hunting equation were modified to improve the efficiency of the motion, and a suitable path for each wolf was present in the searching area. The modifications to the GWO algorithm led to improved convergence speed and accuracy in solving the task scheduling problem in cloud computing.

Jacob et al.[20] combined two optimization algorithms, Cuckoo Search and Particle Swarm Optimization, to reduce the makespan, cost, and deadline violation rate. The newly proposed hybrid algorithm is called CPSO. From the simulation results, the proposed method outperforms PBACO, ACO, MIN-MIN, and FCFS in terms of minimizing the makespan, cost, and deadline violation rate.

Jing et al.[21] proposed a QoS-aware cloud task scheduling algorithm called QoS-DPSO, which aims to satisfy the QoS requirements in cloud computing systems. They took into account the user's preference for QoS requirements and considered enough QoS parameters. The proposed method obtained superior performance by incorporating QoS requirements into the task scheduling process.

Kumar et al.[22] proposed a hybrid multi-objective optimization algorithm called HGA-ACO. They combined Ant Colony Optimization (ACO) algorithm with the Genetic algorithm (GA) to obtain better performance in task allocation. ACO is used to assist GA in avoiding local optimal solutions, while GA is used to enhance the ACO solutions. The proposed hybrid algorithm exhibits better performance in terms of task allocation compared to other existing algorithms.

Hamad et al.[23] proposed a Genetic-Based task scheduling algorithm to minimize the completion time and cost of tasks, and to maximize resource utilization. According to the experiments, the completion time and cost for the proposed method were reduced by 41.83% and 3.6%, respectively, compared to the standard GA. Additionally, the resource utilization was improved by 47%. The proposed algorithm shows potential for improving the efficiency of task scheduling in cloud computing systems.

Wei et al.[24] proposed an improved ant colony algorithm to solve the problem of unbalanced task scheduling load and low reliability in cloud computing environments. They improved the pheromone update and pheromone volatilization methods for the ant colony algorithm to speed up the convergence speed and introduced the load weight coefficient of VM in the update process of local pheromone. Experimental results verify the feasibility of the proposed method, which reduces the task scheduling completion time and convergence time while ensuring load balancing. The proposed method shows potential for improving the performance of task scheduling in cloud computing systems.



From previous studies, it can be concluded that the improvement of meta-heuristic algorithms can be generally divided into two types: one is to improve on the basis of classical algorithms, and the other is to combine two algorithms to form a new algorithm. The proposed method belongs to the first type, which is based on the bat algorithm and finds the optimal task scheduling scheme by mutation while randomly initializing the bat population position. Additionally, the local optimization logic of the bat algorithm is optimized to improve the algorithm's load balancing performance.

### III. RESOURCE SCHEDULING MODEL IN CLOUD ENVIRONMENT

The resource scheduling model in the cloud environment is shown in Fig. 1. In this model, resource scheduling is divided into two levels. The first level is task to virtual machine scheduling, and the second level is virtual machine to host scheduling, which assigns virtual machines to different physical hosts in the data center. This paper mainly focuses on the task scheduling process at the first level. In the task scheduling process, the scheduling algorithm first segments the tasks submitted by users, which is a complicated process in actual operation. For the convenience of research, this process is idealized in this paper, where tasks are assumed to be independent of each other. Tasks are executed in no particular sequence, and cannot be interrupted or migrated. The computing capacity of all computing resources is known. In this paper, makespan, degree of load balancing, and cost are taken as optimization objectives of the algorithm.

#### A. Makespan

Makespan defines the total time required from submitting a task to the completion of the task by the user[25].

With  $m$  tasks,  $Task = \{T_1, T_2, \dots, T_m\}$  and  $n$  VMs,  $VM = \{VM_1, VM_2, \dots, VM_n\}$  where  $m > n$ , assuming that a subtask can run on only one VM, the mapping between a subtask and a VM is by  $TV_{map}$ .

$$TV_{map} = \begin{Bmatrix} T_1V_1 & T_1V_2 & \dots & T_1V_n \\ T_2V_1 & T_2V_2 & \dots & T_2V_n \\ \vdots & \vdots & & \vdots \\ T_mV_1 & T_mV_2 & \dots & T_mV_n \end{Bmatrix} \quad (1)$$

The execution time of the  $i^{th}$  task ( $T_i$ ) executed on the  $j^{th}$  VM ( $VM_j$ ) is denoted by  $Exetime_{ij}$ , and can be calculated as follows:

$$Exetime_{ij} = \frac{length_i}{mips_j} + \frac{size_i}{bw_j} \quad (2)$$

where  $length_i$  and  $size_i$  represents the length and the size of the  $i^{th}$  task, and  $mips_j$  and  $bw_j$  refer to the processing capacity and bandwidth of the  $j^{th}$  VM. If  $E_{VM_j}$  is the total execution time of  $VM_j$ , then:

$$E_{VM_j} = \sum_{i \in I} Exetime_{ij} \quad (3)$$

where  $I$  is the set of subtasks executed on  $VM_j$ . Then, the makespan ( $E$ ) is defined as the maximum total execution time among all VMs:

$$E = \max \{E_{VM_1}, E_{VM_2}, \dots, E_{VM_n}\} \quad (4)$$

Therefore, one goal of the task scheduling problem is to minimize the makespan, which represents the total time required for all tasks to complete their execution.

#### B. Degree of Load Balancing

The degree of load balancing is an essential indicator that describes the current working status of VMs in a cloud computing system. It measures the degree to which the available resources of VMs are utilized. A higher degree of load balancing indicates that the resources of VMs are fully utilized, and the workload is distributed equally among all VMs. In contrast, a lower degree of load balancing indicates that some VMs are overloaded, while others are underutilized. Therefore, achieving a high degree of load balancing is crucial for enhancing the efficiency and performance of cloud computing systems.

In a task scheduling scheme, the execution time of  $VM_j$  is denoted by  $E_{VM_j}$ , and the maximum execution time of all VMs is denoted by  $E_{VM_{max}}$ .

The degree of load balancing in this task allocation scheme can be expressed as follows:

$$D = \frac{1}{n} \sum_{j=1}^n \frac{E_{VM_j}}{E_{VM_{max}}} \quad (5)$$

This equation represents the average ratio of the execution time of each VM to the maximum execution time among all VMs. A higher value of the degree of load balancing indicates that the workload is evenly distributed among all VMs and that the available resources are fully utilized. Therefore, one goal of task scheduling is to maximize the degree of load balancing, which ultimately improves the efficiency and performance of the cloud computing system.

#### C. Cost

Cost is the sum of the costs used by VMs to execute tasks in a task scheduling scheme. It can be calculated as follows:

$$Cost = \sum_{j=1}^n E_{VM_j} C_j \quad (6)$$

where  $E_{VM_j}$  is the total execution time of  $VM_j$  and  $C_j$  is the cost per second of  $VM_j$ . This equation represents the total cost incurred by all VMs in the task scheduling scheme. The cost per second of each VM is determined by various factors, such as the processing power, memory capacity, and network bandwidth. Therefore, minimizing the cost is also an important objective of task scheduling, as it leads to the efficient utilization of resources and reduces the overall cost of the cloud computing system.

#### D. Multiobjective Fitness Function

In this paper, the linear weighting method is used to transform the multi-objective optimization problem into a single

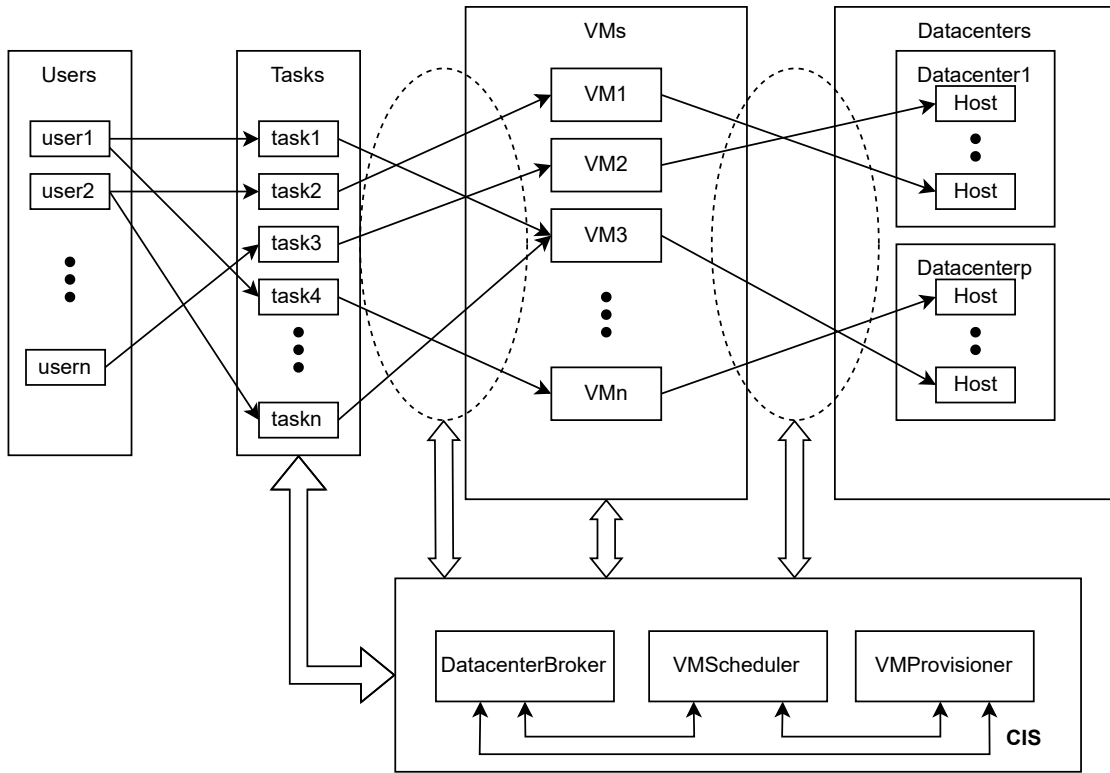


Fig. 1. Task schedule model in cloud environment.

objective optimization problem. Since the different optimization objectives have different dimensions, it is necessary to normalize them. The normalization process is shown below:

$$T_s = \frac{E_s}{m} \quad (7)$$

$$f_T = \frac{T_s - T_{s,min}}{T_{s,max} - T_{s,min}} \quad (8)$$

$$C_s = \frac{Cost_s}{nE_sD_s} \quad (9)$$

$$f_C = \frac{C_s - C_{s,min}}{C_{s,max} - C_{s,min}} \quad (10)$$

Here,  $f_T$  represents the normalized task execution time indicator, where  $E_s$  is the maximum execution time using the current task scheduling scheme,  $T_s$  represents the average execution time of one task.  $f_C$  represents the normalized task cost indicator, where  $D_s$  is the degree of load balancing using the current task scheduling scheme,  $Cost_s$  is the cost using the current task scheduling scheme, and  $C_s$  is the average cost per second per virtual machine.

The fitness function used in this paper is defined as follows:

$$f = \alpha f_T + \beta f_C \quad (11)$$

where  $\alpha \in [0, 1]$ ,  $\beta \in [0, 1]$ , and  $\alpha + \beta = 1$ . The optimization objective of this paper is to minimize the fitness function, which is a linear combination of the normalized task execution time indicator and the normalized task cost indicator. The weights  $\alpha$  and  $\beta$  can be adjusted to give different importance

to the two objectives based on the requirements of the cloud computing system.

Overall, the goal of the task scheduling problem is to find the optimal task allocation scheme that minimizes the makespan, maximizes the degree of load balancing, and minimizes the cost of the system. By transforming the multi-objective optimization problem into a single objective optimization problem and using the fitness function, this paper provides a framework for achieving these goals through task scheduling.

#### IV. STANDARD BAT ALGORITHM

The bat algorithm is a swarm intelligence optimization algorithm that mimics the echolocation behavior of bats in nature to find the optimal solution in a given search space. The optimization process is completed through a series of iterations, where the positions of the bats in the population are updated to improve the quality of the candidate solutions.

In the bat algorithm, each bat is represented by a position vector in a  $d$ -dimensional search space, and is randomly initialized with an initial position and velocity. At each iteration, the bats adjust their positions based on their current location and the global best solution found so far. The update formula for the position and velocity of each bat is:

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (12)$$

$$v_i^{t+1} = v_i^t + (x_i^t - x^*)f_i \quad (13)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (14)$$

where  $\beta$  is a random number between 0 and 1, and  $x^*$  is the current optimal population solution.

The bat algorithm also includes a local search mechanism to promote exploration of the search space. In the local search, each bat generates a new position by randomly walking around the current global best solution. The new position is calculated using the formula:

$$x_{new} = x_{old} + \delta A^t \quad (15)$$

where  $x_{old}$  is the current global best solution,  $x_{new}$  is the new local solution, and  $\delta$  is a randomly generated  $d$ -dimensional vector in the range  $[-1, 1]$ .  $A^t$  represents the current average pulse loudness of the entire population.

The bat algorithm also introduces randomness in the search process by allowing each bat to choose between a global search and a local search with a certain probability. The probability of choosing a global search is controlled by the parameter  $r_i$ , which is initialized to a small value and gradually increases during the search process. If a bat generates a random number  $R$  greater than  $r_i$ , it performs a local search near the global best solution, and if  $R$  is less than  $r_i$ , it performs a global search.

Finally, the bat algorithm updates the pulse loudness and pulse rate of each bat based on its performance in the search process. If a bat finds a better solution, its pulse loudness decreases, and its pulse rate increases, which increases the bat's ability to exploit the promising regions of the search space. The updated pulse loudness and pulse rate are then used in the next iteration to adjust the frequency and loudness of the bat's pulse. The update formula for the pulse loudness and pulse rate is:

$$A_i^{t+1} = \alpha A_i^t \quad (16)$$

$$r_i^{t+1} = r_i^0 (1 - \exp(-\gamma t)) \quad (17)$$

where  $\alpha$  and  $\gamma$  are constants with  $0 < \alpha < 1$  and  $\gamma > 0$ . The parameter  $A_i$  represents the pulse loudness of the  $i$ th bat, and  $r_i$  represents the pulse rate. The pulse loudness is decreased by multiplying it with the constant  $\alpha$  when a better solution is found, and the pulse rate is updated based on the current iteration number  $t$  using the formula given in Eq. (17).

In summary, the bat algorithm is a powerful optimization algorithm that combines global and local search strategies to efficiently explore the search space and find the optimal solution. The algorithm has been successfully applied to a wide range of optimization problems in various fields, including engineering, finance, and computer science. Its effectiveness and robustness make it a popular choice among researchers and practitioners in optimization and swarm intelligence.

## V. MOMDBA-MULTI-OBJECTIVE MUTATED DISCRETE BAT ALGORITHM

Similar to other meta-heuristic algorithms, bat algorithm also has the problem that it is easy to fall into local optimization and the global search ability is insufficient.

According to the characteristics of task scheduling problem, this paper introduces mutation factor, mutation inertia

weight and optimization of local optimization logic to optimize the standard bat algorithm and improve the algorithm performance.

### A. Discretization Coding

The MOMDBA algorithm uses the position of each bat to represent a feasible task scheduling scheme, which is a viable solution to the optimization objective. It assumes that the number of available virtual machines in the cloud platform is fixed, and the number of cloud tasks that need to be processed is constant. Therefore, the position of the  $i^{th}$  bat at time  $t$  can be expressed as an  $m$ -dimensional vector  $x_i^t = (VMtask_1, VMtask_2, \dots, VMtask_m)$ , where  $VMtask_i$  indicates the virtual machine that executes the  $i^{th}$  task.

The speed of each bat  $v_i = (v_{i1}, v_{i2}, \dots, v_{im})$  represents the change in the virtual machines assigned to each cloud task from the current schedule scheme to the new schedule scheme. The dimension of  $v_i^t$  is the same as the dimension of the position, and its update formula is given by:

$$v_i^t = f(x_i^t - x^*) \quad (18)$$

where  $x^*$  is the best solution found so far, and  $f(v_{ik})$  is a function that determines the direction of change for the  $k^{th}$  dimension of the speed. Specifically,  $f(v_{ik})$  is defined as follows:

$$f(v_{ik}) = \begin{cases} 1 & \text{if } v_{ik} > 0 \\ 0 & \text{if } v_{ik} = 0 \end{cases} \quad (19)$$

Here,  $v_{ik}$  refers to the speed of the bat in the  $k^{th}$  dimension, where  $k \in (0, m]$ .

### B. Mutation Factor and Mutation Inertia Weight

The standard bat algorithm updates the bat's optimization direction based on the current bat position and the current optimal solution. However, this approach is not suitable for the task scheduling problem because there is no correlation between different virtual machines. To address this issue, this paper introduces a mutation method to optimize the task scheduling scheme, which includes a mutation factor  $p_i = (p_{i1}, p_{i2}, \dots, p_{im})$  and a mutation inertia weight  $\omega$ .

In the proposed method, the bat's position is updated randomly, and the probability of position update is determined by the mutation factor and the speed of the bat. Specifically, the probability of selecting a random virtual machine for the task is given by:

$$P(x_{ik}^{t+1} = \text{Random}) = p_{ik} \quad (20)$$

The probability of selecting the current optimal solution for the task is given by:

$$P(x_{ik}^{t+1} = x_k^*) = \theta v_{ik}^t p_{ik} \quad (21)$$

And the probability of keeping the current position is given by:

$$P(x_{ik}^{t+1} = x_{ik}^t) = 1 - p_{ik} - \theta v_{ik}^t p_{ik} \quad (22)$$

Here,  $x_{ik}^t$  refers to the position of the bat in the  $k^{th}$  dimension at time  $t$ ,  $k \in (0, m]$ , and  $p_{ik}$  is the mutation factor of the  $k^{th}$  dimension, with values in the range of  $(0, 0.5)$ .  $\theta$  is a constant and  $0 < \theta < 1$ .

To balance the local and global optimization ability of the bats, the mutation probability is adjusted after a bat finds a better solution, using the mutation inertia weight  $\omega$ . The mutation factor  $p_{ik}$  is updated as follows:

$$\begin{cases} p_{ik}^{t+1} = p_{ik}^t \omega & \text{if } x_{ik}^{t+1} = x_{ik}^t \\ p_{ik}^{t+1} = p_{ik}^t & \text{if } x_{ik}^{t+1} \neq x_{ik}^t \end{cases} \quad (23)$$

The mutation inertia weight  $\omega$  is a function of time, and its value decreases as the number of iterations increases, helping the algorithm to converge quickly. Specifically,  $\omega$  is given by:

$$\omega = \omega^0 (1 - \exp(-\lambda t)) \quad (24)$$

Here,  $\lambda$  is a constant parameter with values in the range of  $(0, 1)$ ,  $\omega^0$  is the initial value of the mutation inertia weight, and  $\omega$  is constrained to the range of  $(0, 1)$ . When the number of iterations is small, the mutation probability of bats is large. In this case, the global search ability of the algorithm is strong, which is conducive to jumping out of the local optimal solution and obtaining the global optimal solution. When the number of iterations is small, the mutation probability of the bats is high, which enhances the global search ability of the algorithm and helps it to jump out of local optimal solutions. When a bat finds a better solution and the new solution in the  $k^{th}$  dimension is the same as the old solution, the mutation factor  $p_{ik}$  is updated based on the mutation inertia weight  $\omega$ . However, if the new solution is different from the old solution, the mutation factor remains unchanged. By adjusting the mutation probability using the mutation inertia weight, the proposed method can balance the exploration and exploitation phases and improve the overall performance of the bat algorithm for task scheduling problems.

### C. Local Optimization Logic

In the proposed method, the execution time of each virtual machine (VM) is denoted by  $T = \{E_{VM_1}, E_{VM_2}, \dots, E_{VM_n}\}$ , where  $E_{VM_{max}}$  and  $E_{VM_{min}}$  are the maximum and minimum execution times, respectively. Let  $Exetime_{kmax}$  and  $Exetime_{kmin}$  be the execution times of the cloud task  $k$  on  $VM_{max}$  and  $VM_{min}$ , respectively. During local optimization, the following update rules are applied:

$$E_{VM_{max}}^{t+1} = E_{VM_{max}}^t - Exetime_{kmax} \quad (25)$$

$$E_{VM_{min}}^{t+1} = E_{VM_{min}}^t + Exetime_{kmin} \quad (26)$$

$$x_{newk} = VM_{min} \quad (27)$$

Here,  $x_{newk}$  is the  $k^{th}$  dimension position of the current global optimal solution. The goal of local optimization is to improve the degree of load balancing by reassigning the task  $k$  from  $VM_{max}$  to  $VM_{min}$ .

Before updating the bat population, a random number in the range of  $[0, 1]$  is generated. If the random number  $R$  is greater than the pulse emission rate  $r_i$  of the  $i^{th}$  bat, then

local optimization is performed; otherwise, global optimization is performed. The pulse emission rate of each bat is updated using the same formula (Eq.(17)) as in the standard bat algorithm.

### D. The steps of MOMDBA

The proposed method consists of the following steps:

- **Step 1:** Initialize the bat population by randomly scheduling  $m$  tasks to  $n$  virtual machines. The dimension of the bat location  $x_i$  is the number of cloud tasks  $m$ .
- **Step 2:** Generate a random number  $R$ . If  $R < r_i$ , go to Step 3; otherwise, go to Step 4.
- **Step 3:** Update the bat positions according to mutation factors. The position of each bat is updated based on the current position, the current optimal solution, and the mutation probability. If a better solution is found, update  $r_i$  and  $p_i$ ; otherwise, keep them unchanged. Go to Step 5.
- **Step 4:** Update the bat locations according to a local optimization logic. Calculate the execution times of the tasks on each virtual machine and reassign the tasks to achieve load balancing. Go to Step 5.
- **Step 5:** Check if a better solution is found. If yes, update  $r_i$  and  $p_i$  based on the current mutation probability and the mutation inertia weight. If no, keep  $r_i$  and  $p_i$  unchanged. Go to Step 6.
- **Step 6:** If the current iteration times are less than the maximum number of iterations, go back to Step 1 and repeat the process; otherwise, go to Step 7.
- **Step 7:** Output the optimal bat location as the best task schedule scheme.

## VI. EXPERIMENT AND RESULT

To verify the effectiveness of MOMDBA in solving cloud computing task scheduling problems, the proposed method is simulated using CloudSim and compared with other existing algorithms, including PSO, GA, and LBACO[26], using the publicly available GoCJ dataset proposed by Hussain et al.[27]. The performance of the proposed algorithm is evaluated based on four criteria: fitness function value, makespan, degree of load balancing, and cost.

The GoCJ dataset consists of 19 text files containing task lengths ranging from 100 to 1000. Each line in the text file corresponds to the task length of a task, and the tasks are classified into five types based on their length: small, medium, large, extra-large, and huge. The distribution of each task in the dataset is shown in Table II.

The basic steps of CloudSim simulation are as follows:

- **Step 1:** Initialize CloudSim.
- **Step 2:** Instantiate the DataCenter, DataCenterBroker, and virtual machines.
- **Step 3:** Create a list of virtual machines and register them with the DataCenter. Then, submit the list of

virtual machines to the DataCenterBroker for further management and scheduling.

- **Step 4:** Generate a set of tasks and assign them to the DataCenterBroker for further processing. The DataCenterBroker is responsible for managing and scheduling the tasks on available virtual machines in the data center.
- **Step 5:** Start the simulation.
- **Step 6:** Analyzing the simulation results.

TABLE II. JOB TYPES OF GoCJ

Job type	MI range	Distribution
Small	15,000 - 55,000	20%
Medium	59,000-99,000	40%
Large	101,000-135,000	30%
Extra large	150,000-337,000	6%
Huge	525,000-900,000	4%

### A. Experimental Environment Setting

The experiments in this paper were conducted on a personal computer environment. The detailed configurations of the software and hardware environments are shown in Table III.

The number of virtual machines used in the experiments was set to 15, divided into three groups of low, medium, and high performance, with five virtual machines in each group. The information of the virtual machines is shown in Table IV. The parameter settings of each algorithm used in the experiments are shown in Table V.

TABLE III. SIMULATION ENVIRONMENT

Parameter	Configuration
CPU	AMD Ryzen5 5600X
Memory	16GB
Hard disk	1TB
IDE	IntelliJ IDEA 2022.03

TABLE IV. VIRTUAL MACHINE INFORMATION

VM group	VM ID	VM performance/MIPS	Cost per sec
low performance	0-4	800-1200	0.02
medium performance	5-9	1800-2200	0.06
high performance	10-14	3800-4200	0.13

TABLE V. PARAMETERS SETTING

Algorithm	Parameter	Value
MOMDBA	Population size	50
	Maximum iterations	200
	$\lambda$	0.01
	$\theta$	0.8
	$\gamma$	0.08
	$r^0$	0.8
PSO	$\omega^0$	0.7
	Population size	50
	Maximum iterations	200
	$\omega$	0.9
	$c_1$	2.0
GA	$c_2$	2.0
	Population size	50
	Maximum iterations	200
	$p_c$	0.8
LBACO	$p_m$	0.01
	Population size	50
	Maximum iterations	200
	$\rho$	0.5
	$\alpha$	2.0
	$\beta$	1.0
	$Q$	100

### B. Result

In order to evaluate the performance of MOMDBA, algorithm simulation was conducted on the GoCj data set, with the number of cloud tasks ranging from 100 to 500, and analyzed from four aspects of fitness, makespan, degree of load balancing and cost, and compared with other meta-heuristic algorithms.

The fitness function used in the experiments is defined as Eq. (11), which represents the comprehensive evaluation index of multi-objective optimization. The lower the fitness value, the better the solution found by the algorithm. Fig. 2 shows that the fitness value of MOMDBA is significantly lower than that of other meta-heuristic algorithms under different circumstances.

Table VI shows a reduction in fitness using GoCJ dataset. The data show that MOMDBA is up to 80% less fitness than PSO, 84% less fitness than GA, and 70% less fitness than LBACO. The introduction of mutation factor and mutation inertia weight enables the proposed algorithm to jump out of local optimal solutions and obtain better optimization capability.

Fig. 3 and Fig. 4 show the makespan and cost of each algorithm under different number of cloud tasks, and the specific values are detailed in Tables VII and VIII. It can be seen that with the increase in the number of cloud tasks, the makespan and cost of the algorithms also increase gradually.

Regarding makespan, MOMDBA achieves significantly less makespan than the other algorithms, with a maximum reduction of 56.26% compared to PSO, 59.87% compared to GA, and 25.26% compared to LBACO. This indicates

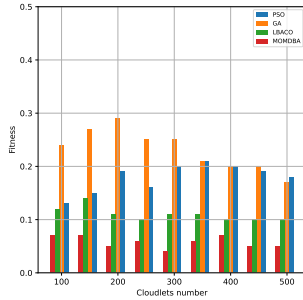


Fig. 2. Fitness based experimental results.

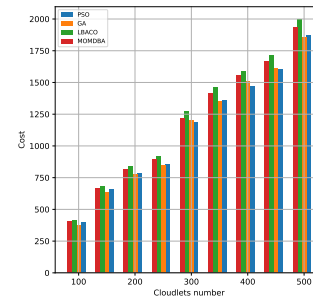


Fig. 4. Cost based experimental results.

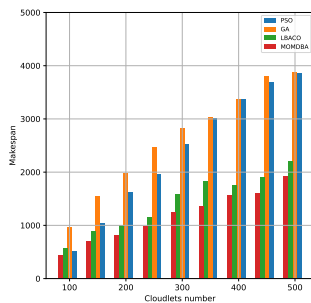


Fig. 3. Makespan based experimental results.

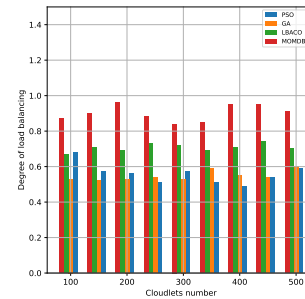


Fig. 5. Degree of load balancing based experimental results.

that MOMDBA can significantly reduce makespan, which can improve the efficiency of the cloud platform and can handle more tasks in less time.

For cost, there is no significant difference between MOMDBA and the other algorithms. Except for reducing the cost of LBACO by a maximum of 4.47%, MOMDBA is 8% higher than GA and 5.52% higher than PSO, respectively. This is acceptable compared to the significant reductions made by makespan.

Regarding the degree of load balancing. Fig. 5 and Table IX show how MOMDBA differs from other algorithms. According to the data in the table, the degree of load balancing of MOMDBA is up to 93.87% higher than PSO, 75.92% higher than GA, and 39.13% higher than LBACO. MOMDBA has excellent load balancing, which benefits from the improved local optimization logic. It allows MOMDBA to maintain a high degree of load balancing even when facing a large number of cloud tasks.

In summary, MOMDBA has stronger optimization performance, less makespan, and higher degree of load balancing than other meta-heuristic algorithms. The introduction of mutation factor and mutation inertia weight enables MOMDBA to achieve better optimization capabilities by jumping out of local optimal solutions. These results demonstrate the effectiveness of the proposed algorithm in solving cloud computing task scheduling problems.

## VII. CONCLUSION

This paper proposes an improved bat algorithm for task scheduling. Based on the original bat algorithm, the mutation factor and mutation inertia weight are introduced, and the logic of local optimization is enhanced. The proposed method is simulated using CloudSim and compared with other meta-heuristic algorithms on a public dataset. The performance of the proposed method is analyzed from four perspectives: fitness, makespan, cost, and degree of load balancing. Experimental results demonstrate that the proposed algorithm has stronger optimization ability and can consistently achieve lower fitness scores. In the case of similar costs, the proposed algorithm outperforms other algorithms in terms of makespan and load balancing.

While MOMDBA performs well in terms of makespan and load balancing, it does not provide a significant cost advantage over other algorithms. In our future studies, we plan to further optimize the objective function and explore more effective approaches to solving cloud computing task scheduling problems in complex scenarios. This may involve considering additional factors such as memory and bandwidth constraints. Additionally, we aim to investigate the potential benefits of combining MOMDBA with deep reinforcement learning techniques to further enhance the algorithm's performance.

By addressing these challenges, we hope to improve the overall service performance of cloud systems and provide more efficient and cost-effective solutions for cloud computing applications.



TABLE VI. FITNESS BASED EXPERIMENTAL RESULTS.

Cloudlets	LBACO	GA	PSO	MOMDBA	Reduction in Fitness using MOMDBA		
					Over LBACO	Over GA	Over PSO
100	0.12	0.24	0.13	0.07	41.66%	70.83%	46.15%
150	0.14	0.27	0.15	0.07	50.00%	74.07%	53.33%
200	0.11	0.29	0.19	0.05	54.54%	82.75%	73.68%
250	0.10	0.25	0.16	0.06	60.00%	76.00%	62.50%
300	0.11	0.25	0.20	0.04	63.63%	84.00%	80.00%
350	0.11	0.21	0.21	0.06	45.45%	71.42%	71.42%
400	0.10	0.20	0.20	0.07	70.00%	65.00%	65.00%
450	0.10	0.20	0.19	0.05	50.00%	75.00%	73.68%
500	0.10	0.17	0.18	0.05	50.00%	70.58%	72.22%

TABLE VII. MAKESPAN BASED EXPERIMENTAL RESULTS

Cloudlets	LBACO	GA	PSO	MOMDBA	Reduction in Makespan using MOMDBA		
					Over LBACO	Over GA	Over PSO
100	577	975	513	441	23.57%	54.77%	14.03%
150	886	1552	1047	697	21.33%	55.09%	33.42%
200	1003	1978	1620	811	19.14%	58.99%	49.93%
250	1151	2470	1972	991	13.90%	59.87%	49.76%
300	1596	2826	2522	1251	21.61%	55.73%	50.39%
350	1829	3026	3014	1367	25.26%	54.82%	54.64%
400	1750	3366	3374	1562	10.74%	53.59%	53.70%
450	1901	3801	3686	1612	15.20%	57.59%	56.26%
500	2216	3878	3868	1919	13.40%	50.51%	50.38%

TABLE VIII. COST BASED EXPERIMENTAL RESULTS

Cloudlets	LBACO	GA	PSO	MOMDBA	Reduction in Cost using MOMDBA		
					Over LBACO	Over GA	Over PSO
100	415	375	399	405	2.40%	-8.00%	-1.50%
150	684	632	658	667	2.48%	-5.53%	-1.37%
200	837	773	786	816	2.50%	-5.56%	-3.82%
250	919	850	851	898	2.29%	-5.64%	-5.52%
300	1274	1201	1186	1217	4.47%	-1.33%	-2.61%
350	1458	1352	1356	1418	2.74%	-4.88%	-4.57%
400	1586	1510	1473	1555	1.95%	-2.98%	-5.27%
450	1715	1608	1602	1668	2.74%	-3.73%	-4.12%
500	1997	1856	1870	1936	3.01%	-4.31%	-3.53%

TABLE IX. DEGREE OF LOAD BALANCING BASED EXPERIMENTAL RESULTS

Cloudlets	LBACO	GA	PSO	MOMDBA	Improvement in degree of load balancing using MOMDBA		
					Over LBACO	Over GA	Over PSO
100	0.67	0.53	0.68	0.87	29.85%	64.15%	27.94%
150	0.71	0.52	0.57	0.90	26.76%	73.07%	57.89%
200	0.69	0.53	0.56	0.96	39.13%	44.79%	71.42%
250	0.73	0.54	0.51	0.88	20.54%	62.96%	72.54%
300	0.72	0.53	0.57	0.84	14.28%	58.49%	47.36%
350	0.69	0.59	0.51	0.85	23.18%	44.06%	66.67%
400	0.71	0.55	0.49	0.95	33.80%	72.72%	93.87%
450	0.74	0.54	0.54	0.95	38.34%	75.92%	75.92%
500	0.70	0.60	0.59	0.91	30.00%	51.67%	54.23%

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# An Adaptive Testcase Recommendation System to Engage Students in Learning: A Practice Study in Fundamental Programming Courses

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**Abstract**—This paper proposes a testcase recommendation system (TRS) to assist beginner-level learners in introductory programming courses with completing assignments on a learning management system (LMS). These learners often struggle to generate complex testcases and handle numerous code errors, leading to disengaging their attention from the study. The proposed TRS addresses this problem by applying the recommendation system using singular value decomposition (SVD) and the zone of proximal development (ZPD) to provide a small and appropriate set of testcases based on the learner's ability. We implement this TRS to the university-level Fundamental Programming courses for evaluation. The data analysis has demonstrated that TRS significantly increases student interactions with the system.

**Keywords**—Testcases recommendation system (TRS); learning management system (LMS); zone of proximal development (ZPD); singular value decomposition (SVD)

## I. INTRODUCTION

A learning management system (LMS) is an educational tool, either in the form of an application or a website, that facilitates interactive online learning, automates administrative tasks, organizes educational content, and records learners' activities [1], [2]. The author in [3] emphasizes that an LMS should be dynamic; that is, it should be active, flexible, customizable, and adaptable. One method to achieve this is to improve the ability to instruct many learners in a personalized manner. As a result, learners would increase their interaction and satisfaction with the system. LMS can serve as a data collection tool for automatic assessment of learning outcomes [4], analysis of learning style [5], and evaluation of learner satisfaction [6].

Moodle<sup>1</sup> is an open-source LMS with a large number of users, with almost 157,289+ registered sites in 241+ countries [7]. Moodle offers various types of assessment questions for learners, such as multiple choice, short answer, matching, etc. On the other hand, programming questions are essential for learners in programming courses. Programming questions require to source code submitted from learners on a set of inputs. Moodle has now supported programming questions through the plugin CodeRunner. Thanks to CodeRunner, Moodle can deliver programming exercises to learners and automatically grade learners' code.

Programming exercises usually include two types: lab and assignment. Lab exercises are small code exercises for learners to practice independently after learning a topic in theory. The assignment is a complex exercise with lengthy descriptions and many requirements. Additionally, it is used to test the synthesis of problems. Through the assignment, learners practice breaking down the problem into smaller parts to solve. At the same time, they learn to use a combination of techniques from different programming topics to solve complex problems. A typical evaluation of programming exercises is to run the code on a set of inputs and check if the output matches the expected output that results from running the lecturer's solution code on the same input set. A set of inputs and the corresponding output is called a testcase. The percentage of correct testcases calculates the score for the programming exercise. The number of testcases of an assignment is usually much more than those of a lab exercise. The reason is that assignments often ask for many problems, so many testcases are needed to check possible cases of these problems. Therefore, grading assignments for learners often takes a lot of time. Assignment time is usually given for a relatively long period of about three to six weeks. In contrast, the lab exercises are often done in one week.

An assignment implemented on Moodle can be evaluated in different ways.

- Lecturers manually grade all submissions by looking through the code the learner submits and marking it based on the lecturer's perspective.
- Lecturers leverage an automatic grading system (AGS) to grade the submitted code. The grading tool automatically runs the learner's code through testcases and then checks the code's output match. This grading method will minimize the lecturer's perspective, making it fairer than manual grading.
- Learners are provided with a place to test their code on a set of sample testcases. The problem when grading with the AGS on the lecturer's local computer is that some learners' code does not run the same results as when running the code on the learner's local computer. The causes may be because learners' code depends on the compiler and operating system. For example, a common mistake is that when declaring an integer variable and not initializing a value, some compilers automatically assign the value 0 to the

<sup>1</sup><http://moodle.org>

variable. However, others will not do initialization, and the variable will have a random value. An independent grading environment helps learners minimize differences between the grading environment and the one they run their code. After the learner submits the assignment, the lecturer often uses another set of testcases for grading.

This paper does not study the first method because it has the teacher's subjective opinion when grading. Meanwhile, two remaining methods still have some drawbacks. Learners need help to think of a set of testcases to assess their code before submission. Coming up with testcases is a must-have skill for programmers. In real projects, programmers are also required to write their testcases to examine their solutions. However, it is difficult for beginner learners to think of testcases. Learners would not improve their programming skills when they couldn't think of testcases.

A straightforward method to help beginner learners is to provide all the testcases that learners do incorrectly. However, when there are many errors in testcases, beginner learners must choose which testcase to correct first. Therefore, we propose a recommendation-based method that suggests a subset of a few incorrect testcases that have difficulty levels suitable for the current performance of learners. The main contributions of this paper can be summarized as follows:

- Propose a testcase recommendation system (TRS) that engages the learners in doing assignments by suggesting a small set of testcases adaptive to learners' performance.
- Implement the proposed TRS to fundamental programming courses at our university to investigate the effectiveness in terms of students' ability to learn in a personalized manner and the enhancement of learner interaction.

The rest of this paper is organized as follows. Section II summarizes related works to clarify the scope of our study. Then, Section III describes our proposed method. The implementation and evaluation are presented in Section IV. Finally, Section V provides concluding remarks and future works.

## II. RELATED WORK

A recommendation system (RS) will help suggest items to users when there are too many items to select. Recommendation systems (RSs) have become popular and are used extensively in e-commerce and other digital companies [8]. Some well-known examples include Netflix's movie RS [9], Amazon's product RS [10], Google's personalized news, Google's advertisement search, and YouTube for videos [11]. RSs are mainly used for two main tasks: predicting how many ratings a user would give for an item (so-called prediction generation) and recommending a set of items to a user (so-called recommendation generation). RSs collect information on users' past behavior on a set of items and use them for the recommendation. Basically, RSs approaches can be classified into three types: Content-based filtering, Collaborative filtering, and Hybrid one.

- **Content-based filtering (CBF)** provides recommendations based on features of users and items, which are usually created according to users' consuming items. The recommended items are those whose characteristics are similar to the consuming items of the target user.
- **Collaborative filtering (CF)** works on the fact that users with similar behavior will have similar tastes or similar buying habits [8]. CF is divided into memory and model-based approach, based on how the data of the rating matrix are processed [12][13]. The memory-based approach in recommendation systems utilizes similarity measures between users or items to identify their relevant neighbors [8]. These neighbors are then used for recommending or predicting items or users. This approach is easy to implement and interpret the results. However, it requires the entire task rating matrix, making it less suitable for high-dimensional and sparse data. Meanwhile, the model-based approach learns and fits a parameterized model to the user-item rating matrix. This model is then used for providing recommendation tasks. Matrix factorization (MF) is a technique in the model-based approach that gained popularity, especially after the Netflix Prize Contest [13]. MF models are known for their relatively high accuracy, scalability, and dimensionality reduction properties [8].
- **Hybrid approach** combines CBF and CF to provide high predictive accuracy than both [13].

The model-based approach learns the model's parameters with the user-item matrix and uses it to make suggestions. User-item matrix contains user ratings for the items. This rating is similar to the scores obtained by learners for testcases. Therefore, we utilize this method to develop a testcase recommendation system (TRS).

In the domain of testcase recommendation system, previous studies have specifically explored its application in the context of software testing. The authors in [14], [15] examine the test scripts used by automation team and recommends testcases based on source code structural similarity for developing newer testcases. The author in [16] builds a recommender system to find an optimal group of tests to be executed with a code change. The authors in [17] implement an item-based collaborative filtering recommender system that develops a test case prioritizing technique using user interaction data and application modification history information. These studies primarily focus on recommending testcases that are similar to the ones already available for software testing. In contrast, our study concentrates on suggesting testcases that align with the learner's performance. These testcases are utilized by the learner for programming practice.

In this study, we adopt the recommendation algorithm to the learners' score data due to data availability. However, the score has not shown preference as the RS model requires preference as a user's item rating. For example, if a learner gets a high score on a test, they may feel bored because the test may be too easy, leading to disengagement in continuous studying. Therefore, we improve the recommendation algorithm on

the learner's score data by consulting the zone of proximal development (ZPD) theory.

According to the ZPD, if the learning materials are too easy or difficult, the learner will become bored or frustrated. The optimal level of instructional material should be within the "zone" that falls between the learner's upper and lower limits of ability [18]. ZPD is applied in various educational contexts, such as adaptive quiz question recommendations [19] and navigating optimized learning paths [20]. It reduces cognitive load and improves learning outcomes without affecting the learning experience [21]. ZPD is also utilized in specific fields like clinical education [22], participatory scenario planning [23], and divergent thinking [24]. Previous studies [25], [26] have aimed to provide a clearer definition of the ZPD compared to Vygotsky's initial conceptualization [27]. The SZPD criterion is proposed, where  $H^* - H > DH$  represents the confused zone, and  $H^* - H < -DH$  represents the bored zone [25]. Here,  $H$  and  $DH$  respectively refer to the goal number of hints and the allowable variation in  $H$  to determine the situation within the ZPD.

In summary, we combine recommendation algorithm and ZPD theory to make recommendations on learners' score data.

### III. THE PROPOSED TRS

Currently, our approach involves providing a platform to enhance the assignment implementation process. This process includes publishing the assignment specifications, opening a forum for discussion, setting the deadline, providing a designated place for testing with sample testcases (which also serves as the submission place for students' work), and finally opening the TRS.

The proposed approach strengthens the internal environment to suggest testcases tailored to each learner's performance. Fig. 1 outlines our assignment implementation process that begins with learners completing a set of sample testcases that are publicly available. The completion rate is determined by the instructor (e.g., 80%). Once learners surpass the completion rate, they are prompted to request more complicated testcases from the recommendation system. Learners practice and debug their code using the provided testcases. Once all testcases have been solved correctly within a limited time, learners can request a new set of testcases. However, there is a limitation on the number of requests per day. This measure reduces the system load and is a basis for applying the ZPD theory.

When a learner submits their code, the system evaluates the correctness of each testcase's result. There is a similarity between the TRS and a typical recommendation system, where learners are considered users, testcases are items, and learner scores correspond to the ratings that users provide for items. Thus, we apply the singular value decomposition (SVD) technique from the typical recommendation system to TRS. Furthermore, the matrix representing user scores for each testcase is what we call *learner-testcase matrix*, similar to the user-item matrix in a typical recommendation system.

However, in TRS, a higher score from a learner does not necessarily indicate a higher preference for that testcase. A high score could result from an easy testcase, making the

learner bored. One approach is to directly ask the learner about their preference for the suggested testcase using explicit profiling. However, this method may annoy and distract learners from the primary assignment goal. In contrast, the implicit profiling method captures user interactions within the system, improving system effectiveness and avoiding the drawbacks of explicit profiling. Combining interactive data from the system with the SZPD allows for suggesting testcases to suit learners' abilities.

Our proposed approach, which utilizes singular value decomposition (SVD) technique and zone of proximal development (ZPD) theory named **SVD-ZPD**, consists of four main steps as follows:

- 1) **Fitting SVD to predict learner scores for testcases.** The SVD technique is applied to the learner-testcase matrix to predict the scores for any learner. When a learner submits their code, incorrect testcases typically receive a score of 0. With SVD, incorrect testcases will have a non-zero score, indicating the extent of the error. By sorting the incorrect testcases based on these scores, we can identify the testcases that the learner is more likely to answer incorrectly.
- 2) **Determining the learner's current performance.** We determine the learner's performance state within the ZPD based on the number of times the learner requests a new set of testcases from the TRS. Let  $R$  be the goal number of new testcase requests and  $DR$  be the allowed variation in  $R$  to consider the learner within the ZPD. Let  $R^*$  be the actual number of code submissions by the learner on the previous day. We also introduce two constraints: (a) a maximum of requests per day, and (b) the learner must correctly complete all testcases from the previous request to be eligible for a new set of testcases. So,  $R^* - R$  represents the learner's current performance. In this scenario, we have:
  - If  $R^* - R < -DR$ , the learner has not answered many testcases correctly, indicating that the current testcases may be too difficult, and the learner is in the confused zone.
  - If  $R^* - R > DR$ , the learner quickly answers the testcases and continuously requests new ones, indicating that the current testcases may be too easy and the learner is in the bored zone.
  - In other cases, the learner is in the ZPD zone.
- 3) **Determining the appropriate difficulty level based on the learner's current performance.** The previous step provides a general guideline for adjusting the difficulty level: decrease the difficulty level if the learner is in the confused zone and increase it if the learner is in the bored zone. This step defines more detailed rules for increasing and decreasing the difficulty level. While there can be multiple approaches, in this initial study, we propose the following simple rules (but we don't limit the approach to these rules):
  - Difficulty level includes three levels: easy, medium, and hard. It is initially set to easy.
  - If the learner is in the bored zone, increase the difficulty level by one adjacent level. If

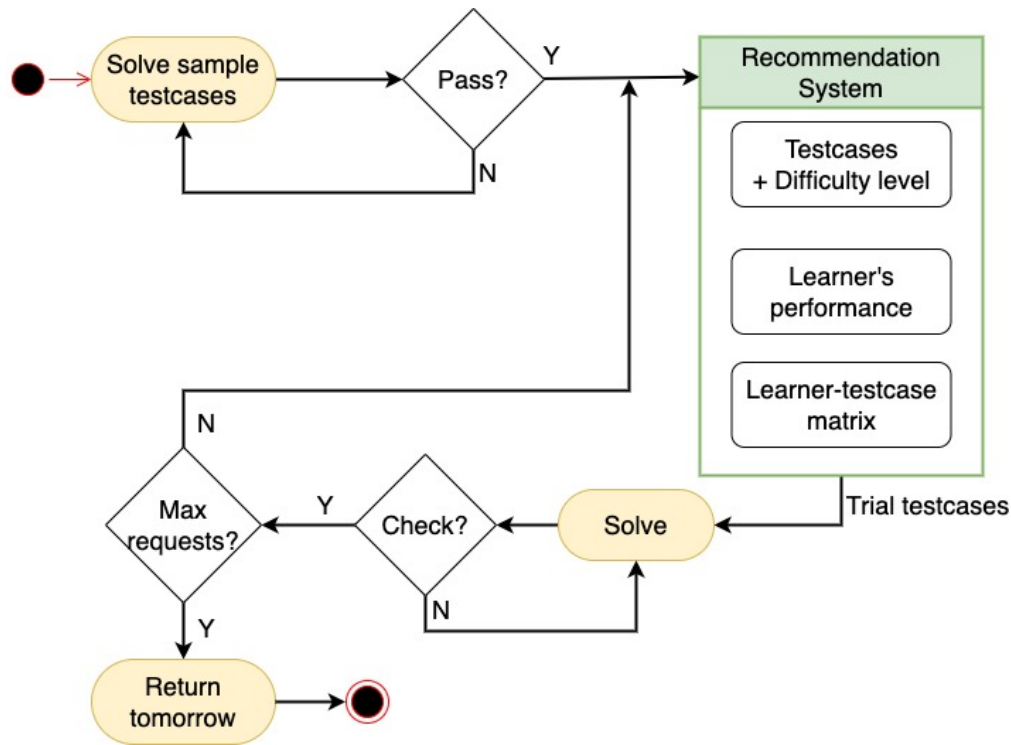


Fig. 1. Illustration of the proposed TRS process.

it is already at the highest level, keep it unchanged.

- If the learner is in the confused zone, decrease the difficulty level by one adjacent level. If it is already at the lowest level, keep it unchanged.
- If the learner is within the ZPD, keep the difficulty level unchanged.

4) **Selecting testcases with the same difficulty level from the previous step in descending order of predicted scores obtained from the first step.**

#### IV. EVALUATION

The proposed TRS is implemented in one assignment of the Fundamental Programming course at our university for the second semester of the 2022–2023 academic year, where Moodle is used as an online learning tool. The effectiveness of TRS is examined by comparing the assignment recorded on Moodle of the three most recent semesters of the same course: the second semester of the 2020-2021 year (SEM-202), the second semester of the 2021-2022 year (SEM-212), and the second semester of the 2022-2023 year (SEM-222).

##### A. Features of Implementing Assignment

For each semester, we will analyze the information that the system provides to the learners, the main features, and the information that can be obtained for the assignment implementation process.

In SEM-202, learners will receive a set of sample testcases and a place to allow automatic submission. Learners run these sample testcases on their own on the local computer. Learners

compare the program's running results with the provided expected results to assess whether the program runs correctly. This set of testcases usually includes only simple testcases and has a small number of testcases. Learners will submit their work on the system before the deadline. Then, the teacher will grade the score on the personal computer and post the score on the system for learners. The drawback of this implementation is that learners can not improve their programming skills because learners have to wait until the deadline expires to receive their marks. While learners are doing the test, they can't see the scores and errors to correct them.

In SEM-212, the system still provides the same materials as SEM-202. Moreover, the system offers an additional place for automatic grading and instant results on sample testcases. This place helps learners receive immediate feedback and ensures the submission runs appropriately in the grading environment. In addition, the interactive information of learners on the system will be more, such as the time of submission, submission, and grading results. The problem with this implementation is that the system only provides one static set of simple testcases. Beginner learners need help to think of complex testcases to improve their programming skills.

In SEM-222, the system still provides the same materials as SEM-212. However, through the proposed TRS, the system offers more testcases suitable for each learner at each time. After correcting the sample testcases, learners can request more testcases from TRS. Then, TRS will provide a small set of testcases that the learner is doing wrong, and these testcases should have a difficulty level matching the learner's current ability. In addition, TRS requires learners to do all testcases correctly to be given a new set of testcases, and they can only



be asked for a maximum of five times a day. The total number of testcases used for suggestion is 124; each request is five testcases.

Table I summarizes the main features of the assignment implementation process over the three semesters, including information for learners, key features, and recorded information. Notably, different from SEM-202 and SEM-212, the last semester is demonstrated by 2 rows, one for sample testcases submission and the other for TRS. As a result, we can see from this table that the system, in addition to TRS, has more key features and can gather more useful information.

### B. Comparison

Table II compares the assignment implementation in three semesters on four factors: supportive self-study environment to summarize knowledge, instructional environment, learning and development of learners, and the system's interaction with learners.

We analyze the following three questions regarding the self-study support environment to summarize knowledge. The first question is about the ability to serve a large number of learners (all three semesters have a place to release Assignments to learners, for learners to submit papers, and have an automatic grading method). The second question is how to implement a self-study support environment for many learners (SEM-202 provides a place to submit papers and automatically grade papers after deadlines, SEM-212 delivers a place to submit papers and return results instantly, SEM-222 provides the same environment as SEM-212 and has additional testcase suggestions). The last question is about the ability to evaluate work results for many learners (all three semesters can automatically grade learners' codes).

In terms of the learner guidance environment, this is an environment that provides feedback to help learners improve their work and programming skills. We analyze the instructional environment according to two questions: Is there an instructional environment for learners? What are the limitations of the effectiveness of the instructional environment? In SEM-202, a forum is provided for learners to ask questions about Assignments. The teacher then answers these questions. The efficacy of a forum depends on the questions posted by learners and the responses provided by instructors and other learners. To examine the effectiveness, appropriate data analysis tools related to the interactive content on the forum are needed. On the other hand, sample testcases are a set of simple testcases for learners to test the code on their own under personal computers. The limitation of sample testcases is that the instructor does not know how learners have utilized them. The completeness level and suitability of the sample testcases for guiding learners cannot be determined. Semester SEM-212 still provides forum and sample testcases. However, sample testcases in SEM-212 are automatically graded and give instant results to learners. The improvement in this method is that the instructor knows whether learners have studied and worked with testcases through their submission attempts. After completing the assignment and grading, the instructor can determine whether the sample testcases are comprehensive enough to guide the learners. Semester SEM-222 not only provides the same environment as SEM-212 but also provides

TRS. The challenge is establishing a diverse testcases bank that can be divided into smaller sets to provide appropriate hints based on the learners' abilities at different stages.

Regarding the learning and development of learners, we analyze according to three questions as shown in Table II. Does the system keep track of the learning process: SEM-202 is not recorded because only the last submission is submitted. At the same time, SEM-212 and SEM-222 are recordable at the time of submission and submission code.

We analyze the interaction with learners according to a question about how the system interacts with learners, as shown in the table. The answer consists of two lines describing the information the system receives from the learner and the information the system gives to the learner. The information obtained from the learners was the same over the three semesters. However, the information brought to learners has increased gradually over three semesters. The final semester has the most information for learners. As more information reaches learners, learners can personally practice and improve their programming skills.

### C. Statistical Results and Findings

The statistical results after implementing the assignment over three semesters (SEM-202, SEM-212 and SEM-222) are summarized in Table III. The important points of this table should be taken into account as follows.

- This table contains seven information fields including information provided to learners, total number of learners, number of learners who submitted code, number of days having submissions, number of submissions, average number of submissions per learner, and average number of submissions per day.
- The information provided to learners may be sample testcases or information provided from TRS. Note that the information provided by TRS is only available from SEM-222.
- The number of days with submissions in SEM-202 is marked as N/A (not available) since the system does not record individual submission instances. Each learner is only permitted to submit one work for the assignment, so the total number of submissions equals the number of learners. The average number of submissions per day cannot be calculated because the number of days is not recorded.

The following analyses compare SEM-212 with SEM-202 and SEM-222 with SEM-212 regarding sample test cases. Then, the most appropriate context among the three semesters will be identified. Finally, the information from TRS will be analyzed to better understand the system's value.

Considering two semesters, SEM-212 and SEM-202, although the number of learners in SEM-212 is smaller than in SEM-202, the number of submissions is higher. The reason is that SEM-212 can record the information of learners' multiple attempts. In other words, the process implemented in SEM-212 improves the interaction between learners and the system compared to SEM-202. This also serves as an example to

TABLE I. FEATURES OF THE ASSIGNMENT IMPLEMENTATION PROCESS IN THREE SEMESTERS: SEM-202, SEM-212, AND SEM-222

Semester	Provided information for learners	Key features	Recorded Information
SEM-202	Sample testcases	- Automated submission platform for learners. - Learners receive grading results after the deadline.	- Overall grading score.
SEM-212	Sample testcases	- Automated submission platform for learners. - Learners receive grading results after the deadline. - Automated grading and immediate feedback on sample testcases submissions.	- Overall grading score. - Submission history: submission time and grading results for sample testcases.
SEM-222	Sample testcases	- Automated submission platform for learners. - Learners receive grading results after the deadline. - Automated grading and immediate feedback on sample testcases submissions.	- Overall grading score. - Submission history: submission time and grading results for sample testcases.
	Various sets of testcases sent based on individual learners and timing.	- Submissions and requesting testcases for incorrect answers. - Testcase sets tailored to learners' abilities through the TRS system.	- Submission history: submission time and grading results for recommended testcase sets.

TABLE II. COMPARISON OF ASSIGNMENT IMPLEMENTATION IN 3 SEMESTERS

Factor	Related questions	SEM-202	SEM-212	SEM-222
Self-study support environment to summarize knowledge	Is there an environment that supports self-study and automatic grading to serve a large number of learners?	Yes	Yes	Yes
	How to implement a self-study support environment for learners?	The site to submits codes; codes are automatically graded after the deadline	The site to submits codes and returns results instantly on sample testcases; codes are automatically graded after the deadline	The site to submits codes and returns results instantly on sample testcases; the site suggests testcases; codes are automatically graded after the deadline
	Can the learner's work results be assessed?	Yes	Yes	Yes
Instructional environment	Is there an environment that instructs learners?	- Forum - Sample testcases for self-evaluation by learners	- Forum - Sample testcases with instant grading	- Forum - Sample testcases with instant grading - TRS
	What are the limitations of the instructional environment's effectiveness level?	- Forum: relies on learner questions and instructor and peer responses - Sample testcases for self-evaluation by learners: challenge to assess the level of completeness and suitability of these testcases in guiding learners.	- Forum likes on the left - Sample testcases with instant grading: can track learners' engagement with testcases through their submissions; the level of completeness and suitability of the testcases can be assessed on submissions	- Forum and sample testcases with instant grading like on the left - TRS: challenge to establish a diverse testcases bank.
Learners' learning and development	Is it possible to keep track of the learning process?	No (only the last submission is recorded)	Possible (when the learner submits the code)	Possible and enhanced by <b>TRS</b>
	Is there a way to keep track of learner development?	No (only the last submission is recorded)	Possible	Possible and enhanced by <b>TRS</b>
	Is there a way to support learners' problem-solving skills development?	No	Yes (returns results of grading sample testcases)	Yes (returns results of grading sample testcases; provides testcases hints according to learner's ability)
Interaction with learners	How is the interaction?	- Allow multiple submissions - Grading is done for only the last submission.	- Allow multiple submissions - Grading is done for the final submission; intermediate scores on sample testcases are provided for each submission.	- Allow multiple submissions - Grading is done for the final submission; intermediate scores on sample testcases are provided for each submission; suggested testcases and scores are provided for each submission on the <b>TRS</b> system.

support the question in Table II regarding the existence of a method to keep track of the learning process.

The number of learners in SEM-222 (1484) increased by 1.7 times compared to the number of learners in SEM-

TABLE III. STATISTICAL RESULTS AFTER IMPLEMENTING ASSIGNMENT IN 3 SEMESTERS

Semester	Information provided to learners	Total number of learners	Number of learners who submitted code	Number of days having submissions	Number of submissions	Average number of submissions per learner	Average number of submissions per day
SEM-202	Sample testcases	933	852 (91.32%)	N/A	852	1.0	N/A
SEM-212	Sample testcases	864	723 (83.68%)	15	5463	7.56	364.2
SEM-222	Sample testcases	1484	1332 (89.76%)	27	25009	18.78	926.26
	TRS	1484	1082 (72.91%)	14	11427	10.56	816.21

212 (864), and the number of learners participating in code submission increased by 1.8 times. The participation rate in submissions increased (89.76% compared to 83.68%), or in other words, the non-participation rate decreased. Therefore, can it be inferred that the submission system in SEM-222 better supports learners? The number of days with submissions in SEM-222 is nearly double that of SEM-212. So, could the longer submission time in SEM-222 allow learners to have more opportunities to complete their assignments? The number of submissions in SEM-222 (25009) is significantly higher than in SEM-212 (5463). Thus, is this due to the longer allowed submission time or better learner support? The average number of submissions per learner in SEM-222 (18.78) is 2.5 times higher than in SEM-212 (7.56). This indicates that the SEM-222 system supports better interaction compared to SEM-212. Furthermore, if we compare the average number of submissions per day between SEM-222 and SEM-212, the ratio is 2.5 (926.26/364.2), which is higher than the ratio between SEM-222 and SEM-212 (1.7). This suggests that the SEM-222 system provides better support to learners than the SEM-212 system.

The above results indicate that SEM-212 performs better than SEM-202, and SEM-222 performs better than SEM-212. Overall, SEM-222 has the best implementation. The level of system interaction, based on the number of submissions, is 29.4 times higher in SEM-222 (25009/852) compared to the semester with the lowest number of submissions (SEM-202), even though the ratio of the number of learners between these two semesters is only 1.6 (1484/933). Considering only the information regarding sample testcases, SEM-222 displays a significantly higher interaction level than SEM-212 and significantly outperforms SEM-202.

If we consider the additional information from TRS in SEM-222, the number of submissions increases by 45.7% (11427/25009) compared to the number of submissions in the sample testcases. Based on the total number of submissions in SEM-222 (including TRS), the system's interaction level is 42.8 times higher than the semester with the least collected interaction (SEM-202). Although this is the first implementation of TRS, the participation rate is quite impressive at 72.91%. However, it is still lower than the percentage of people who submitted on the sample testcases (89.76%). From this, we can see that students tend to resubmit their assignments on the sample testcases every time they improve their code on TRS. The reason could be that students want to ensure their submitted version is evaluated on the sample testcases. Alternatively, it is possible that students do not trust the consistency between the solutions of the two systems.

To examine the detailed impact of TRS on the sample testcases, the group of learners who submitted assignments in SEM-222 needs to be divided into two smaller groups: the group that used the TRS system (Use TRS) and the group that did not use the TRS system (Not-use TRS). Fig. 2(a) shows the percentage distribution of learners between the Use TRS and Not-use TRS groups. And Fig. 2(b) illustrates the percentage distribution of submissions between the Use TRS group (22082) and the Not-use TRS group (2927) on the system of sample testcases. Let's consider the index that measures the level of interaction through submissions on the system referred to as the average interaction index. It is calculated by dividing the number of submissions by (the number of people who submitted multiplied by the number of days of submission).

- The average interaction index of the group of learners on the sample testcases in SEM-212:  $5463 / (723 * 15) = 0.5$ .
- The average interaction index of the group of learners on the sample testcases in SEM-222:  $25009 / (1332 * 27) = 0.70$ .
- The average interaction index of the group of learners on TRS in SEM-222:  $11427 / (1082 * 14) = 0.75$ .
- The average interaction index of the Use TRS group on the sample testcases in SEM-222:  $22082 / (1082 * 27) = 0.76$ .
- The average interaction index of the Not-use TRS group on the sample testcases in SEM-222:  $2927 / (250 * 27) = 0.43$ .

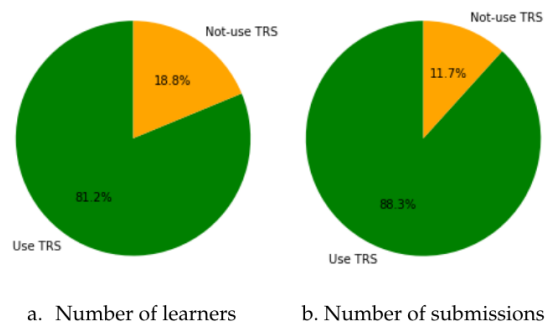


Fig. 2. Comparison between Use and Not-use TRS in SEM-222.

The average interaction score on the TRS system (0.75) is higher than the average interaction score on the sample test-

cases system during the same semester (0.70). This indicates that the TRS group has a higher level of interaction with the sample testcases in SEM-222.

Subsequently, let's examine the level of interaction between the Use TRS group and the Not-use TRS group on the sample testcases in SEM-222. The data collected in Table III shows that the number of students using TRS is 1082, and the number of students not using TRS is  $(1332 - 1082) = 250$ . The ratio of the number of people between the two groups is  $1082 / (1332 - 1082) = 1082 / 250 = 4.3$ , while the submission ratio on the sample testcases between these two groups is  $22082 / 2927 = 7.5$  (1.7 times higher than the ratio of students in the two groups). This indicates that the Use TRS group has nearly twice the interaction with the sample testcases compared to the Not-use TRS group. We can also calculate similar results by determining the ratio between the average number of submissions of the Use TRS group ( $22082 / 1082$ ) and the Not-Use TRS group ( $2927 / 250$ ).

The average interaction score of the student group on the sample testcases in SEM-212 (0.5) is lower and approximately equal to the average interaction score of the Not-use TRS group on the sample testcases in SEM-222 (0.43) - meaning  $0.5/0.43 = 1.16$  times higher. This indicates that the Not-use TRS group in SEM-222 has a slightly lower interaction level than the student group in the semester without TRS support (SEM-212). This is a less active group in the exercise process and does not actively utilize the support from the teaching environment.

The average interaction score of the Use TRS group on the sample testcases in SEM-222 (0.76) is significantly higher (about 1.5 times) than the average interaction score in SEM-212 (0.5). This indicates that the Use TRS group in SEM-222 interacts more actively than the other groups (Not-use TRS in SEM-222 and the student group in SEM-212). In other words, this is the contribution of the TRS system.

## V. CONCLUSION

This paper proposed a testcase recommendation system (TRS) for assisting learners in completing assignments in introductory programming courses. TRS provides a small set of testcases adaptive to the learner's current level of proficiency. Using learners' performance data, we propose a new testcase recommendation process based on the SVD model and the ZPD theory.

TRS was implemented and deployed in the university-level fundamental programming course in the second semester of the 2022-2023 year. Then, we investigated TRS's effectiveness by conducting a comparison with two previous semesters (SEM-202 and SEM-212) without using TRS. The statistical results have shown that SEM-222 had the highest level of interaction with learners among the three semesters (2.5 times higher than SEM-202). Additionally, the proposed TRS received acceptance and significant interaction from learners during its initial semester.

Our future work is to examine the effectiveness of TRS for learners in greater depth and make more comparisons with other testcase recommendation methods. Moreover, we aim to identify strategies for gathering information on learners'

satisfaction, particularly in a new environment that supports additional testcase suggestions for assignments. We will also explore the integration of automated techniques that generate testcases using a formal descriptive language. Furthermore, our investigation will involve developing a testcase bank to provide diverse and differentiated recommendations. Lastly, the solution will be packaged as a module for seamless integration into various learning management systems (LMS), specifically focusing on Moodle LMS.

## ACKNOWLEDGMENT

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# Brain Tumor Semantic Segmentation using Residual U-Net++ Encoder-Decoder Architecture

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**Abstract**—Image segmentation is considered one of the essential tasks for extracting useful information from an image. Given the brain tumor and its consumption of medical resources, the development of a deep learning method for MRI to segment the brain tumor of patients' MRI is illustrated here. Brain tumor segmentation technique is crucial in detecting and treating MRI brain tumors. Furthermore, it assists physicians in locating and measuring tumors and developing treatment and rehabilitation programs. The residual U-Net++ encoder-decoder-based architecture is designed as the primary network, and it is an architecture that is hybridized between ResU-Net and U-Net++. The proposed Residual U-Net++ is applied to MRI brain images for the most recent and well-known global benchmark challenges: BraTS 2017, BraTS 2019, and BraTS 2021. The proposed approach is evaluated based on brain tumor MRI images. The results with the BraST 2021 dataset with a dice similarity coefficient (DSC) is 90.3%, sensitivity is 96%, specificity is 99%, and 95% Hausdorff distance (HD) is 9.9. With the BraST 2019 dataset, a DSC is 89.2%, sensitivity is 96%, specificity is 99%, and HD is 10.2. With the BraST 2017 dataset, a DSC is 87.6%, sensitivity is 94%, specificity is 99%, and HD is 11.2. Furthermore, Residual U-Net++ outperforms the standard brain tumor segmentation approaches. The experimental results indicated that the proposed method is promising and can provide better segmentation than the standard U-Net. The segmentation improvement could help radiologists increase their radiologist segmentation accuracy and save time by 3%.

**Keywords**—Brain tumor segmentation; medical image segmentation; BraTS; U-Net; U-Net++; residual network

## I. INTRODUCTION

Brain tumors are growing in the cells of the human brain abnormally. They are divided into two main types, which are malignant and benign, and malignant is more widely spread than benign. They have a significant impact on people and society. Gliomas, either high-grade gliomas (HGG) or low-grade gliomas (LGG), comprise the majority of malignant brain tumors. Because it enables medical professionals to find and quantify tumors and develop strategies for their treatment and recovery, brain tumor segmentation is crucial for diagnosing and treating brain tumors. Medical image segmentation divides a medical image into different regions and separates anatomical structures. These are called “regions of interest” and are appropriate for a specific medical application [1], [2].

There are two main medical image segmentation techniques: manual and auto segmentation. Manual segmentation is the gold standard approach that still consumes time and effort, not only time and effort but also needs experts. Auto segmentation techniques are divided into many techniques:

region-based, edge-based, thresholding, atlas-based, clustering, and deep learning.

It is used in clinical studies to guide and monitor disease progression. It also has many uses, such as diagnosing diseases, planning treatments, studying anatomy, finding the problem, figuring out how much tissue there is, and doing computer-integrated surgery.

According to all of these usages, medical image segmentation has many challenges. These challenges are noise, different colors, patterns, orientations, textures, and insufficient resolution. Furthermore, the medical image is heterogeneous in shape, volume, and texture. These challenges make the segmentation task more complex and require multiple pre-processing approaches.

Recently, it has been suggested that deep learning methods could be used to make different applications for segmenting and classifying medical images. Deep Learning networks can segment and pull out features so that segmentation can be done with just one prediction model [3].

The deep learning model for medical images is classified into two main categories: 2D Fully Convolution Networks, such as U-Net architecture, and 3D Fully Convolutional Networks, where 2D convolutions are covered with 3D convolution.

Image segmentation is one of several deep learning-based applications being researched in the medical field. Consequently, there are several techniques and numerous network architectures. Based on its attributes, such as network design, training procedure (supervised, semi-supervised, unsupervised, and transfer learning), and input size (patch-based, whole volume-based, 2D, and 3D), segmentation techniques based on deep learning may be subdivided into several categories according to network design, training procedure, and input size. Therefore, depending on its architecture, it may be split into six categories: convolutional neural networks, fully convolutional networks; regional convolutional networks; auto-encoders; generative adversarial networks; and hybrid deep learning-based approaches.

The proposed Residual U-Net++ pipeline with the whole phases is shown in Fig. 1 and illustrated step by step for each phase as an overview.

This paper's main contributions are summarized as follows:

- A new hybridization approach based on U-Net++ and



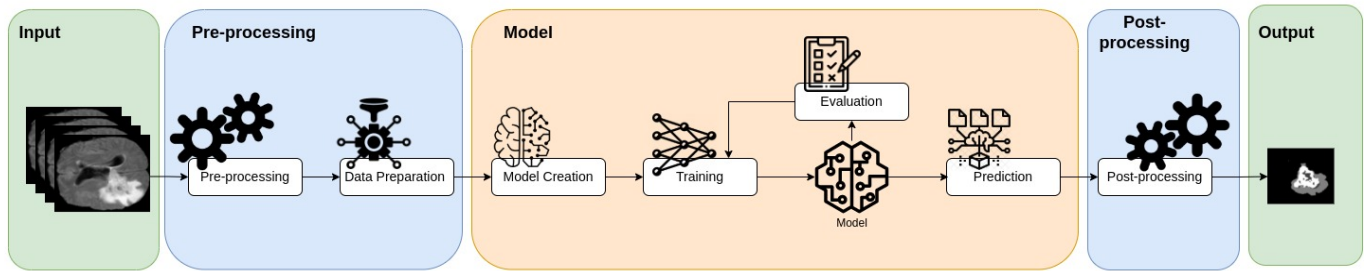


Fig. 1. Proposed residual U-Net++ pipeline.

ResU-Net is introduced, which combines the advantages of both architectures to improve the accuracy of brain tumor segmentation.

- A novel combination of pre-processing techniques and loss functions is proposed, further enhancing the hybrid approach's performance.
- The proposed Residual U-Net++ architecture is applied to three global benchmark challenges in brain tumor segmentation, including BraTS 2017, BraTS 2019, and BraTS 2021, and outperforms several state-of-the-art methods in all challenges, thus contributing significantly to the field.
- A discrete version of Residual U-Net++ is presented, specifically designed to address multi-level segmentation problems, and evaluated on a public benchmark real abdominal MRI images dataset of the brain as a case study.
- Several evaluation metrics, including the Dice Similarity Coefficient (DSC), Sensitivity (SEN), Specificity (SP), and 95% Hausdorff Distance (HD), are used to comprehensively assess the performance of the proposed approach, thus contributing to the standardization of evaluation methods in medical image segmentation research.

The rest of the paper is structured as follows: Section II represents the related work, Section III explains the details used in the model, which are dataset, pre-processing, architecture, loss function, and evaluation metrics. Section IV shows the results, followed by a discussion of the results in Section V. Finally, Section VI presents the conclusion.

## II. RELATED WORK

Zhang et al. [4] examine the significance of a newly created attention gate for tasks involving segmenting brain tumors as an attention module. They use datasets from BraTS, which are BraTS 2017, BraTS 2018, and BraTS 2019. They focus on investigating the efficacy of attention gates for tasks involving segmenting brain tumor images. They propose a model called the Attention Gate Residual U-Net, or AGResU-Net, which combines attention gates and residual modules within a fundamental and singular U-Net architecture to accomplish this purpose.

Neural Architecture Search (NAS) makes good progress in improving image accuracy. Accordingly, it has been extended

to be used recently in image segmentation. Weng et al. [5] use NAS with U-Net as U-Net is applied a lot in different medical image segmentation with successful results. Therefore, both are used by Weng et al. [5] to design and develop three primitive operations that make search space that find two cell architectures, DownSC and UpSC, useful in medical image segmentation especially. Their dataset without pre-training was PASCAL VOC2012 which consisted of Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and ultrasound. It gets better performance and fewer parameters than U-Net when evaluated on the three datasets [5].

Li et al. [6] proposed Residual-Attention U-Net++ as an extension of the U-Net++ model with a residual unit and attention mechanism. In angiography, they used three medical image datasets, skin cancer, cell nuclei, and coronary artery. Their results with the skin cancer dataset were an Intersection over Union (IoU) was 82.32% and a dice coefficient was 88.59%, and with the cell nuclei dataset, an IoU was 87.74%. The dice coefficient was 85.91%, and with the angiography dataset, an IoU was 66.57%, and a dice coefficient was 72.48%.

## III. MATERIALS AND METHOD

### A. Dataset

BraTS stands for Brain Tumor Segmentation, collected and prepared as a challenge per year. It is the most commonly used dataset for brain tumor segmentation as it is public [7], [8], [9], [10], [11], [12], [13], [14], [15]. It consists of a collection of MRI brain images, and all brain images are stripped of the skull and oriented similarly. Four MRI modalities exist for each patient, including Flair, T1, T1ce, and T2. The experts and the organizers of BraTS were labeling the training dataset ground truths. The example MRI brain image and associated ground truth are shown in Fig. 2.

On three benchmarks (BraTSraTS 2017, BraTS 2019, and BraTS 2021), we evaluate the effectiveness of ResU-Net++. Table I contains detailed information about the three datasets used for each year's challenge.

The BraTS 2017 dataset provides 285 glioma patients as a training dataset, consisting of 210 HGG cases and 75 LGG cases. There are 46 patients of uncertain grades included as validation dataset.

The BraTS 2019 dataset provides 335 glioma patients as a training dataset, consisting of 259 HGG cases and 76 LGG

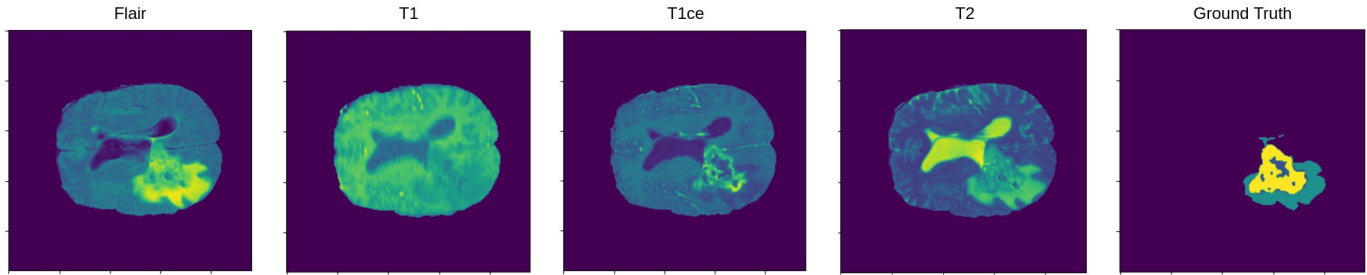


Fig. 2. Example of the brain MRI image with its ground truth from the BraTS 2019.

TABLE I. PUBLIC DATASETS THAT ARE USED FOR BRAIN TUMOR SEGMENTATION.

Name	Total Data Size	Training Data	Validation Data	Testing Data
BraTS 2017	477	285	46	146
BraTS 2019	653	335	127	191
BraTS 2021	2000	1251	219	530

cases. There are 127 patients of uncertain grades included as validation dataset.

The BraTS 2021 dataset provides 1251 glioma patients as a training dataset, which contains more patient cases than the previous two. There are 219 patients of uncertain grades included as validation dataset.

BraTS 2017 is used the most often because it is the first release to include training, validation, and test data. It is used in benchmarks and can be used with low computational power, in contrast to BraTS 2021. BraTS 2021 needs high computational power, takes more time, and gives high accuracy due to extensive data.

### B. Proposed Residual U-Net++ Pre-processing

As discussed before, MRI brain tumor segmentation is a problem that is challenging due to noise, different colors, patterns, orientations, textures, and heterogeneous shapes, volumes, and textures. Data processing is still an essential and crucial stage, even if deep learning-based techniques are more noise-resistant. Furthermore, we use multimodal 3D MRI brain scan datasets, specifically BraTS 2017, BraTS 2019, and BraTS 2021, in this study. The normal region takes up 98.5% of the pixels in the multilabel brain tumor segmentation, whereas the abnormal area only makes up 1.5% of the pixels. Each 3D MRI image data set in the BraTS database has a volume size of 240 x 240 x 155. That image of the axial brain has the highest resolution, and the plane of the axial generates most of the volume in the dataset. We employ a 3D axial brain image to construct multiple 2D image slices for each 240 x 240. To create a sequence of 2D slice images, we remove the 3D image's 1% highest voxel intensities and 1% lowest voxel intensities. While this is happening, we use a patching technique to process these 2D image slices, cropping each slice into many tiny patches with a size of 128 x 128 to handle the class imbalance issue.

Furthermore, we use z-score normalization on 2D images. Moreover, Gaussian regularisation also on 2D images to limit

the device noise effect, improve the contrast of an image, and relieve the overfitting problem. The Z-score normalization technique transforms each picture using the intensity's mean value and standard deviation, and it is calculated as follows:

$$z' = \frac{z - \mu}{\sigma} \quad (1)$$

Where  $z$  is the input image,  $z'$  is the normalized image,  $\mu$  is the input image mean, and  $\sigma$  is the input image standard deviation.

In addition, Gaussian regularisation also involves adding Gauss noise to images to increase model training accuracy. It efficiently reduces over-fitting during the model training phase by penalizing interference objects produced by noise for lowering the weighted square, which has an equivalent impact as L2 regularisation. These images of 2D patches are used in the network for segmenting brain tumors as input after data pre-processing for balancing data voxels. This data preparation step could improve the segmentation performance, normalizing the data and successfully handling the class imbalance issue.

### C. Proposed Residual U-Net++ Architecture

This paper introduced ResU-Net++, an integrated neural network for medical image segmentation that uses the benefits of U-Net++ and residual units. Its general layout is shown in Fig. 3. As we can see, the suggested architecture uses redesigned skip paths to connect the encoder and decoder networks, with U-Net++ as the primary network structure. The encoder network's feature map was sent to the decoder network through dense convolution blocks. According to the above-mentioned method, the feature graph semantic levels in the encoder and decoder are almost identical.

The skip pathway was constructed as follows: The node's output is represented by  $x^{i,j}$ . According to the encoder sub-network, the downsampling layer is indexed by  $i$ , and the dense block's convolution layer is indexed by  $j$  along the skip

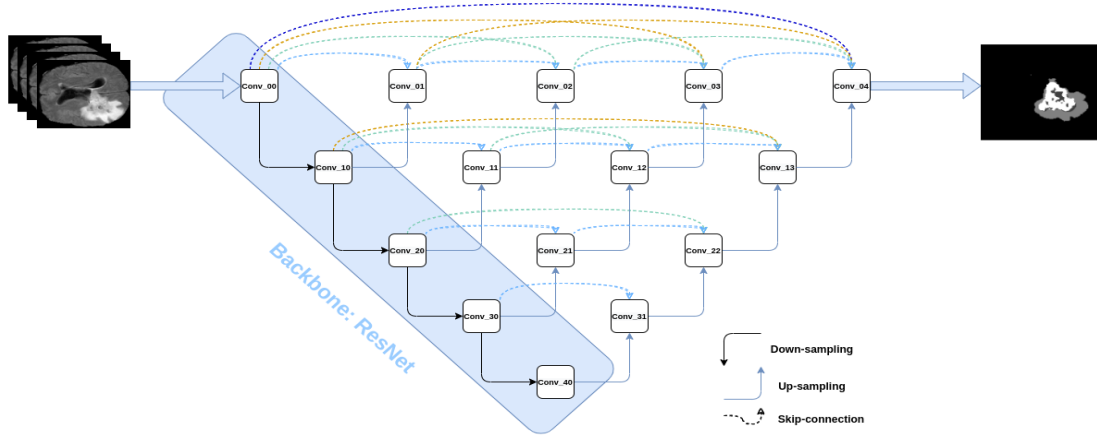


Fig. 3. Proposed residual U-Net++ architecture.

pathway. The mathematical equation that follows can be used to determine  $x^{i,j}$ :

$$x^{i,j} = \begin{cases} CR\{x^{i-1,j}\}, & j = 0. \\ CR\left\{\left[\int_{i-1}^{k=0} x^{i,k}, U(x^{i+1,j-1})\right]\right\}, & j > 0. \end{cases} \quad (2)$$

Where  $[\cdot]$  signifies the concatenation layer,  $U(\cdot)$  stands for the upsampling operations, and  $CR\{\cdot\}$  represents a convolution operation followed by a ReLU activation. The first skip pathway in Residual U-Net++ is further explained in Fig. 4.

The following applied equations illustrate the detailed analysis of the first skip pathway of Residual U-Net++:

$$x^{0,1}(conv\_01) = CR\{[x^{0,0}, U(x^{1,0})]\} \quad (3)$$

$$x^{0,2}(conv\_02) = CR\{[x^{0,0}, x^{0,1}, U(x^{1,1})]\} \quad (4)$$

$$x^{0,3}(conv\_03) = CR\{[x^{0,0}, x^{0,1}, x^{0,2}, U(x^{1,2})]\} \quad (5)$$

$$x^{0,4}(conv\_04) = CR\{[x^{0,0}, x^{0,1}, x^{0,2}, x^{0,3}, U(x^{1,3})]\} \quad (6)$$

This pairing has two advantages: first, U-Net++ reduces the semantic gap between the feature maps of the encoder and decoder subnetworks; second, the residual unit makes network training easier and solves the degradation issue, increasing the accuracy of Residual-Attention U-Net++.

#### D. Loss Function

The MRI brain tumor segmentation challenge displays a significant class imbalance, with healthy voxels making up 98.46% of the total voxels, necrosis and non-enhancing voxels accounting for 0.23% of voxels, edema accounting for 1.02% of voxels, and enhancing tumors accounting for 0.29% of voxels. Generalized dice loss (GDL) [16] is a loss function

often used and resistant to data imbalance. It helps bridge the gap between evaluation metrics and training samples. Weighted cross entropy (WCE) [17] has also been used to solve class imbalance and multi-task training problems. As a result, we developed a union loss function  $L$  that combined generalized dice loss  $L_{GDL}$  and weighted cross entropy loss  $L_{WCE}$  to give improved supervision for model training [18]. Loss function  $L$  is represented as follows:

$$L = L_{GDL} + \lambda.L_{WCE} \quad (7)$$

where  $L_{GDL}$  represents the generalized dice loss is defined as Eq. 8 and  $L_{WCE}$  represents the weighted cross entropy loss is defined as Eq. 9

$$L_{GDL} = 1 - 2 \frac{\sum_{i=1}^N \omega_i \sum_k g_{ik} p_{ik}}{\sum_{i=1}^N \omega_i \sum_k (g_{ik} + p_{ik})} \quad (8)$$

$$L_{WCE} = - \sum_k \sum_{i=1}^N \omega_i g_{ik} \log(p_{ik}) \quad (9)$$

Where  $N$  is the total number of labels, and  $\omega_i$  is the weight for the  $i$ th label. For generalized dice loss,  $\omega_i$  is set to

$$\omega_i = \frac{1}{(\sum_k g_{ik})} \quad (10)$$

$p_{ik}$  represents the  $i$ th and  $k$ th pixel of the segmented binary image value.

$g_{ik}$  represents the  $i$ th and  $k$ th pixel of the binary ground truth image value.

#### E. Evaluation Metrics

There are four evaluation metrics used in measuring segmentation performance for Residual U-Net++ approach. These metrics are examined by comparing the segmented image  $P$  to the manually segmented image  $T$ .

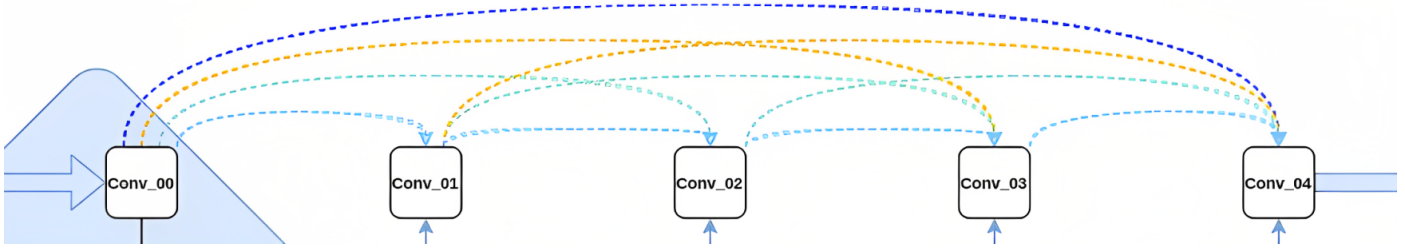


Fig. 4. The first skip pathway of residual U-Net++.

1) *Dice Similarity Coefficient (DSC)*: The dice similarity coefficient is a metric to measure the performance of the segmentation that is used to evaluate it based on the intersection between both segmented images, manual and predicted, given as

$$DSC = 2 \frac{|T \cap P|}{|T| + |P|} \quad (11)$$

Where  $T$  represents the manually segmented image as several elements, and  $P$  represents the predicted segmented image sets as several elements. Zero is the worst DSC value, and one is the best [19].

2) *Sensitivity (SEN)*: Sensitivity is a metric to measure the performance of true positives of the correct detection ratio, given as

$$SEN = \frac{|TP|}{|TP| + |FN|} 100 \quad (12)$$

Where  $TP$  is the number of correctly detected positive pixels (a “true positive”),  $FP$  is the number of incorrectly detected negative pixels (a “false positive”), and  $FN$  is the number of incorrectly detected positive pixels (a “false negative”) [19].

3) *Specificity (SP)*: Specificity is a metric to measure the performance of true negatives of the correct detection ratio, given as

$$SP = \frac{|TN|}{|TN| + |FP|} 100 \quad (13)$$

Where  $TN$  is the number of correctly detected negative pixels (a “true negative”), and  $FP$  is the number of incorrectly detected negative pixels (a “false positive”) [19].

4) *Ninety-Five Percentage Hausdorff Distance (HD)*: Ninety-five percent Hausdorff distance is a performance metric that measures the 95<sup>th</sup> percentile of the maximum distance of the reference image set to the nearest point in the predicted image set, given as

$$HD(P, T) = \max[d(T, P), d(P, T)], \quad (14)$$

Where  $T$  represents the number of elements in the manually segmented image, and  $P$  represents the number of elements in the predicted segmented image sets. Both are a finite set [19].

Regarding all of these performance metrics that we used, each one of them is used according to need. DSC is the most accurate performance metric due to evaluating the intersection

between manual and predicted segmented images, and it is the most commonly used. Also, HD is the second performance metric that is frequently used. SEN is used when the true positives are the attention point, and SP is used when the true negatives are the attention point.

## IV. RESULTS

As mentioned above, our experiments use three datasets: BraTS 2017, BraTS 2019, and BraTS 2021.

### A. BraTS 2017

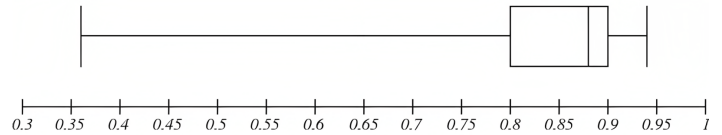


Fig. 5. Box plot for the DSC of results from the BraTS 2017 dataset.

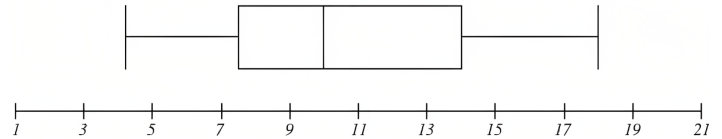


Fig. 6. Box plot for the HD of results from the BraTS 2017 dataset.

### B. BraTS 2019

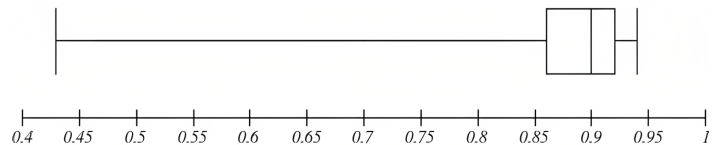


Fig. 7. Box plot for the DSC of results from the BraTS 2019 dataset.

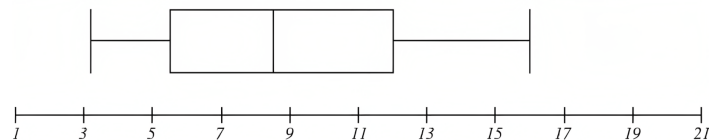


Fig. 8. Box plot for the HD of results from the BraTS 2019 dataset.

TABLE II. COMPARED SEGMENTATION RESULTS WITH DIFFERENT DSC METHODS FOR BRATS 2017

Author	Method	Whole	Core	Enhancing
Zhang et al. [4]	U-Net	0.852	0.759	0.698
Zhang et al. [4]	ResU-Net	0.862	0.774	0.732
Zhang et al. [4]	AGResU-Net	0.870	0.777	0.709
<b>Proposed</b>	<b>Residual U-Net++</b>	<b>0.876</b>	<b>0.862</b>	<b>0.833</b>

TABLE III. COMPARED SEGMENTATION RESULTS WITH DIFFERENT DSC METHODS FOR BRATS 2019

Author	Method	Whole	Core	Enhancing
Zhang et al. [4]	AGResU-Net	0.870	0.777	0.709
Aboelenein et al. [20]	MIRAU-Net	0.885	0.879	0.818
Sheng et al. [21]	ResU-Net	0.881	0.796	0.707
<b>Proposed</b>	<b>Residual U-Net++</b>	<b>0.892</b>	<b>0.892</b>	<b>0.853</b>

C. BraTS 2021

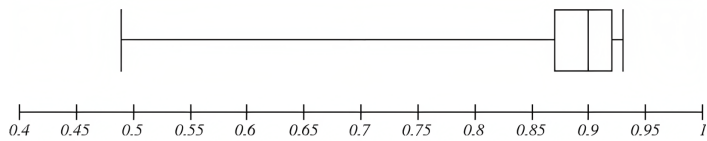


Fig. 9. Box plot for the DSC of results from the BraTS 2021 dataset.

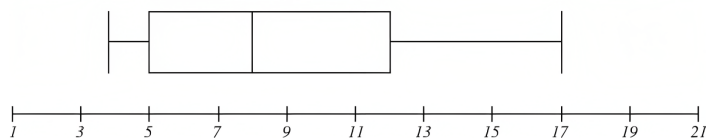


Fig. 10. Box plot for the HD of results from the BraTS 2021 dataset.

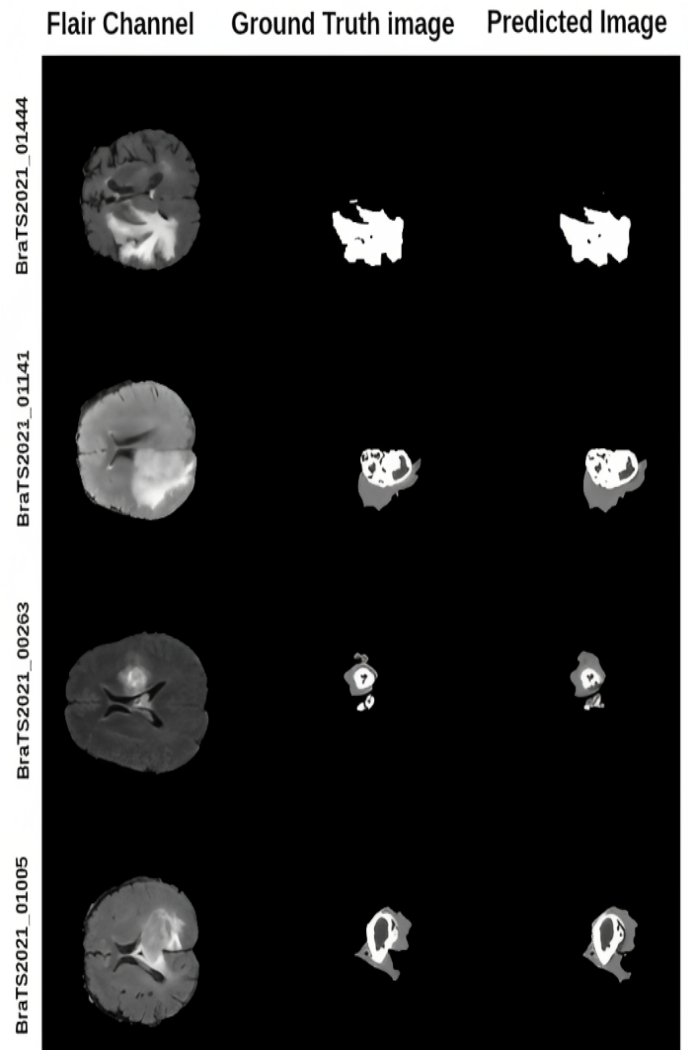


Fig. 11. Samples of segmentation results from the BraTS 2021 dataset.



TABLE IV. COMPARED SEGMENTATION RESULTS WITH DIFFERENT DSC METHODS FOR BRA TS 2021

Author	Method	Whole	Core	Enhancing
Yan et al. [22]	U-Net	0.870	0.870	0.800
Ahmed et al. [23]	MS UNet	<b>0.919</b>	0.862	0.824
Raza et al. [24]	dResU-Net	0.866	0.835	0.800
<b>Proposed</b>	<b>Residual U-Net++</b>	0.903	<b>0.896</b>	<b>0.857</b>

TABLE V. MEAN SCORES OF TESTING DIFFERENT MODELS ON BRA TS 2017, BRA TS 2019, AND BRA TS 2021 DATA FOR DSC, SENSITIVITY, SPECIFICITY, AND HAUSDORFF DISTANCE

Dataset	DSC	Sensitivity	Specificity	HD
BraTS 2017	0.876	0.94	<b>0.99</b>	11.2
BraTS 2019	0.892	0.96	<b>0.99</b>	10.2
BraTS 2021	<b>0.903</b>	<b>0.96</b>	<b>0.99</b>	<b>9.9</b>

## V. DISCUSSION

The results show that the proposed Residual U-Net++ model uses three datasets: BraTS 2017, BraTS 2019, and BraTS 2021. We present the results for each dataset separately and evaluate it using four evaluation metrics: DSC, Sensitivity, Specificity, and HD.

Section IV-A shows the results for BraTS 2017. Table II, Regarding the DSC value of the whole tumor, core tumor, and enhancing tumor, Residual U-Net++ performs better than U-Net, ResU-Net, and AGResU-Net stand-alone approaches. Fig. 5 shows the box plot for the DSC results to observe that the almost results are above 80% from the first quartile and are at most 95%. To get a sense of them, its values representing HD are concluded in a box plot, as shown in Fig. 6.

Section IV-B shows the results for BraTS 2019. Table III, Regarding the DSC value of the whole tumor, core tumor, and enhancing tumor, Residual U-Net++ performs better than other approaches, especially ResU-Net as a stand-alone approach without nested U-Net. Fig. 7 shows the box plot for the DSC results to observe that the almost results are above 86% from the first quartile and are at most 94%. To get a sense of them, its values representing HD are concluded in a box plot, as shown in Fig. 8.

Section IV-C shows the results for BraTS 2021. Table IV, In terms of the DSC value of the core tumor and enhancing tumor, Residual U-Net++ performs better than other approaches. Also, it is slightly different from other top values of the whole tumor. Fig. 9 shows the box plot for the DSC results to observe that the almost results are above 87% from the first quartile and are at most 94%. To get a sense of them, its values representing HD are concluded in a box plot, as shown in Fig. 10.

From Table V, We get the complete results for all evaluation metrics: DSC, Sensitivity, Specificity, and HD, and for all datasets. We observe that BraTS 2021 gets more accurate results than BraTS 2019 and BraTS 2017, which is regarding the amount of data because BraTS 2021 is the largest dataset compared with BraTS 2019 and BraTS 2017. Also, BraTS 2019 gets more accurate results than BraTS 2017 for the same reason. Furthermore, the large amount of data gets more variant

cases for the tumor.

This proposed model enhances the results compared with other approaches by 0.23 for the DSC value of the core tumor and 0.05 for the DSC value of the enhancing tumor. Fig. 11 shows samples of segmentation results for BraTS 2021.

## VI. CONCLUSIONS

In this research, we proposed the Residual U-Net++ model, which combined ResU-Net modules and U-Net++ with a single U-Net design. Small-scale brain tumor segmentation was improved using ResU-Net++. We comprehensively evaluated the Residual U-Net++ model using three reliable BraTS 2017, BraTS 2019, and BraTS 2021 brain tumor standards. The results of the experiments demonstrated that Residual U-Net++ outperformed U-Net and ResU-Net. On all three datasets, the experimental results indicated that the suggested Residual U-Net++ model performed better in segmentation tasks when compared with other approaches, including UNet++ and other models. Due to the 2D U-Net model's limitations, Residual U-Net++ significantly lost local characteristics and context information across various slices. We will investigate 3D network design in the future to enhance Residual U-Net++ segmentation Net's performance and expand the enhanced architecture to other datasets to demonstrate its generalizability.

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# Multi-dimensional Data Aggregation Scheme Supporting Fault-Tolerant Mechanism in Smart Grid

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**Abstract**—With the large-scale deployment of smart grids, the scheme of smart grid data aggregation has gradually enriched in recent years. Based on the principle of protecting user privacy, existing schemes usually choose to introduce a trusted third party (TTP) to participate in the collaboration. However, this also increases the risk of privacy exposure as the attacker can target the TTP which provides services to smart grid operators. In addition, many existing schemes do not take into account the operational requirements of smart meters in case of failure. Furthermore, some schemes ignore the control center's demand for analyzing multi-dimensional data, which causes a lot of inconvenience in actual operation. Therefore, a fault-tolerant multi-dimensional data aggregation scheme is proposed in this paper. We have constructed a scheme without TTP participation in collaboration, and also meet the following two requirements. The scheme not only ensures the normal operation of the system when the smart meter fails but also meets the requirements of the control center for multi-dimensional data analysis. Security analysis shows that the proposed scheme can resist external attack, internal attack, and collusion attack. The experimental results show that the proposed scheme improves the fault tolerance and reduces the computational cost compared with the existing schemes.

**Keywords**—Cryptography; fault tolerance; privacy; multi-dimensional data aggregation; encryption; smart grid

## I. INTRODUCTION

The smart grid [1], [2] is a modern power grid that is significantly different from the traditional power grid [3], [4]. Traditional power grids can only transmit power from power plants to users, while smart grids can communicate with other power systems through power data. Therefore, the smart grid can significantly improve the reliability, flexibility, security, efficiency and load adjustment/balancing of the power system, and has the potential to replace the traditional power grid. In addition, an important characteristics of smart grid is that real-time power data can be counted to reflect the personal behavior of power users, such as whether they are bathing, watching TV, and what electrical appliances are being used at home. However, if the user's power information plaintext is maliciously attacked during the transmission of public channels, personal information will be leaked. Therefore, it is an urgent need to protect the user's electricity information so that malicious attackers cannot get the correct information. For this reason, many scholars have introduced smart grid data aggregation schemes to protect user's privacy. However, the following problems are ignored in some schemes.

Firstly, scheme [18] indicates that schemes [17], [23] cannot resist collusion attack. Because in the above two

schemes, the encryption key for smart meter users to encrypt power information is only the public key of another entity in the system, and there is no blinding factor embedded in the encryption process of the meter. On the one hand, if the aggregator (AG) colludes with the control center (CC), CC will receive the user's power consumption ciphertext sent by AG. At this time, CC is curious about the electricity data information of a user. It will decrypt the ciphertext using a private key to obtain the user's electricity plaintext, leading to the leakage of user privacy. On the other hand, if the legal person in CC is curious about the user's electricity information, he can obtain the data by eavesdropping and then use CC's decryption key to obtain the user's personal privacy information.

Secondly, schemes [15], [27] choose a trusted third party (TTP) to participate in collaboration when building a system, but this can cause fault tolerance problems or low flexible structures. In the registration phase, TTP generates public parameters and key pairs, distributing them to other entities. To resist collusion attack, TTP distributes blinding factors to each smart meter and CC. Only the correct number of meters and corresponding CC can eliminate the influence of blinding factors. This ensures that CC can only obtain the total power consumption of the entire region, rather than the power information of individual users. However, the system constructed in the above way may have the following problems after deployment. Firstly, this system can no longer add/delete smart meter after all smart meter users have registered. Secondly, if the smart meter fails, CC cannot decrypt the aggregated ciphertext.

Thirdly, smart meters in some scenarios [5], [18] can only report one-dimensional data type. However, in real life, smart meters need to report multi-dimensional data types. For example, these data can be classified by different electrical appliances (air conditioner, refrigerator, washing machine, rice cooker, etc.). By using these multi-dimensional data, the smart grid can make more efficient and reasonable power dispatching [29].

Finally, in Chen *et al.*'s scheme [6], data aggregation is constructed by elliptic curve cryptography (ECC), which protects users' privacy while reducing computational cost and communication cost. However, the scheme has low fault tolerance. Furthermore, the system cannot operate normally in the case of smart meter failure. In the scheme, CC decrypts the ciphertext as follows:  $C_{uk} = g_x \cdot \prod_{i=1}^n c_{ik} = e \left( H(t_i), d_x \cdot R_A + \sum_{i=1}^n R_{si} \right) \cdot g^{\sum_{i=1}^n m_{ik}} = g^{\sum_{i=1}^n m_{ik}}$ , where  $d_x$  is the private key of CC,  $R_A$  is the public key of all smart

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meters, and  $\sum_{i=1}^n R_{si}$  is the decryption key of all smart meters. If CC wants to decrypt correctly, it needs to make the equation:  $d_x \cdot R_A + \sum_{i=1}^n R_{si} = 0$ . Assuming there existing smart meter fails, so that it cannot report power data ciphertext in a short time. In the result, CC cannot get the equation contained in the ciphertext information  $d_x \cdot R_A + \sum_{i=1}^n R_{si} \neq 0$ . Because the encryption key  $R_{si}$  is only known by the smart meter, other entities cannot be obtained, so CC cannot make the bilinear pairing  $e\left(H(t_i), d_x \cdot R_A + \sum_{i=1}^n R_{si}\right) = 1$ , and cannot get the power data  $g^{\sum_{i=1}^n m_{ik}}$ , this represents CC decryption failure.

Based on the above reasons, we propose a multi-dimensional data aggregation scheme supporting fault-tolerant mechanism in smart grid. For ease of description, the proposed scheme is referred to simply as MAFTM in the remainder of the paper. The proposed scheme not only designs fault repair mechanism to improve fault tolerance but also achieves multi-dimensional data aggregation using super incremental sequence. The main contributions of the proposed scheme are as follows.

- 1) Fault-tolerant mechanism: After the system completes the registration, even if the smart meter fails, the system can still work properly. By using this mechanism, the normal smart meter data is not affected by the damaged meter, and the maximum utilization of the collected data is realized.
- 2) Multi-dimensional data aggregation: The built system can reports multi-dimensional data types by introducing super-incremental sequences, and CC can perform mean/variance analysis on these power data to better regulate power.
- 3) No trusted third party (TTP): In order to avoid the adversary attacks against TTP, there is no TTP participating in the proposed scheme. In addition, there is no need to trust external entities.
- 4) Insider attacks resiliency: Smart meters use independent keys to encrypt power data, and CC cannot decrypt the ciphertext information of a single meter through the private key before receiving the aggregated ciphertext.

The remaining part of this paper consists of six chapters: The Section II describes in detail the research achievements of scholars in data aggregation in recent years, as well as the relevant technologies used. In the Section III, we introduced the techniques used in the solution. In the Section IV, we introduced the system model and security model of the proposed scheme. In the Section V, we detailed the overall process of the system. In the Section VI, we conducted safety analysis on the proposed scheme through four aspects. Finally, in the Section VII, we summarized this article.

## II. RELATED WORK

The smart grid has undergone many changes from its initial concept to its current widespread application. The traditional data aggregation scheme can only allow CC to get total

power information for the entire HAN area, which is called one-dimensional data aggregation. When CC conducts a fine-grained analysis of one-dimensional power data, the scheme cannot meet the requirements. However, multi-dimensional data aggregation can turn various types of power data into aggregated ciphertext. CC obtains the sum of power plaintext information for a cycle period in the entire region by decrypting the aggregated ciphertext. Because the electricity from power plants cannot be easily stored, CC formulates power scheduling and regulates electricity prices based on data information from each time. Multidimensional data aggregation can better assist CC in performing the above operations and achieve more fine-grained analysis results. Therefore, many scholars have proposed data aggregation schemes.

In the research of multidimensional data aggregation in recent years, homomorphic encryption cryptosystem is a widely used privacy protection technology. Some schemes [7], [8] use homomorphic encryption technology to build systems, and use the characteristics of additive homomorphism to operate ciphertext as well as plaintext directly, but they can do better in terms of communication efficiency. The time efficiency required to calculate and receive data in a smart grid is also one of the factors we need to consider. In order to achieve more efficient computing cost and minimize communication latency as much as possible, Lu *et al.* [9] constructed a more efficient aggregation scheme that can consume less system resources in terms of computational costs named EPPA in 2012. The above scheme utilizes the characteristics of super incremental sequences to construct multidimensional data, enabling CC to separate the total electricity consumption data of different sequences through algorithms when decrypting ciphertext data and utilizes the Paillier homomorphic cryptosystem [10] to encrypt power consumption data. In addition, in order to improve validation efficiency, this scheme achieves batch validation in the aggregation stage based on the Weil pairing [11] proposed. A trusted organization OA is also introduced to guide the system. In 2019, Chen *et al.* [12] constructed an aggregation scheme. The scheme utilizes the Paillier homomorphic Cryptosystem to implement fine-grained data analysis requirements. In this scheme, the user can upload different types of power data through the electricity consumption values for different types of electrical appliances. In addition, CC can also perform variance analysis on multi-dimensional data. In 2019, Ming *et al.* [13] considered that one-dimensional data cannot meet the requirements of power suppliers for fine-grained analysis of power data when scheduling electricity, and proposed a multidimensional aggregation scheme called P2MDA. P2MDA uses super-increasing sequence [14] and ElGamal homomorphic encryption technology to ensure user privacy while completing multi-dimensional data aggregation with less computational cost, so that smart meters can classify power consumption data based on power supply devices. The above aggregation scheme is mainly studied for multi-type data requirements and efficient computing performance. But it is worth noting that they all rely on TTP to build systems, which can provide opportunities for malicious attackers.

In addition, some scholars try to implement multi-dimensional data aggregation without using homomorphic encryption technology. Committed to accelerate the efficiency of authentication and reduce the computational cost, Boudia *et al.* [15] set up an aggregation scheme based on ECC that can

transmit multiple data types in 2017. The scheme completed multidimensional data reporting without the need for pairing operations, which makes it low computational cost. So as to resist human-factor-aware differential aggregation (HDA) attack, Jia *et al.* [16] proposed two different aggregation protocols, one is the basic aggregation protocol, and the other is an improved advanced aggregation protocol in 2017. In this scheme, smart meter users divide data information into  $M$  shares when uploading power consumption data. Therefore, only aggregators with the correct key can correctly aggregate power data. However, the disadvantage of this scheme is that the system cannot decrypt normally when facing the problem of meter failure in real life.

Furthermore, some scholars consider that smart meters may fail in real life. Therefore, they study how to improve the fault tolerance of aggregation schemes. Xue *et al.* [17] constructed an aggregation scheme for service outsourcing called PPSO in 2019. In this scheme, CC can respond to the dynamic electricity price demand in real-time through the analysis of aggregated data. PPSO aims to improve system fault-tolerance and flexibility. Considering that smart meters may fail in real life, Wang *et al.* [18] focused their attention on the fault tolerance of the system and proposed a scheme. In order to improve fault tolerance, the scheme uses Paillier homomorphic encryption without the participation of TTP and the blinding factor  $K$  negotiated among smart meters. To build a dynamic framework without TTP, Xue *et al.* [19] conducted research on fault Tolerance and proposed a scheme in 2020. The scheme uses Paillier homomorphic encryption and built a dynamic secret sharing to improve fault tolerance. In the above scheme, smart meter users can ensure that the system will not collapse due to the failure of some smart meter through dynamic secret sharing, which improves the fault tolerance of the system. The disadvantage is that Xue *et al.*'s scheme [17] unable to defend collude attacks, while Wang *et al.*'s scheme [18] requires additional computational cost to negotiate and preserve the information of the blinding factor  $K$ . Moreover, Xue *et al.*'s scheme [19] cannot perform multi-dimensional data aggregation.

Finally, some scholars have improved the performance of data aggregation schemes by combining different technologies. Wu *et al.* [20] utilized fog assistance to enhance the scheme's fault tolerance and protect user privacy in 2021. Lu *et al.* [21] introduced blockchain into the smart grid in 2021, utilizing the characteristics of blockchain to improve verification efficiency. In addition, Zhang *et al.* [24] implemented dual message encryption using a modified BGN homomorphic system and improved fault tolerance of the scheme using secret sharing technology in 2022. Zhao *et al.* [25] designed a smart and practical aggregation scheme based on the Fog server in 2020, protecting users' privacy and security.

In summary, in recent years, research on data aggregation schemes in smart grids has focused on multidimensional data types, whether TTP participates in collaboration, and fault tolerance. But most of the schemes are based on Paillier homomorphic encryption, the communication cost is high. On the one hand, some schemes consider reporting multi-dimensional data when building systems using TTP. However, these schemes ignore the fault tolerance of the system. On the other hand, some schemes improve the fault tolerance of

the system but cannot report multi-dimensional data types. In contrast, the proposed scheme uses elliptic curve cryptography [26] to construct the system, which can perform calculations more efficiently and effectively reduce computational costs. In addition, the fault-tolerant mechanism designed in this paper can ensure that CC can also obtain the power ciphertext of other normal meters when the smart meter fails.

### III. PRELIMINARIES

In this section, the related concepts used in the smart grid data aggregation scheme are mainly introduced.

#### A. Bilinear Pairing Map

The bilinear mapping pairing  $e : G_1 \times G_1 \rightarrow G_T$  used in this paper is defined based on the elliptic curve over finite field  $GF(q)$ , where  $q$  is a large prime. In the above definition, where  $G_1$  is an additive cyclic group and  $G_T$  is a multiplicative cyclic group, both  $G_1$  and  $G_T$  of orders  $p$ . In addition, the bilinear mapping pairing  $e : G_1 \times G_1 \rightarrow G_T$  also meets the following three conditions [30]

- 1) *Bilinearity*: For any  $P, Q \in G_1$  and  $x, y \in Z_p^*$ , we have  $e(xP, yQ) = e(P, Q)^{xy}$ .
- 2) *Non-degeneracy*: There are two elements  $P, Q \in G_1$  satisfying  $e(P, Q) \neq 1_{G_T}$ , where  $1_{G_T}$  is the identity element of  $G_T$ .
- 3) *Computability*: For all  $P, Q \in G_1$ , there exists a polynomial-time algorithm to compute  $e(P, Q)$ .

#### B. Superincreasing Sequence

In practical situations, CC needs to analyze multiple data types in order to better regulate electricity. In order to achieve the above goals, one of the key technologies used in this scheme is superincreasing sequence. A superincreasing sequence consists of a series of positive real numbers  $s_1, s_2, \dots$ , And this sequence also satisfies the requirement that the newly selected elements are much larger than all previously selected elements. In addition, we can write it in this form [31]:  $s_{n+1} > \sum_{j=1}^n s_j$ .

#### C. Elliptic Curve Cryptography

Koblitz and Miller proposed the definition of discrete logarithm problem on a set of points of an elliptic curve in 1985. Like RSA, ECC also belongs to a type of asymmetric key mechanism. ECC is an efficient cryptosystem for resource constrained devices. This is mainly attributed to ECC's ability to achieve better security performance with smaller key size, lower power consumption, and lower computational cost compared to other algorithms such as RSA.

In addition, the mathematical base of ECC lies on the hardness of the Elliptic Curve Discrete Logarithm Problem (ECDLP). ECDLP states that if there are two points  $P, Q \in E(p)$  (where  $E(p)$  is an elliptic curve) then it is mathematically difficult to find an integer  $n$  such that  $Q = nP$ . In our proposed scheme, the hardness of ECDLP is taken into consideration [32].

#### IV. MODELS

In this section, we made assumptions about two pieces of content. In the former, we define the three major entities in the system. In the latter, we assume the trust level of entities in the system and provide a brief introduction to security performance.

##### A. System Model

In this paper, the system requires the collaboration of three entities to function properly, which includes: Control Center (CC), Aggregator (AG) and Smart Meter (SM), where an aggregator and several smart meters form a Home Area Network (HAN). This paper mainly studies the power consumption of all smart meters in an HAN, we use  $n$  to express the total number of smart meter, namely  $SM_1, SM_2, \dots, SM_n$ . In addition, the image representation Fig. 1.

**Control Center (CC):** Throughout the entire system, CC, which is the highest management agency of the system, has powerful data analysis ability, computing power and huge storage space. CC is responsible for decrypting the power aggregate ciphertext information sent by the AG. Moreover, when the power information cannot be sent due to the fault of the meter, CC is also needed to make the system operate normally to ensure that the aggregated ciphertext information of the remaining smart meters is not affected.

**Aggregator (AG):** AG is the second layer in the system. Compared with CC, AG has lower computing power, lower security level and is more vulnerable to enemy attacks. During the communication process, AG will collect the power ciphertext information of all smart meters in HAN in real-time. If a smart meter fault is detected, AG will perform a fault repair mechanism. Otherwise, AG will directly aggregate the ciphertext. Finally, the aggregated ciphertext is sent to CC.

**Smart Meter (SM):** SM is the third layer in the system and can communicate bidirectionally with AG. In the registration phase, each SM will select a random number as its blinding factor, then uses the blinding factor and the public key of other entities to calculate the encryption key. During the communication process, SM periodically records the user's power information and encrypts it with an encryption key. Then, SM send this encrypted data to AG. In addition, SM may fail in the system, making data reporting impossible for a short time.

##### B. Security Model

In this paper, there are three different entities, and not all of them are fully trusted (such as some outsourced service providers), so it is necessary to define each entity. We assume that the CC and the AG entities in the system are *honest-but-curious*. This represents that CC and AG will work according to the aggregation protocol process, but they will also be curious about the uploaded data content after completing the work. In addition, SM users  $SM_1, SM_2, \dots, SM_n$  are *honest*. For each smart meter, they will collect data according to the process every cycle and then encrypt and upload them. They will not try to obtain the power information of other smart meter, nor will they cooperate with other entities to obtain the private data in the system.

Data transmission through insecure communication channels is vulnerable to various attacks, such as external attacks. More seriously, attackers may also steal users' power data by invading the databases of AG and CC. What needs to be ensured is that user privacy information is not stolen by malicious enemies This scheme aim to resist external attack, internal attack, and collusion attack.

#### V. OUR PROPOSED MAFTM SCHEME

We have divided the execution process of the MAFTM scheme into the following five steps: System Initialization, Entity Registration, SM Data Reporting, AG Data Aggregation, CC Decryption Ciphertext. As shown in Fig. 2, we also provided a schematic diagram of the execution process of the Fault-Tolerant Mechanism.

##### A. System Initialization

At this stage, CC generates the parameters required for elliptic curve cryptography, selects a secure hash function, sets the super increment sequence, and finally CC publishes the public parameters to other entities in the system.

- 1) CC generates a bilinear pairing map  $e : G_1 \times G_1 \rightarrow G_T$ , where  $G_1$  is an additive cyclic group,  $G_T$  is a multiplicative cyclic group and both  $G_1$  and  $G_T$  of orders  $q$ . Then CC will select  $P$  as the random generator of  $G_1$  and  $g$  as the random generator of  $G_T$ .
- 2) CC selects a secure hash function  $H : \{0, 1\}^* \rightarrow G_1$ .
- 3) CC defines  $d$  as the maximum value for each data type,  $n$  as the number of smart meters  $SM_i$ , and then selects a super increasing sequence  $\vec{a} = (a_1, a_2, \dots, a_k)$ , where  $a_1, a_2, \dots, a_k$  are large primes and satisfy  $\sum_{j=1}^{i-1} a_j \cdot n \cdot d < a_i$ ,  $i = 1, 2, 3, \dots, k$  and  $\sum_{i=1}^k a_i \cdot n \cdot d < q$ . CC calculates  $g_\phi = g^{a_\phi}$ ,  $\phi = 1, 2, 3, \dots, k$  and gets  $(g_1, g_2, \dots, g_k)$ .
- 4) Finally, CC will disclose the parameter

$$pp = \{q, G_1, G_T, e, P, g, \vec{a}, H, g_1, \dots, g_k\}$$

to other entities in the system.

##### B. Entity Registration

At this stage, each entity in the system will independently select random numbers and generate corresponding public and private key pairs, and then they will negotiate and calculate a public-private key pair for encryption/decryption of power data. Suppose the registration message is sent over a private and secure channel, which means that the adversary cannot launch an attack during the registration phase.

- 1) CC selects a random number  $sk_x \in Z_q^*$  as the private key and calculates that the public key is  $pk_x = sk_x \cdot P$ , CC sends  $pk_x$  to AG.
- 2) Meter  $SM_i$  selects a random number  $sk_i \in Z_q^*$  as the private key, calculates the public key as  $pk_i = sk_i \cdot P$ ,  $SM_i$  sends the public key  $pk_i$  to AG.

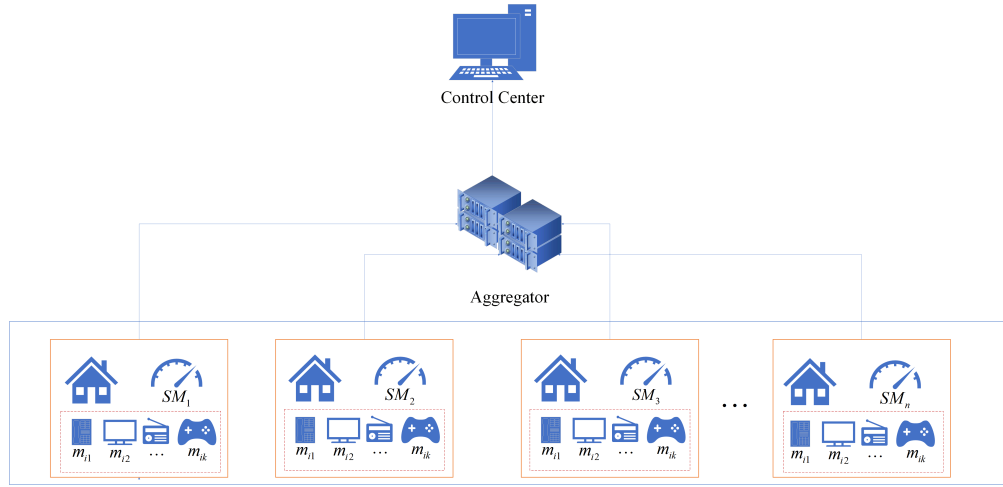


Fig. 1. System model.

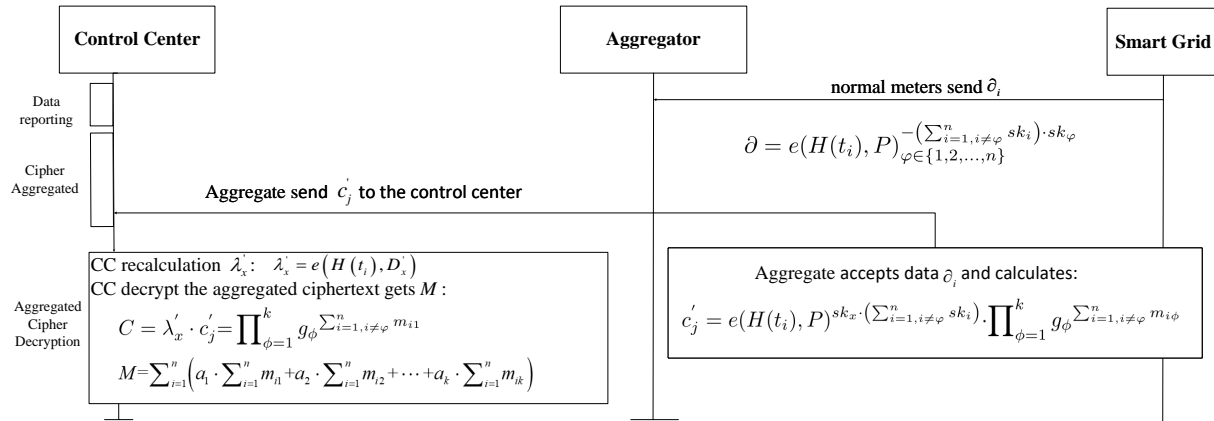


Fig. 2. Fault tolerance mechanism.

- 3) AG selects a random number  $sk_j \in Z_q^*$  as the private key and calculates the public key as  $pk_j = sk_j \cdot P$ . When AG receives the public key of all smart meters, it will calculate  $L_i = (\sum_{\beta=1}^i pk_{\beta} - \sum_{\beta=i+1}^n pk_{\beta} - pk_x)$  and send  $L_i$  to  $SM_i$  ( $i = 1, \dots, n$ ). After receiving  $L_i$ ,  $SM_i$  calculates the encryption key  $S_i = sk_i \cdot L_i$  for encrypting real-time power data.
- 4) AG calculates the sum  $pk_{\alpha} = \sum_{i=1}^n pk_i$  of the public keys of all  $SM_i$  and sends  $pk_{\alpha}$  to CC. CC computes the decryption key  $D_x = sk_x \cdot pk_{\alpha} = sk_x \cdot \sum_{i=1}^n pk_i$  to decrypt the total power data.

### C. SM Data Reporting

At the beginning of each data reporting cycle,  $SM_i$  collect multiple types of data  $m_{i1}, m_{i2}, m_{i3}, \dots, m_{ik}$ , where  $1, 2, 3, \dots, k$  represent the dimension of the data type and are encrypted using the encryption key  $S_i$ . The steps are as follows.

- 1) Smart meter  $SM_i$  extracts data  $m_{i1}, m_{i2}, \dots, m_{ik}$ .

- 2) Smart meter  $SM_i$  gets timestamp  $t_i$ .
- 3) Smart meter  $SM_i$  calculates  $\lambda_i = e(H(t_i), S_i)$ .
- 4) Smart meter  $SM_i$  encrypts  $m_{i1}, m_{i2}, \dots, m_{ik}$ :

$$c_i = \lambda_i \cdot g_1^{m_{i1}} \cdot g_2^{m_{i2}} \cdot \dots \cdot g_k^{m_{ik}} \quad (1)$$

### D. AG Data Aggregation

At this stage, AG sets a counter to troubleshoot the meter. If the meter is damaged, AG will perform a fault recovery operation. Otherwise, AG aggregates the ciphertext  $c_i$ . The steps are as follows.

- 1) AG sets counter  $count = count + 1$  to record whether there is a meter failure. If  $count=n$ , it represents the normal operation of all meters.

- AG calculates:

$$c_j = \prod_{i=1}^n c_i = \prod_{i=1}^n \lambda_i \cdot \prod_{\phi=1}^k g_{\phi}^{\sum_{i=1}^n m_{i\phi}} \quad (2)$$

- AG sends  $\{c_j\}$  to CC.



2) If  $count < n$ , it means that the meter fails and AG performs the recovery work:

- The fault meter public key is compiled into the set  $F = \{pk_\varphi\}_{\varphi \in \{1,2,\dots,n\}}$ .
- AG informs the rest of the normal meter  $\{SM_i\}_{i \neq \varphi}$  to calculate the missing data:

$$\partial_i = e(-sk_i \cdot H(t_i), pk_\varphi)_{\varphi \in \{1,2,\dots,n\}} \quad (3)$$

- AG receives data  $\{\partial_i\}$  for data aggregation:

$$\begin{aligned} \partial &= \prod_{i=1, i \neq \varphi}^n \partial_i = e\left(\sum_{i=1, i \neq \varphi}^n sk_i \cdot H(t_i), -pk_\varphi\right) \\ &= e(H(t_i), P)_{\varphi \in \{1,2,\dots,n\}}^{-\left(\sum_{i=1, i \neq \varphi}^n sk_i\right) \cdot sk_\varphi} \end{aligned} \quad (4)$$

$$\begin{aligned} c'_j &= \partial \cdot e(H(t_i), \sum_{i=1, i \neq \varphi}^n S_i) \cdot \prod_{\phi=1}^k g_\phi^{\sum_{i=1, i \neq \varphi}^n m_{i\phi}} \\ &= e(H(t_i), P)^{sk_x \cdot \left(\sum_{i=1, i \neq \varphi}^n sk_i\right)} \cdot \prod_{\phi=1}^k g_\phi^{\sum_{i=1, i \neq \varphi}^n m_{i\phi}} \end{aligned} \quad (5)$$

- Then AG sends  $\{c'_j, F\}$  to CC and inform the occurrence of meter damage.

#### E. CC Decryption Ciphertext

At this stage, CC obtains power plaintext by decrypting aggregated ciphertext. If the meter damage information sent by AG is received, CC will recalculate the decryption key  $D'_x$  to decrypt the aggregate ciphertext  $c_j$ .

- 1) CC computes  $\lambda_x = e(H(t_i), S_i)$  under normal condition. Then the decryption operation is performed:

$$C = \lambda_x \cdot c_j = g_1^{\sum_{i=1}^n m_{i1}} \dots g_k^{\sum_{i=1}^n m_{ik}} \quad (6)$$

The final control center gets  $M$ :

$$\begin{aligned} M &= \sum_{i=1}^n \left( a_1 \cdot \sum_{i=1}^n m_{i1} + \dots + a_k \cdot \sum_{i=1}^n m_{ik} \right) \\ &= \log_g C \end{aligned} \quad (7)$$

- 2) If the meter damage information is received, CC recalculates the decryption key  $D'_x$ :

$$D'_x = sk_x \cdot pk_\alpha = sk_x \cdot \sum_{i=1, i \neq \varphi}^n pk_i \quad (8)$$

$$\lambda'_x = e\left(H(t_i), S'_x\right) \quad (9)$$

Then the decryption operation is performed:

$$C = \lambda'_x \cdot c'_j = \prod_{\phi=1}^k g_\phi^{\sum_{i=1, i \neq \varphi}^n m_{i\phi}} \quad (10)$$

Through Algorithm 1, the regional total power data of each data type is obtained:  $\eta_\phi = \sum_{i=1}^n m_{i\phi}$ ,  $\phi = 1, 2, 3, \dots, k$ . In addition, fault meter number is less than  $n/2$ , fault-tolerant mechanism can run normally.

The Algorithm 1 execution process is as follows:

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#### Algorithm 1 Multidimensional data extraction.

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**Input:** superincreasing sequence  $\vec{a}$  and  $M$

**Output:**  $\eta_\phi$  for  $\phi = 1, 2, \dots, k$

**Begin:**

```

1:   Set  $X = M$ 
2:   for  $\phi = k$  to 1 do
3:      $\eta_\phi = \frac{X - (X \bmod a_\phi)}{a_\phi}$ 
4:   end
5:   return  $(\eta_1, \eta_2, \dots, \eta_k)$ 
end

```

---

Where:

$$\begin{aligned} X = M &= a_1 \sum_{i=1}^n m_{i1} + a_2 \sum_{i=1}^n m_{i2} + \dots \\ &+ a_{k-1} \sum_{i=1}^n m_{i(k-1)} + a_k \sum_{i=1}^n m_{ik} \end{aligned}$$

For any data type less than constant  $d$ , we can obtain the following results:

$$\begin{aligned} a_1 \sum_{i=1}^n m_{i1} + a_2 \sum_{i=1}^n m_{i2} + \dots + a_{k-1} \sum_{i=1}^n m_{i(k-1)} \\ < a_1 \sum_{i=1}^n d + a_2 \sum_{i=1}^n d + \dots + a_{k-1} \sum_{i=1}^n d \\ &= \sum_{j=1}^{k-1} a_j \cdot n \cdot d < a_k \end{aligned}$$

So, gets:

$$\begin{aligned} X \bmod a_k &= a_1 \sum_{i=1}^n m_{i1} + \dots + a_{k-1} \sum_{i=1}^n m_{i(k-1)} \\ \eta_k &= \frac{X - (X \bmod a_k)}{a_k} = \sum_{i=1}^n m_{ik} \end{aligned}$$

Therefore, we can use Algorithm 1 to obtain:

$$\eta_\phi = \sum_{i=1}^n m_{i\phi}, \phi = 1, 2, 3, \dots, k \quad (11)$$

## VI. SAFETY ANALYSIS

In practical applications, privacy security is one of the most concerning issues for users. We discuss the security of the system from the following four aspects: Against External Attack, Internal (AG) Attack, Collusion (AG and CC) Attack, and Fault tolerance.

### A. Against External Attack

Malicious attackers will use a series of attack methods to obtain information, among which they use communication channels to steal unauthorized information, which is referred to as external attack. In this system environment, the SM encrypts the power data by the encryption key  $S_i = sk_i \cdot L_i$ , where  $L_i = \left(\sum_{\beta=1}^i pk_\beta - \sum_{\beta=i+1}^n pk_\beta - pk_x\right)$ . If the external attacker obtains the encrypted information  $c_i = \lambda_i \cdot g_1^{m_{i1}} \cdot g_2^{m_{i2}} \cdot \dots \cdot g_k^{m_{ik}}$  (where  $\lambda_i = e(H(t_i), S_i)$ ) of the smart meter  $SM_i$ . So as to decrypt the ciphertext  $c_i$ , external attackers need to make  $e(H(t_i), P)^{sk_i \cdot \left(\sum_{\beta=1}^i sk_\beta - \sum_{\beta=i+1}^n sk_\beta - sk_x\right)} = 1$ . This moment, the external attacker first needs to get the  $sk_i$  of the

$SM_i$ , then obtain the public key  $pk_i, i \in \{1, 2, \dots, n\}$  of each smart meter and the public key  $pk_x$  of CC. Finally, external attackers calculate  $-S_i = -L_i \cdot sk_i$  to decrypt the encrypted information  $c_i$ . However, the private key  $sk_i$  of the smart meter  $SM_i$  is only known to the entity itself, and the public keys of SM/CC are sent through private and secure channels during the registration phase, which cannot be obtained by outsiders. Therefore, external attackers cannot calculate  $-S_i = -L_i \cdot sk_i$  and cannot decrypt encrypted information.

If an external attacker obtains the aggregate ciphertext  $c_j = e(H(t_i), P)^{-sk_x \cdot (\sum_{i=1}^n sk_i)} \cdot \prod_{\phi=1}^k g_\phi^{\sum_{i=1}^n m_{i\phi}}$  sent by AG to CC through eavesdropping on the communication channel, they want to decrypt the aggregate ciphertext. As known from the aggregate ciphertext, an attacker who wants to decrypt data needs to make  $e(H(t_i), P)^{-sk_x \cdot (\sum_{i=1}^n sk_i)} = 1$ . At this time, the attacker needs to obtain  $sk_x$  of CC and  $pk_i, i \in \{1, 2, \dots, n\}$  of all smart meters. However, this part of the information is also not available to other entities and external personnel. In addition, if an external attacker obtains the  $sk_x$  of CC and the  $pk_i, i \in \{1, 2, \dots, n\}$  of all smart meters, he can only obtain information on total electricity consumption, and unable to get the real time power information of a user through aggregated data. Through the above discussion, MFATM can effectively resist external attack initiated by malicious attackers

### B. Internal (AG) Attack

Internal attackers will search for suitable devices (such as lost legitimate AG) to steal unauthorized power consumption data, a process known as internal (AG) attack. In the aggregation stage, the legitimate AG collects the ciphertext information of all smart meters. Although AG can get the power ciphertext of a user at this stage, the user's electricity usage information  $m_i$  cannot be recovered from the ciphertext  $c_i = \lambda_i \cdot g_1^{m_{i1}} \cdot g_2^{m_{i2}} \cdot \dots \cdot g_k^{m_{ik}}, \lambda_i = e(H(t_i), S_i)$ . As in ciphertext  $c_i$ , the attackers and those who know the public key information of all entities in the system. So AG only demand to obtain the  $sk_i$  of  $SM_i$  to construct the bilinear pairing  $e\left(H(t_i), \left(\sum_{\beta=1}^i pk_\beta - \sum_{\beta=i+1}^n pk_\beta - pk_x\right)\right)^{-sk_i}$ . However, the  $sk_i$  is only known to the entity itself. Therefore, internal attack through aggregators cannot decrypt ciphertext data. In addition, AG aggregates the ciphertexts of  $n$  smart grid devices into a new total power data ciphertext  $c_j = \prod_{i=1}^n c_i = e(H(t_i), (\sum_{i=1}^n pk_i))^{sk_x} \cdot \prod_{\phi=1}^k g_\phi^{\sum_{i=1}^n m_{i\phi}}$  in the ciphertext aggregation phase. At this point, the attacker launches an attack on the aggregated ciphertext, hoping to steal the user's electricity usage information. The attacker needs to obtain the  $sk_x$  of CC. However, the  $sk_x$  is only known to the entity itself, and other entities and outsiders cannot be obtained. Therefore, the internal attack performed by AG in aggregation phase cannot decrypt the total ciphertext data.

### C. Collusion (AG and CC) Attack

Suppose AG and CC collude and share a single user's ciphertext  $c_i = \lambda_i \cdot g_1^{m_i}$ . However, SM uses the encryption key  $S_i = sk_i \cdot L_i$  for encryption, even if CC gets  $L_i$  calculated by AG, it cannot be decrypted. Because CC cannot get the private key  $sk_i$  of the smart meter  $SM_i$ . Furthermore, CC will try to use the decryption key  $D_x = sk_x \cdot pk_\alpha = sk_x \cdot \sum_{i=1}^n pk_i$  to

decrypt the ciphertext of a single SM. However, this situation is not feasible, because the decryption key  $D_x$  is designed based on all SMs. Therefore, the decryption key  $D_x$  does not have the ability to decrypt the ciphertext of a single SM.

### D. Fault Tolerance

The fault tolerance is realized, and the fault-tolerant mechanisms will not leak any useful electric data about the cooperative users. It is worth noting that, the fault means that the SM device cannot send data normally. If the CC and the AG faults occur, the SM intentionally sends false data, etc., they are not within the scope of the faults discussed in this article.

Fault-tolerance mechanisms typically include fault detection, troubleshooting, and aggregate recovery operations. We implement these functions through the following three steps:

- 1) AG uses a counter to detect faults;
- 2) When AG gets the missing data calculated by the normal SM, it cannot use the data to decrypt the user information;
- 3) When smart meter users in the system cannot upload power data normally due to equipment failure and other reasons, the recovery operation of the aggregator can enable normal smart meter users to calculate an aggregate value. In this case, CC can get an aggregated ciphertext, and after CC successfully decrypts it can get the power consumption data of other normal smart meter users. The maximum utilization rate of effective power data has been achieved.

In other words, even if some SM cannot work, the proposed scheme MAFTM can still restore the normal aggregation process through AG's fault tolerance mechanism, so that the power data information of other users is not affected. At the same time, because AG cannot infer the encryption key of the smart meter from the data calculated by the normal meter, it cannot be used to decrypt the user's personal information through these data, which protects the user's privacy. In fact, while implementing fault-tolerant mechanisms, we also need some additional computational cost. However, the additional computational cost itself is low, and the possibility of executing fault-tolerant mechanisms is also low (although there is a need for fault-tolerant mechanisms to exist). Considering the actual situation, we have also considered additional computational cost while designing a fault tolerance mechanism. In other words, the execution of fault-tolerant mechanisms only consumes relatively small computational resources.

## VII. PERFORMANCE

We will compare MAFTM scheme with some existing schemes in three aspects: Feature Comparison, Computational Cost, and Fault Folerance.

### A. Feature Comparisons

Firstly, we will compare MAFTM scheme with the other eight schemes [6], [14], [15], [17], [18], [19], [21], [27] for a feature comparison (the comparison results are shown in the Table I). Chen *et al.* [6] constructed a system without a TTP based on elliptic curve cryptography, and the computational

TABLE I. FUNCTION COMPARISON OF RELATED SCHEMES

Schemes	Against External Attack	Against Internal Attack	Against Collusion Attack	Fault Tolerance	Multidi Mensional	TTP Required
Chen <i>et al.</i> [6]	Yes	Yes	Yes	No	Yes	No
Lu <i>et al.</i> [14]	Yes	Yes	No	No	Yes	Yes
Boudia <i>et al.</i> [15]	Yes	Yes	No	No	Yes	Yes
Xue <i>et al.</i> [17]	Yes	Yes	No	Yes	No	No
Wang <i>et al.</i> [18]	Yes	Yes	Yes	Yes	Yes	No
Xue <i>et al.</i> [19]	Yes	Yes	Yes	Yes	No	No
Lu <i>et al.</i> [21]	Yes	Yes	Yes	No	Yes	Yes
Wang <i>et al.</i> [27]	Yes	Yes	No	Yes	Yes	No
MAFTM	Yes	Yes	Yes	Yes	Yes	No

cost is low. However, the system cannot operate normally when the smart meter fails, and the fault tolerance is low. Moreover, the multi-dimensional data reported in the scheme is encrypted multiple times in the same form, which increased computational burden on the system. Zuo *et al.* [22] shows that Lu *et al.*'s scheme [12] unable to defend collusion attack. Boudia *et al.*'s scheme [15] uses a relatively single public and private key pair to encrypt and decrypt plaintext when building the system. If CC accidentally obtains the power data of the meter, it will cause the problem of user privacy leakage, which means that the scheme [15] can only be applied to a three-tier system, and in the Chen *et al.*'s scheme [6]. Once again, it is pointed out that [15]. cannot resist collusion attack. Xue *et al.* [17] designed a fault-tolerant mechanism to improve fault tolerance, but Wang *et al.* [18] showed that the scheme [17] cannot resist collusion attack. Wang *et al.* [18] designed a fault-tolerant mechanism to improve fault tolerance and realized multi-subset data reporting. Xue *et al.* [19] used dynamic secret sharing to improve fault tolerance but could not achieve multi-dimensional data reporting. Lu *et al.* [21] used Paillier and introduced the blockchain into the edge layer to reduce the computational pressure on the edge layer. However, the scheme has low ability to resist faults and requires TTP for collaboration. Chen *et al.* [6] shows that Wang *et al.*'s scheme [27] cannot resist collusion attack. The proposed scheme MAFTM uses ECC to build the system. Smart meters use independent keys to encrypt power data. In the data reporting phase, smart meter users use the super increment sequence to report multidimensional data types. In addition deigns a fault-tolerant mechanism to solve the problem of meter failure. Performance analysis shows that while implementing fault-tolerant mechanisms, the proposed scheme MAFTM also has some improvement in computational cost compared to existing schemes.

After completing the feature comparison, we will compare the *Computational Cost* and *Fault Toletance*. Firstly, we choose the schemes [17], [18] with fault-tolerant mechanism. Secondly, we selected some classic data aggregation schemes [15], [27]. Therefore, in the subsequent part of the paper, we compare MAFTM scheme with the schemes [15], [17], [18], [27].

### B. Computational Cost

$T_e$  is an element exponentiation in  $Z_N^*$ ,  $T_{mul}$  is an element multiplication in  $Z_N^*$ ,  $T_b$  is a bilinear map pairing,  $T_H$  is a hash to an element of  $Z_N^*$ ,  $T_{H-G}$  is a hash to an element of  $G_1$ ,  $GT_e$  is an element exponentiation in  $G_T$ ,  $GT_{mul}$  is an element multiplication in  $G_T$ .  $G_{mul}$  is an element multiplication in  $G_1$ .

$G_{add}$  is an element addition in  $G_1$ .  $TD_e$  is time of Paillier encryption operation. Compared with exponential and pairing operations,  $G_{add}$  and  $T_H$  can be ignored and their values will not be calculated in the comparison. We use the java pairing-based cryptography (JPBC) [28] library to obtain the computational time of cryptographic operations, where  $N$  is 512 bits and  $G$  is 512 bits. The operating environment for this experiment is laptop with Intel Core i7-7700HQ (2.80GHz) processor, 8GB memory and 64-bit Window10 operating system. Finally, we use  $n$  to express the number of smart meters in the experimental simulation (see Table II for details).

TABLE II. COMPUTATIONAL TIME OF DIFFERENT OPERATIONS

Operation	time(ms)
$T_e$	0.88
$T_{mul}$	0.74
$T_b$	6.85
$TD_e$	5.33
$T_{H-G}$	1.31
$GT_e$	0.64
$GT_{mul}$	0.51
$G_{mul}$	9.7

1) *User's Computational Cost:* We assume that there are  $K$  data types. SM costs  $T_{H-G} + T_b + K(GT_{mul} + GT_e) + G_{mul}$  in the MAFTM scheme. Scheme [15], scheme [17] and scheme [27] cost  $2KG_{mul} + 2G_{mul}$ ,  $3T_e + 2T_{mul} + TD_e$  and  $2GT_e + GT_{mul} + G_{mul}$ , respectively. Scheme [18] requires an additional cost for constructing blind factors, totaling  $3T_e + 3T_{mul} + K(T_e + T_{mul}) + 4T_{H-G} + 3T_b$ .

2) *AG's Computational Cost:* In the MAFTM scheme and compared schemes [17], [18], [28], AG needs to execute  $n$  multiplication operations. The total computational cost is  $nT_{mul}$ . AG executes  $n$  addition operation in the scheme [15], the total cost is  $nG_{add}$ .

TABLE III. COMPUTATIONAL COSTS: ACOMPARATIVE SUMMARY

Schemes	SM	AG
MAFTM	$T_{H-G} + T_b + K(GT_{mul} + GT_e) + G_{mul}$	$nGT_{mul}$
Boudia[15]	$2KG_{mul} + 2G_{mul}$	$nG_{add}$
Xue[17]	$3T_e + 2T_{mul} + TD_e$	$nGT_{mul}$
Wang[18]	$3T_e + 3T_{mul} + K(T_e + T_{mul}) + 4T_{H-G} + 3T_b$	$nGT_{mul}$
Wang[27]	$2GT_e + GT_{mul} + G_{mul}$	$nGT_{mul}$

In summary, we will compare the computational costs of scheme MAFTM and scheme [15], [17], [18], [27] on the SM side and AG side. Table III lists the computational cost of each scheme. Fig. 3 shows the computational cost of the SM in the data reporting phase, Fig. 4 shows the computational cost required for data aggregation process. Furthermore, the data

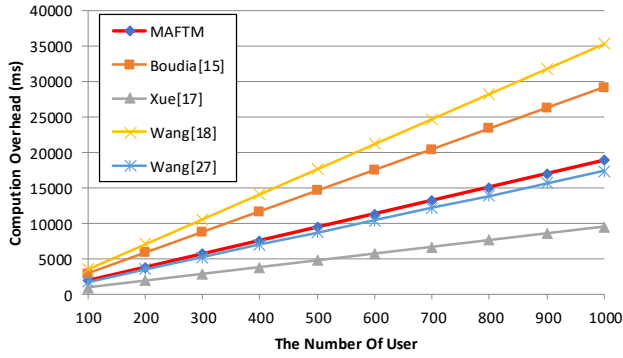


Fig. 3. Data reporting phase computational cost.

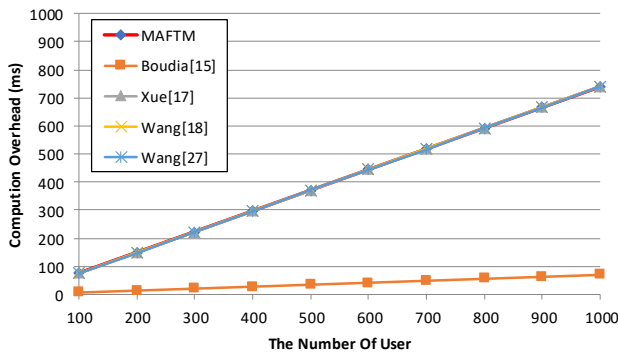


Fig. 4. The computational cost required for AG.

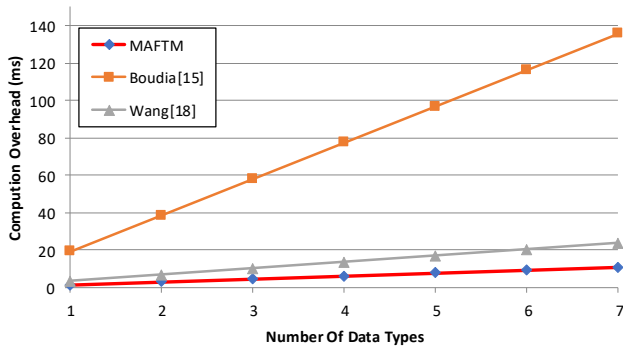


Fig. 5. Additional computational cost of data type K.

type  $K$  is 1 in the above computational cost. We compare the MAFTM scheme with schemes that implement multi-dimensional data aggregation, Fig. 5 shows the additional computational cost of data type  $K$  on the SM side.

### C. Fault Tolerance

If SM sends a power data ciphertext every 15 minutes, it sends an average of 17520 times a year. Assuming that every smart meter fails once in six years, we can know that  $1/100000 = 0.00001$  is the probability of failure through calculation. However, the failure probability of SM in daily life is far lower than 0.00001 [18]. Assuming that there are 1000 smart meters in a HAN area, it can be calculated that the minimum probability of a smart meter being damaged in six years is 0.01. Therefore, the number of times a fault-tolerant mechanism is executed is not high, but it is necessary to exist. In addition, the computational cost required to implement the fault-tolerant mechanism is affordable. When a fault-tolerant mechanism is executed, AG needs to collect computational information from a normal smart meter, where the fault computational cost for a single meter is  $T_{H-G} + T_b + GT_e + (n - s)G_{add}$ , where  $s$  is the number of SM that have failed. In addition, the formula  $e(H(t_i), P)$  can be calculated in advance and each smart meter is the same, so it only needs to be calculated once. Therefore, the fault computational cost of a single meter is  $T_e$ . The additional computational cost required in the aggregation phase is  $(n - s)T_{mul}$ .

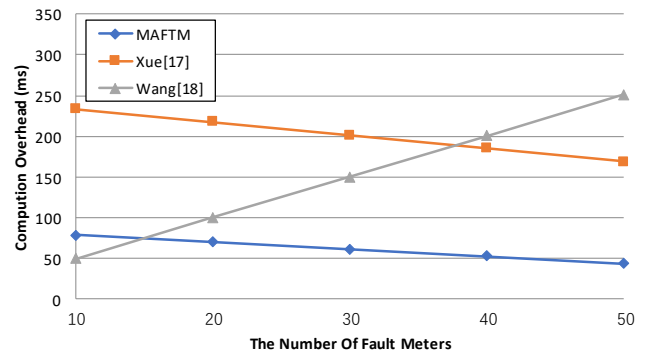


Fig. 6. Additional costs required for fault recovery (Number of faulty meters unchanged)

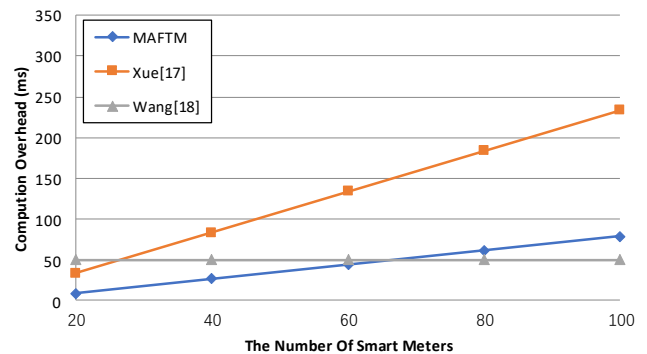


Fig. 7. Additional costs required for fault recovery (Constant number of users).

We will compare the additional Fault Tolerance cost with the schemes [17], [18]. The additional computational cost requires to start the fault-tolerant mechanism is  $(s + 1)T_e + T_H$  in the scheme [17]. When the fault-tolerant mechanism is executed, the additional computational cost of each SM is  $4T_e + 2T_{mul} + T_H$  in the scheme [18]. The extra cost of AG is  $(n - 1)T_{mul}$ . Assume that the number of meters from 20 to 100, the number of faulty meters  $s = 10$ . The computational cost required to execute the fault-tolerant mechanism is shown in Fig. 6. On the contrary, we assume that the number of faulty smart meter is 0 to 50, while the number of normal smart meter is  $n=100$ . The additional cost of the fault-tolerant mechanism is shown in Fig. 7.

### VIII. CONCLUSION

Aiming at the problems of relying on TTP to participate in collaboration, low fault tolerance, and unable to report multi-dimensional data in the current data aggregation scheme, this paper proposes the MAFTM scheme. MAFTM is based on ECC to construct multi-dimensional data aggregation without TTP participation. At the same time, we consider that SMs may fail in real life, causing CC to fail to decrypt normally. In order to prevent the sudden failure of the SM, we also designed a fault-tolerant mechanism. In this article, we demonstrate through comparative analysis that the MAFTM scheme is more functionally complete. Furthermore, performance analysis shows that the MAFTM scheme has a lower computational cost on the SM and AG sides. Finally, the additional cost generated by implementing fault-tolerant mechanism is also lower compared to other schemes. However, the disadvantage is that the fault-tolerant mechanism proposed in this article requires more than half of the SMs to participate in the collaboration. If a large range of SMs fail, the MAFTM scheme is likely to fail to perform the recovery function properly. In addition, the aggregation of more diverse data types remains a challenging issue, such as the collection of aggregated data under multi-subset structures. We will continue to study in future work to enhance the efficient utilization of power data by control centers.

### ACKNOWLEDGMENT

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# SbChain+: An Enhanced Snowball-Chain Approach for Detecting Communities in Social Graphs

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**Abstract**—In this paper, we present snowball-chain (SbChain+) approach, which is an improved version of SbChain community detection method in terms of precision with which communities are identified in a social graph. It exploits the topology of a social graph in terms of the connections of a node, i.e., its degree centrality, betweenness centrality and the number of links within its neighborhood defined by the local clustering coefficient. Two different functions have been used to identify neighbors for a given node. Hence, two approaches have been discussed with their pros and cons. In general, SbChain+ takes a social graph as an input and aims to identify communities around the core nodes in the underlying network. The core nodes are expected to have a high degree and have densely connected neighbors and guides in identifying cliques from the graph. The proposed approach takes its inspiration from snowball sampling technique and keeps merging the nodes with their neighboring nodes based on certain criteria to form snowballs. One of the functions discussed (SbChain+(i)) uses a hyperparameter,  $\lambda$  for merging snowballs which further leads to the formation of communities. This hyperparameter also helps in achieving the desired level of coarseness in the communities, and it can be adjusted to fine tune the identified communities. While the second function (SbChain+(ii)) uses an average out degree function to merge snowballs. The *modularity* values are calculated at each level of the dendrogram formed by combining nodes and snowballs to decide an appropriate cut for community determination. SbChain+ is empirically evaluated using these two different functions over both real-world and LFR-benchmark datasets and results are evaluated on *modularity* and *normalized mutual information*. The aim of this study is to improve upon the previously discussed technique (SbChain) and to study the use of hyperparameter, i.e., the performance of a technique with or without the hyperparameter.

**Keywords**—*Clique; clustering; community detection; graph mining; snowball sampling; social network analysis*

## I. INTRODUCTION

Online social network is an ever-growing entity which can be modeled in the form of graphs (*aka* social graphs) with users or entities as the nodes and their interactions or relationships as weighted or unweighted edges [1]. Community detection is an application of studying social graphs that provides useful information about groups that might exist due to similar interests, occupation and so on. It is formally stated by Girvan and Newman as the *community detection* problem in [2]. Communities are expressed as a group of nodes that are coherent and are well-connected or have similar characteristics,

and sparse connections with the other nodes or dissimilar characteristics with the rest of the nodes. Identifying communities enables an in-depth understanding of the arrangement of nodes and edges in a social graph, because they correspond to the entities and their respective relationships within a group or inter-groups. Hence, it can be useful in identifying highly cohesive sub-structures.

There are various approaches like density-based, hierarchical, and label propagation methods for community detection. The density-based approach aims to find core points in the network that have a high number of neighbors based on a pre-defined threshold value. It also identifies the isolated nodes or outliers in the same manner and then grows the communities. Density-Based Spatial Clustering of Applications with Noise (DBSCAN) [3] uses two external parameters, a *minpoint* threshold and a *neighborhood parameter* depending on which the results may differ. A density-based approach, called CMiner, is presented in [4] which finds overlapping communities using a new distance function derived from the average reciprocated interactions among nodes. The authors also proposed another approach in [5], called OCTracker, for finding overlapping communities using a density-based framework and tracking the various aspects of community evolution. Hierarchical approaches are another set of methods for community detection in social networks that may work either in a bottom-up manner or in a top-down manner. Bottom-up approach considers each node to be a separate community and combines nodes in an iterative manner to maximize modularity. On the other hand, top-down approach considers the entire network to be a single community and divides it in an iterative manner until the desired set of communities are obtained. However, some hierarchical approaches have found to have very high complexities depending upon the cost function to be optimized. In [6], the authors proposed a unified framework, called HOCTracker, which identifies hierarchical overlapping communities in social networks. Label propagation is another approach for community detection in social networks. The Label Propagation Algorithm (LPA) changes a node label to the label of its majority neighbors. However, since LPA uses local information, it gets stuck in local optima. Snowball-Chain (SbChain) is another community finding approach which works well when nodes find their best neighbors in the initial few iterations.

In this paper, we present two improved versions of our previous work Snowball-Chain (SbChain) [7], termed as Enhanced

Snowball-Chain (SbChain+(i) and SbChain+(ii)). It uses simple topological features of a graph, like degree centrality, betweenness centrality, clustering coefficient and average out degree function for detecting communities in undirected and unweighted social graphs, which is the major advantage of this SbChain+ when compared with other techniques in the current work. The idea behind SbChain+ is that the nodes having high centrality value and cliques among their neighbors may become good candidates to form communities. Therefore, the technique starts with the identification of seed nodes (i.e., the nodes having high degree and well-connected neighbors), it aims to identify their best scoring neighbors based on two different functions. Hence, two approaches based on two different functions for SbChain+ are discussed in the subsequent sections, with their pros and cons. One of them uses common neighbor merging strategy (function-i) and the other uses average out degree function (ODF) (function-ii). The nodes merge to form snowballs based on one of these functions. SbChain+(i) and SbChain+(ii) are compared with five other well established state-of-the-art community detection techniques, including Infomap [8], LPA [9], LPA (semi-synchronous) [10], Louvain [11], and SbChain [7]. Approaches like LPA is based on local node interactions and ignore the global information of nodes (like betweenness centrality etc.) in the graph. Whereas, SbChain+ considers all the information of the node by using local as well as global clustering coefficient. It can also be seen that according to [12] Louvain is unable to detect outliers unlike SbChain+. SbChain+ separates nodes with zero degree value before the algorithm begins its processing. The results reveal the effectiveness of the proposed SbChain+ for community detection in real-world social graphs when compared with these techniques. In short, the major contributions/enhancements in this work can be summed up by the following points:

- 1) Consideration of degree, betweenness centrality and normalized clustering coefficient for seed node identification leading to improvement in terms of community formation.
- 2) Two improved weight functions based on the concept of common neighbors using a hyperparameter and average ODF, respectively, to calculate the interaction intensity for a pair of nodes. The pros and cons of each of these functions is also studied.
- 3) An improved empirical validation of the proposed approach over both real-world and LFR-benchmark datasets in terms of identified number of communities, modularity (Q) and Normalized Mutual Information (NMI) for real-world datasets.

The rest of the paper is organized as follows. Section II presents a brief review of the existing literatures on community detection. Section III mentions the preliminary concepts used by the proposed approach. Section IV presents the functional details of our proposed SbChain+ method. Section V presents a discussion on hyperparameter tuning with pros and cons of both the functions used in SbChain+. Section VI presents details about the datasets, experimental settings, and an analysis of the experimental results. The complexity analysis of SbChain+ is mentioned in section VII. Finally, section VIII concludes the paper with future directions of

research.

## II. RELATED WORK

A lot of research in the field of community detection has been conducted in the past few years. In [13] and [14], review of existing community detection methods is presented. It divides the detection methods into probabilistic and deep learning categories. The traditional approaches utilize probability-based models for community identification, whereas complex networks are converted to lower dimensional data and worked upon by using deep learning methods. In this paper, we consider a classical approach for community detection that utilizes the parameters from the graph itself. Commonly used community detection methods for connected data are mainly based on Markov clustering algorithm, which uses a random walk process on the given network to identify communities in the form of clusters. The algorithm in [15] proposed a function-modularity intensity which uses network edges along with their weights for community evolution. Another common approach for identifying communities is implemented using hierarchy-based methods. The method in [16] is based on edge removal. It proposes to eliminate the edges having a high score calculated in terms of betweenness centrality and identifies optimized community based on the modularity values. A similar work is presented in [17] which combines nodes that maximize modularity in an agglomerative hierarchical order. It begins with assuming each node as a community and keeps combining nodes until highest value of modularity is achieved. Another work in [18] used spectral clustering along with global maximization of the modularity function.

Density-based approaches like Density-Based Spatial Clustering of Applications with Noise (DBSCAN) [3] and Ordering Points To Identify Cluster Structure (OPTICS) [19] have also been proposed in literature for community detection. DBSCAN uses two user-defined parameters called as the *minimum point threshold* and *neighborhood radius*. OPTICS uses two distance measures – *core-distance* and *reachability-distance* to consider core as well as the points that lie inside the high-density clusters. Inspired from DBSCAN, a Structural Clustering Algorithm for Networks (SCAN) was proposed in [20]. It aims to detect hubs and outliers along with the communities. However, it also requires two parameters, namely, a minimum similarity threshold parameter and minimum number of neighbors. However, it does not provide any details about parameter settings. A popular overlapping community detection approach is Clique Percolation Method (CPM) which is based on growth of communities using  $k$ -cliques [21]–[23], wherein communities are defined by maximal union of adjacent  $k$ -cliques. The adjacency of cliques is decided by the number of common nodes between them [22].

Label Propagation Algorithm (LPA) [9] follows another community detection approach, which changes the label of each node to the most frequently occurring label in its neighborhood. The process continues until all the nodes are updated and no more changes can be made to the labels. LPA has been an inspiration for several other works in community detection. For example, authors in [24] proposed CenLP (Centrality-based Label Propagation) algorithm which considers weighted networks for community detection. They proposed a function to calculate the centrality of a node and its similarity

with the neighboring nodes. Another work in [25] creates a compactness function based on a node's weight which is calculated based on two factors: (i) common number of neighbors between a given node and its surrounding nodes, and (ii) degree of node under consideration. The neighboring communities are defined based on high degree nodes and their high degree neighbors. Communities are identified using weighted compactness function value between a node and its neighboring community. An adjustment strategy is devised to achieve an improved accuracy. Other studies in community detection (e.g., [26]) used the score of immediate neighbors of a node to decide its label. Evolutionary algorithm discussed in [27] also finds the community structure based on modularity maximization. The communities formed are merged based on a function calculated via intra-community and intercommunity links.

A study in [28] finds connected components that form a preference network, leading to the formation of communities. The preference network is formed by finding preference nodes using their spread capabilities. It identifies the highest number of overlapping neighbors between a given selector node and its one-path length neighbors. This is calculated using the `gossip` algorithm proposed in [29]. Another similarity-based approach was proposed in [30] which is called Community Detection Algorithm based on Structural Similarity (CDASS) and works in two phases. In phase one, the edges bearing a low similarity value are removed, leading to formation of several disconnected components in the network. The components are consolidated eventually to form a set of communities. The second phase identifies optimal communities from the previous phase to give the required results using an evaluation function. The function used in the second phase is realized from different structural parameters of the nodes in the given network. Another work that uses local graph information is discussed in [31] called Flow Propagation Algorithm (FlowPro). It can compute the community of exactly one node by using the flow based on edge weights. Each node stores half of the receiving flow and the process continues until there is no flow left to be circulated.

A few deep learning-based techniques are presented in [32], [33]. In [32], a weighted path matrix having path length two is created. It helps in identifying similarity among a node and its neighbors with path length of two or less. Further, a deep sparse autoencoder and k-means clustering algorithm is used to identify the communities. The work in [33] uses an existing technique to design an encoder for identification of communities and their respective nodes. It uses a dual decoder for unsupervised community detection. Another work in [34] uses graph compression technique for analysis of huge networks. The probability of a node to become a seed is calculated using two parameters, quality, and density of the nodes. Finally, the number of communities and initial seed set is recognized using these parameters. A work in [35] develops a framework called Seed Expansion with generative Adversarial Learning (SEAL) uses a graph neural network that uses sequential decision process and is trained via policy gradient. It works on the concept of discriminator and generator, the former identifies fake or real communities. While the latter fits in features of communities the real communities.

In [36], a genetic algorithm for feature selection to find

communities is discussed. Features are identified and then classified into clusters based on community detection approaches. Next step employs a genetic algorithm that to pick up features based on a novel operation. A local community detection process in [37] works in two parts, where a core detection stage identifies communities based on modularity density. The next stage is the extension stage identifies coherent communities based on Jaccard coefficient.

Our proposed SbChain+ method is inspired from the afore-said similarity-based approaches which first find the seed nodes based on certain criteria and then search for highly connected nodes in the neighborhood. This leads to formation of snowballs, which keep expanding until no more nodes can join, eventually leading to the formation of communities. SbChain+ is compared with both LPA and Infomap that utilize the concept of random walks and decompose the network into groups based on probability flow. It is also compared with Louvain, in which communities are grown in a hierarchical manner by adding nodes that lead to gain in modularity, marking the first phase of the community identification process. Thereafter, weights of the links belonging to a particular community are summed up to complete the second phase. Finally, first and second phases are iteratively repeated until the community formation process converges and a maximum modularity value is achieved.

### III. PRELIMINARIES

For a graph  $G(V, E)$  represented by  $V = \{v_1, v_2, \dots, v_n\}$  as a set of  $n$  nodes and  $E = \{e_{ij} = (v_i, v_j) | v_i, v_j \in V \& \exists \text{ a link between } v_i \text{ and } v_j\}$  as a set of edges, the motive is to identify the seed or core nodes that form snowballs, and merging the snowballs/nodes finally to form communities. The notations used in the subsequent sections of this paper are briefly described in Table I.

TABLE I. NOTATIONS AND THEIR BRIEF DESCRIPTIONS

Notation	Description
$\mathcal{N}(v_i)$	Set of immediate neighbors of a node $v_i$
$k(v_i)$	Degree centrality of $v_i$
$b(v_i)$	Betweenness centrality of $v_i$
$LCC(v_i)$	Normalized local clustering coefficient of $v_i$
$\mathcal{N}_{best}(\mathcal{V})$	A set of best neighbors for a given set $\mathcal{V} \subseteq V$ , calculated by a score function
$s^{(n)}$	A set of nodes of length $n$ , called snowball
$\mathcal{N}(s^{(n)})$	Neighbor set of $s^{(n)}$ , given by $\mathcal{N}(v_1) \cup \mathcal{N}(v_2) \cup \dots \mathcal{N}(v_n)$

For a graph  $G$ , the SbChain+ algorithm initiates by sorting the nodes in non-increasing order based on their scores, which is generated by equation (1), as explained in the following definition.

**Definition 1. (Score).** The score for a given node  $v_i$  is calculated based on its normalized clustering coefficient, degree and betweenness centrality, as formally presented in equation (1).

$$score(v_i) = (LCC(v_i) + k(v_i) + b(v_i))/3.0 \quad (1)$$

The degree, betweenness centrality and clustering coefficient parameters are used in this study because they provide con-

nectedness of a node with its neighboring nodes, and connectedness of the neighboring nodes, respectively. The degree centrality for a node is the fraction of nodes it is connected to in the graph. Betweenness centrality of a node is given by the sum of the fraction of all-pairs shortest paths that pass through it. The clustering coefficient also provides information about clique formation within the neighbor set of a node. All the three parameters are normalized to bring them on the same scale.

It should be noted that equation (1) works differently for a seed node  $v_i$  and a snowball  $s^{(n)}$ . For  $v_i$ , the individual value of all the parameters is added, while for a snowball value  $s^{(n)}$ , the individual values for each node comprising the snowball are picked and divided by the number of nodes in the snowball as given by equation (2).

$$score(s^{(n)}) = score(v_1) + \dots + score(v_n) / \|s^{(n)}\| \quad (2)$$

The nodes are selected one at a time in non-increasing order of their score to grow and form communities. Considering  $v_i$  be the first selected node, the approach proceeds by finding the best neighboring node denoted by  $\mathcal{N}_{best}(v_i)$  from  $\mathcal{N}(v_i)$ . This node  $\mathcal{N}_{best}(v_i)$  is the one having the highest value of score given by equation (1). After the first round of iteration, many nodes combine with their best neighbor and their scores are updated by equation (2). However, it should be noted that a node  $v_i$  combines with  $\mathcal{N}_{best}(v_i)$  on conditions defined by two different functions as mentioned below.

**Definition 2.** (Function-i) According to this function  $v_i$  combines with  $\mathcal{N}_{best}(v_i)$  if the degree of overlap among their neighbor set, i.e, cardinality of the overlapping set obtained by taking the intersection of its own neighbor set and that of the neighbor set of  $v_i$  is higher than the hyperparameter  $\lambda$  among all the neighbors of  $v_i$ , given by equation (3).

$$weight = \frac{\|\mathcal{N}(v_i) \cap \mathcal{N}(\mathcal{N}_{best}(v_i))\|}{\min\{\|\mathcal{N}(v_i)\|, \|\mathcal{N}(\mathcal{N}_{best}(v_i))\|\}} > \lambda \quad (3)$$

**Definition 3.** (Function-ii) According to this function  $v_i$  combines with  $\mathcal{N}_{best}(v_i)$  if the value of average ODF formed by the subgraph of their neighbors is less than the individual average ODF of  $v_i$  with  $\mathcal{N}(v_i)$  and  $\mathcal{N}_{best}(v_i)$  with  $\mathcal{N}(\mathcal{N}_{best}(v_i))$  as given by equations (4) and (5)

$$avgODF(S(v_i)) \geq avgODF(S(s^{(n)})) \quad (4)$$

$$avgODF(S(\mathcal{N}_{best}(v_i))) \geq avgODF(S(s^{(n)})) \quad (5)$$

The nodes are bound to follow *non-redundant node strategy* when the process of community detection starts. According to this strategy, a node  $v_i$  merges with only its prime neighbor given by  $\mathcal{N}_{best}(v_i)$  in the current iteration. The same is applicable for  $\mathcal{N}_{best}(v_i)$  as well, as it cannot join other nodes/snowballs in the same iteration, i.e., both these nodes are not allowed to join other nodes in the same iteration. This strategy leads to formation of mutually exclusive communities.

When nodes join with their best node from the respective neighborhood set, they form snowballs as given by definition 4.

**Definition 4.** (Snowball). A snowball  $s^{(n)}$  is set of connected components formed by enumerating nodes contained in it, where  $n$  is the cardinality of the set. It is formed either by merging a node  $v_i$  with  $\mathcal{N}_{best}(v_i)$  or by joining two or more snowballs.

It is pertinent to note that the superscript  $n$  signifies the number of elements in a snowball. Hence, there can exist many snowballs with a common value of  $n$ . Nonetheless, they can be distinguished by the elements contained in the set, as these elements are mutually exclusive. These snowballs ( $s^{(n)}$ ) form a subgraph with their immediate neighbors (neighbors of the nodes that are contained in the it).

The set of neighbors for a snowball depicted by  $\mathcal{N}(s^{(n)})$  is defined by the union of neighbor set of each node contained in  $s^{(n)}$ , i.e.,  $\mathcal{N}(v_1), \mathcal{N}(v_2), \dots, \mathcal{N}(v_n)$ . A snowball can combine any of the existing snowballs by a given condition which calculates the common nodes among the existing snowball and the newly formed snowball (formed by merging the two snowballs). A snowball is allowed to join any one of the existing snowballs, the one which has the maximum common neighbors with the current snowball. This process keeps continuing until no further snowballs can combine, and the final result is the community set as mentioned in definition 5.

**Definition 5.** (Community set). A set of community may comprise of a single node or snowballs or both, that cannot be merged any further and have maximum value of (modularity) among all the iterations.

#### IV. PROPOSED SBCHAIN+

The functional details of the proposed approach for finding communities, called Enhanced **Snowball-Chain** or **SbChain+** are presented in this section, and it is designed for a simple graph, i.e., an undirected and unweighted graph. The inspiration for the approach comes from agglomerative hierarchical clustering which operates in a bottom-up manner, starting with single nodes as individual communities. These nodes expand to form snowballs by finding highly connected neighboring nodes. Snowballs keep adding nodes to form clique-like structures. The snowballs keep expanding till the criteria is met and until the convergence is fulfilled, i.e., the set of communities for a given iteration are identical to the community set from the previous iteration. The community set with the highest value of modularity is the final set of community returned by the algorithm, among all the calculated values from all the iterations.

##### A. SbChain+ Algorithm

SbChain+ given by algorithm 4 commences by storing the structural properties of all the nodes, like their respective neighbors, local clustering coefficient, and degree, betweenness centrality, each of which is represented as a set. These sets are stored in the form of key-value pairs by the name of  $\mathcal{N}, LCC, k$  and  $b$ , respectively, where the key is defined by the node and the value varies with the corresponding set values. The loop keeps running for  $|V|$ , where  $V$  represents

---

**Algorithm 1:** *bestNeighbor*( $\mathcal{V}, \mathcal{N}(\mathcal{V}), score$ )

---

**Input :** A set  $\mathcal{V} \subseteq V$ , neighbor list  $\mathcal{N}(\mathcal{V})$ , *score* of each node/snowball in the current iteration  
**Output:** Best neighbor set of  $\mathcal{V}$  i.e.  $\mathcal{N}_{best}(\mathcal{V})$

```

1 maxScore  $\leftarrow 0$ 
2  $\mathcal{V}' \leftarrow \emptyset$ 
3 if  $\|\mathcal{N}(\mathcal{V})\| = 0$  then
4    $\leftarrow$  return  $\emptyset$ 
5 foreach  $v \in \mathcal{N}(\mathcal{V})$  do
6   foreach snowball in score do
7     // snowball is a set of nodes
8     if  $v$  is a part of snowball then
9        $\leftarrow$   $\mathcal{V}' \leftarrow$  snowball
10      else
11         $\leftarrow$  continue
12      if score( $\mathcal{V}'$ ) > maxScore then
13         $\leftarrow$  maxScore  $\leftarrow$  score( $\mathcal{V}'$ )
14         $\leftarrow$   $\mathcal{N}_{best}(\mathcal{V}) \leftarrow \mathcal{V}'$ 
14 return  $\mathcal{N}_{best}(\mathcal{V})$ 

```

---



---

**Algorithm 2:** *neighborApproval*( $i$ )( $\mathcal{N}(\mathcal{V}_1), \mathcal{N}(\mathcal{V}_2), \lambda$ )

---

**Input :** Neighbor set  $\mathcal{N}(\mathcal{V}_1)$ , neighbor set  $\mathcal{N}(\mathcal{V}_2)$ , *hyperparameter*  $\lambda$   
**Output:** Snowball  $s^{(n)}$

```

1  $s \leftarrow \emptyset$ 
2 //  $s$  is a snowball
3 if  $\frac{\|\mathcal{N}(\mathcal{V}_1) \& \mathcal{N}(\mathcal{V}_2)\|}{\min(\|\mathcal{N}(\mathcal{V}_1)\|, \|\mathcal{N}(\mathcal{V}_2)\|)} \geq \lambda$  then
4    $n \leftarrow \|\mathcal{V}_1 \cup \mathcal{V}_2\|$ 
5    $\leftarrow$  Add  $\langle \mathcal{V}_1, \mathcal{V}_2 \rangle$  to  $s^{(n)}$ 
5 return  $s^{(n)}$ 

```

---

the node set in graph  $G$ . However, it exits the loop when two consecutive iterations result in identical set of communities.

Before the iterations start, an initial score  $score^{(1)}$  and neighbor list  $\mathcal{N}$  is calculated for each node  $v_i$  as a preprocessing step in algorithm 4. The score is calculated as per equation (1) or (2) and signifies the influence of a node/snowball in the graph, and calculated using the connections among its neighbor (given by LCC) and its own connections with the other nodes (given by degree and betweenness centrality). The flag value for each node is set to 0 for every iteration, so that each node can merge once in every iteration with its best neighbor. As each iteration  $i$  proceeds, the nodes (or snowballs) represented by the set  $\mathcal{V}_j$  from  $score^{(i)}$  are arranged in non-increasing order. Each  $\mathcal{V}_j$  is checked for a flag value, if the value is set, it means that the given  $\mathcal{V}_j$  has merged with some nodes/snowball to form another snowball in the current iteration, it is not processed

---

**Algorithm 3:** *neighborApproval*( $ii$ )( $\mathcal{N}(\mathcal{V}_1), \mathcal{N}(\mathcal{V}_2)$ )

---

**Input :** Neighbor set  $\mathcal{N}(\mathcal{V}_1)$ , Neighbor set  $\mathcal{N}(\mathcal{V}_2)$   
**Output:** Snowball  $s^{(n)}$

```

1  $s \leftarrow \emptyset$ 
2 //  $s$  is a snowball
3 if  $avgODF(\mathcal{N}(\mathcal{V}_1)) \geq avgODF(\mathcal{N}(\mathcal{V}_1) \cup \mathcal{N}(\mathcal{V}_2))$  and  $avgODF(\mathcal{N}(\mathcal{V}_2)) \geq avgODF(\mathcal{N}(\mathcal{V}_1) \cup \mathcal{N}(\mathcal{V}_2))$  then
4    $n \leftarrow \|\mathcal{V}_1 \cup \mathcal{V}_2\|$ 
5    $\leftarrow$  Add  $\langle \mathcal{V}_1, \mathcal{V}_2 \rangle$  to  $s^{(n)}$ 
5 return  $s^{(n)}$ 

```

---



---

**Algorithm 4:** SbChain+( $G, \lambda$ )

---

**Input :** A graph  $G(V, E)$  and threshold  $\lambda$   
**Output:** Final community set  $C, Q, NMI$

```

1  $\forall v_i$ , calculate  $\mathcal{N}(v_i), score^1(v_i)$ 
2  $maxQ \leftarrow -1, m \leftarrow |E|, sScore \leftarrow score^1$ 
3 for  $i \leftarrow 1$  to  $|V|$  do
4   Arrange  $score^i$  in non-increasing order
5    $\forall v_i, flag(v_i) \leftarrow 0$ 
6   foreach  $\mathcal{V}_j \in score^i.keys$  do
7     //  $\mathcal{V}_j$  is a set of nodes or snowballs
8     if  $flag(\mathcal{V}_j) = 1$  then
9        $\leftarrow$  continue
9      $\mathcal{V}' \leftarrow bestNeighbor(\mathcal{V}_j, \mathcal{N}(\mathcal{V}_j), score^i)$ 
10    //  $\mathcal{V}'$  is  $\mathcal{N}_{best}(\mathcal{V}_j)$ 
11    if  $\mathcal{V}' = \emptyset$  then
12      Add  $\mathcal{V}_j$  to community
13       $\leftarrow$  continue
14    if  $flag(\mathcal{V}') = 1$  then
15       $\leftarrow$  continue
16     $s^{(n)} \leftarrow neighborApproval(i)(\mathcal{N}(\mathcal{V}_j), \mathcal{N}(\mathcal{V}'), \lambda)$ 
17    if  $s^{(n)} = \emptyset$  then
18       $\leftarrow$  continue
19     $maxInter \leftarrow 0, flag(\mathcal{V}_j), flag(\mathcal{V}') \leftarrow 1$ 
20     $sScore(s^{(n)}), setflag \leftarrow 0$ 
21    foreach  $s \in s^{(n)}$  do
22       $sScore(s^{(n)}) \leftarrow sScore(s^{(n)}) + sScore(s)$ 
23     $score^i(s^{(n)}) \leftarrow \frac{sScore(s^{(n)})}{\|n\|}$ 
24    for  $j \leftarrow 1$  to  $|comm|$  do
25       $weight \leftarrow \frac{\|s^{(n)} \& comm(j)\|}{\min(\|s^{(n)}\|, \|comm(j)\|)}$ 
26      if  $weight > maxInter$  then
27         $maxInter \leftarrow weight$ 
28         $setflag \leftarrow 1, saveIndex \leftarrow j$ 
29      else
30         $\leftarrow$  counter  $\leftarrow$  counter + 1
31      if  $j = |comm|$  and  $setflag = 1$  then
32         $comm(j) \leftarrow comm(j) \cup s^{(n)}$ 
33         $sScore(comm(j)) \leftarrow sScore(comm(j)) + sScore(s^{(n)})$ 
34         $score^{i+1} \leftarrow \frac{sScore(comm(j))}{\|sScore(comm(j))\|}, score^i \leftarrow \frac{sScore(s^{(n)})}{\|n\|}$ 
35         $score^i.pop(\mathcal{V}_j), score^i.pop(\mathcal{V}'), score^{i+1}.pop(s^{(n)})$ 
36      if  $counter = |comm|$  then
37         $counter \leftarrow 0$ 
38        Add  $s^{(n)}$  to  $comm$ 
39         $score^i, score^{i+1} \leftarrow \frac{sScore(s^{(n)})}{\|sScore(s^{(n)})\|}$ 
40         $score^i.pop(\mathcal{V}_j), score^i.pop(\mathcal{V}')$ 
41      Copy keys from  $score^i$  to  $score^{i+1}$  and  $comm$  which were not updated
42       $Q \leftarrow Modularity(m, comm, E), NMI \leftarrow NMI(comm, GT)$ 
43      if  $maxQ < Q$  then
44         $\leftarrow$   $maxQ \leftarrow Q, maxNMI \leftarrow NMI$ 
45      if  $score^i.keys = score^{i-1}.keys$  then
46         $\leftarrow$  break
45 return community, maxNMI, maxQ

```

---

any further and the iteration continues with the next set in the order. Hence, as per the non-redundant node strategy, the algorithm jumps to the next best  $\mathcal{V}_j$ . The best neighbor for a node  $\mathcal{V}_j$  is represented by  $\mathcal{N}(\mathcal{V}_j)$  is returned by the algorithm 1. It should be noted that both  $\mathcal{V}_j$  and  $\mathcal{N}_{best}(\mathcal{V}_j)$  are sets; therefore, they can contain more than one node. If these sets contain more than one node then they are called a snowball. Hence, it is represented as a set  $\mathcal{V}'$ . It should be noted that if  $\mathcal{V}'$  is an empty set, therefore,  $\mathcal{V}_j$  is a isolated node and forms a community of its own. Next,  $\mathcal{V}'$  is also verified further for non-redundant node strategy, by checking its respective flag value. Further, a node joins its best neighbor based on two neighbor approval functions as discussed further.

1) *neighborApproval(i)*: It should be noted that we discuss two functions for approval of the best neighbor for a given node as given by algorithm 2 and algorithm 3. According to algorithm 2 called *neighborApproval(i)*, both the sets, i.e.,  $\mathcal{N}(\mathcal{V}_1)$  and  $\mathcal{N}(\mathcal{V}_2)$ , are checked for overlapping criteria using the hyperparameter  $\lambda$ . This parameter lays the minimum value of overlap that should exist for two snowballs to combine. If their *weight* given by (1) is greater than or equal to the  $\lambda$  value, then the sets merge to form a snowball  $s^{(n)}$  which is returned by the algorithm else it returns an empty set.

2) *neighborApproval(ii)*: In algorithm 3 *neighborApproval(ii)*, the average out degree function of the original two sets given by  $\mathcal{N}(\mathcal{V}_1)$  and  $\mathcal{N}(\mathcal{V}_2)$  and their union ( $\mathcal{V}_1 \cup \mathcal{V}_2$ ) is calculated as per equation (6) given by [38].

$$avgODF(C) = \frac{1}{n_C} \sum_{u \in C} \frac{|\{(u, v) \in E : v \notin C\}|}{k_u} \quad (6)$$

It gives the average of the number of outgoing edges for each community node as compared to the total edges incident on that node. Therefore, if the value of *avgODF* is smaller for the combined snowball (than the initial two sets),  $s^{(n)}$  is returned else an empty set is returned.

Considering *neighborApproval(i)* in algorithm 4, if a snowball  $s^{(n)}$  is returned then the flag for all the nodes in the snowball is set to one. Therefore, these nodes cannot combine with other nodes in the current iteration, leading to formation of disjoint communities. Further, the score of the snowball is calculated by taking an average of the score of the elements in the snowball. It should be noted that a new snowball is allowed to merge with an existing snowball on a criteria stating that they have maximum overlap among all the existing snowballs, given by a parameter called *weight* as mentioned in step 15. A snowball is allowed to join only one existing snowball, i.e., the one with the maximum common nodes.  $score^i$  and  $score^{i+1}$  are updated to include the average score values for of snowball and merged snowball, respectively. If the new snowball does not combine with any existing snowball, then it forms a community of its own as per step 34. The nodes that did not merge with other nodes/snowballs are copied from  $score^i$  to  $score^{i+1}$  and *comm*. In every iteration, modularity and NMI (using ground truth GT) are calculated. This process continues till two consecutive iterations return an identical community set. The final set of communities is returned along with the respective modularity and NMI values, as per the

algorithm has the maximum modularity value among all the iterations.

## V. DISCUSSION

The hyperparameter ( $\lambda$ ) used in this study determines the limit of common nodes that should exist between two subgroups to merge them to form a snowball. This parameter is decided upon empirically, but it is guided by the ratio of edges to nodes in the social graph. It is also given by half of the average degree ( $k_{avg}$ ) of the nodes, as given in Table XI. It can be observed from this table that  $k_{avg} > 19$  for all LFR datasets. This signifies that the nodes are densely connected in the graph and can merge on a low  $\lambda$  value. Setting a high value of  $\lambda$  would result in joining of all the nodes, and eventually leading towards the formation of a single community. Therefore, it is observed that the results are best around  $\lambda \leq 0.6$ . Similarly, for lower values of average degree (i.e.,  $k_{avg} < 5$ ), a higher percentage of overlap is required because the neighbors (or  $k(v_i)$ ) of two nodes/subgroups to be merged can be very low. The low degree nodes can easily be merged at lower  $\lambda$  values, leading to the formation of a single community in the entire dataset. Hence, based on our experiments, the suitable value for the  $\lambda$  hyperparameter is,  $\lambda > 0.6$ .

It should be noted that *SbChain+(i)* outperforms *SbChain+(ii)* in terms of the quality of the identified communities. The reason for this is that the  $\lambda$  parameter allows a node or snowball to join other nodes or snowballs because the overlap among them keeps increasing with each iteration. Whereas, average ODF in case of *SbChain+(ii)* has stricter rules for merging. Therefore, the overlap among snowballs is not as much as in the case of former technique, i.e., the growth of the communities is comparatively slower in latter. The drawback associated with the former technique is that, although the  $\lambda$  value is guided by the ratio of number of edges to the number of nodes, there is a scope of error associated with it. While, the shortcoming of *SbChain+(ii)* is that it produces average results since it allows a node to merge with its best neighbor based on increasing the density of edges inside a community than outside.

*SbChain+* improves upon *SbChain* by changing the the seed function to include various centralities, discussing two neighbor finding functions (with and without parameters). It can be seen that both *SbChain+(i)* and *SbChain+(ii)* outperform *SbChain* in terms of the quality of the identified community. Although, *SbChain+* shows comparable or good results for real-world datasets, it needs to be checked for large networks.

## VI. EXPERIMENTAL SETUP AND RESULTS

This section describes the results and their analysis obtained by applying *SbChain+* approach with two different functions, *neighborApproval(i)* and *neighborApproval(ii)* on various datasets, namely, *SbChain+(i)* and *SbChain+(ii)*, respectively. The efficacy of these two techniques is verified using six real-world datasets and two sets of computer-generated Lancichinetti Fortunato Radicchi (LFR) benchmark datasets having 1K and 5K nodes, respectively. The details of the datasets are presented in the following subsections. Modularity (Q) and Normalized



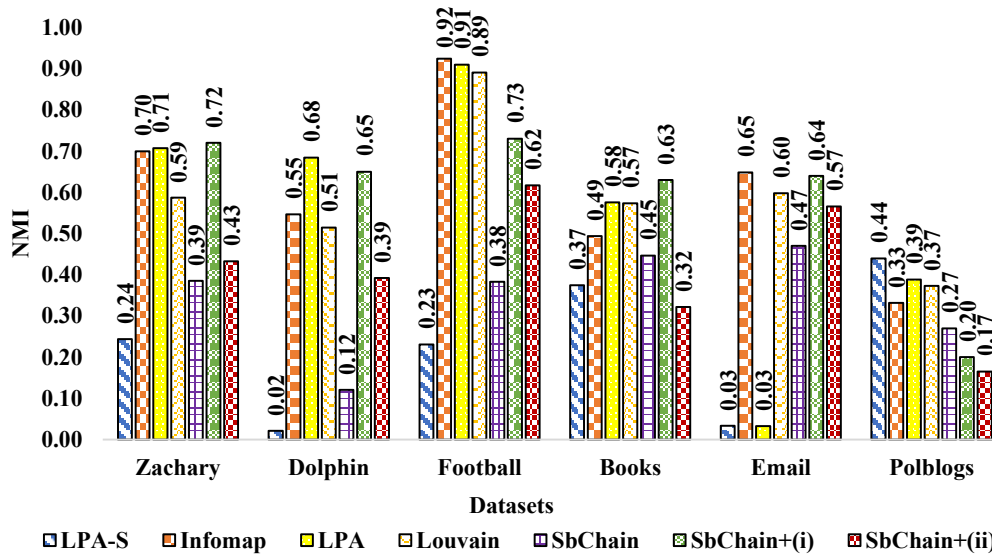


Fig. 1. Visualization of the performance comparison results of SbChain+ with state-of-the-art methods over real-world datasets in terms of NMI.

Mutual Information (NMI) are used to assess the quality of communities formed by SbChain+ and the other techniques. It should be noted that the values marked with \* represent a very small number and is rounded off to 0.00.

TABLE II. STATISTICS OF REAL-WORLD NETWORKS

Dataset	#Nodes	#Edges	#Communities
Karate	34	78	2
Dolphin	62	159	2
Polbooks	105	441	3
Football	115	613	12
Email [39]	1005	16064	42
Polblogs [40]	1490	16715	2

### A. Real-World Datasets

The real-world datasets used in our experiment are briefly summarized in Table II<sup>1</sup>. The performance evaluation and comparison results of SbChain+(i) and SbChain+(ii) with some of the state-of-the-art methods, including Infomap [8], Label Propagation Algorithm (LPA) [9], LPA (semi-synchronous) [10], Louvain [11], and our previously developed SbChain, in terms of Normalized Mutual Information (NMI), and modularity (Q) are shown in Tables III and IV, respectively.

It can be observed from the Tables III and IV that SbChain+ performs significantly better or comparably most real-world datasets. The average NMI produced by SbChain+(i) is comparable to the average NMI by Infomap among all the techniques. It is pertinent to note that both SbChain+ techniques are seen to perform better than SbChain as shown in Fig. 1 and 2. It should also be noted that SbChain and LPA techniques produce different result every time they are run.

### B. Synthetic Datasets

As described in [41], Lancichinetti-Fortunato-Radicchi (LFR) benchmark networks are used to generate synthetic datasets by tuning different parameters. In our experiments, LFR datasets with 1K and 5K nodes are generated using the parameter values presented in Tables V and VI, respectively. These datasets are denoted as LFR-1K and LFR-5K datasets, respectively. Out of these parameters,  $\mu$  is the mixing parameter and defines the number of connections with neighbors in other communities. The value of  $\mu$  is set within the range of [0.1, 0.5] for LFR-1K and LFR-5K, and the step-size is changed at an interval of 0.1 for both LFR-1K and LFR-5K datasets. It controls the percentage of edges between communities. By changing the  $\mu$  values in the given range, different datasets are created and accordingly named as LFR-1K.1 – LFR-1K.5 and LFR-5K.1 – LFR-5K.5. Values upto 0.5 are considered for  $\mu$  parameter as the modular structure of a community becomes fuzzy beyond this value.

The empirical evaluation and comparison results of SbChain+ with the aforementioned techniques in terms of NMI, and modularity (Q) are presented in Tables VII-VIII for LFR-1K dataset, and in Tables IX-X for LFR-5K dataset. These tables present the varying  $\mu$  in the range of [0.1, 0.5] for LFR-1K and LFR-5K datasets, with the respective NMI, and Q for all the approaches.

It can be seen that our technique gives average results in most of the cases, The NMI for SbChain+ is LFR-1K as can be seen from Table VII is seen to outperform SbChain, LPA(SS). And, in general SbChain+(i) produces better results than SbChain+(ii). It is also seen that modularity values for LFR-1K from VIII are seen to be average, i.e., Infomap, Louvain and LPA produce a better modularity value than SbChain+. Fig. 3 and 4 show comparison charts for LFR-1K datasets in terms of NMI and modularity.

SbChain+(i) performs averagely in for LFR-5K datasets in terms of NMI and modularity, as seen from Tables

<sup>1</sup><http://www-personal.umich.edu/~mejn/netdata/>

TABLE III. PERFORMANCE COMPARISON OF  $SbChain+$  WITH STATE-OF-THE-ART METHODS OVER REAL-WORLD DATASETS IN TERMS OF NMI

Datasets	Community Detection Methods						
	Infomap	LPA(SS)	Louvain	LPA	SbChain	SbChain+(i)	SbChain+(ii)
Karate	0.70	0.24	0.59	0.71	0.39(0.3)	0.72(0.8)	0.43
Dolphin	0.55	0.02	0.51	0.68	0.12(0.3)	0.65(0.7)	0.39
Football	0.92	0.23	0.89	0.91	0.38(0.8)	0.73(0.7)	0.62
Polbooks	0.49	0.37	0.57	0.58	0.45(0.6)	0.63(0.7)	0.32
Email	0.65	0.03	0.60	0.03	0.47(0.4)	0.64(0.8)	0.57
Polblogs	0.33	0.44	0.37	0.39	0.26(0.8)	0.20(0.6)	0.17

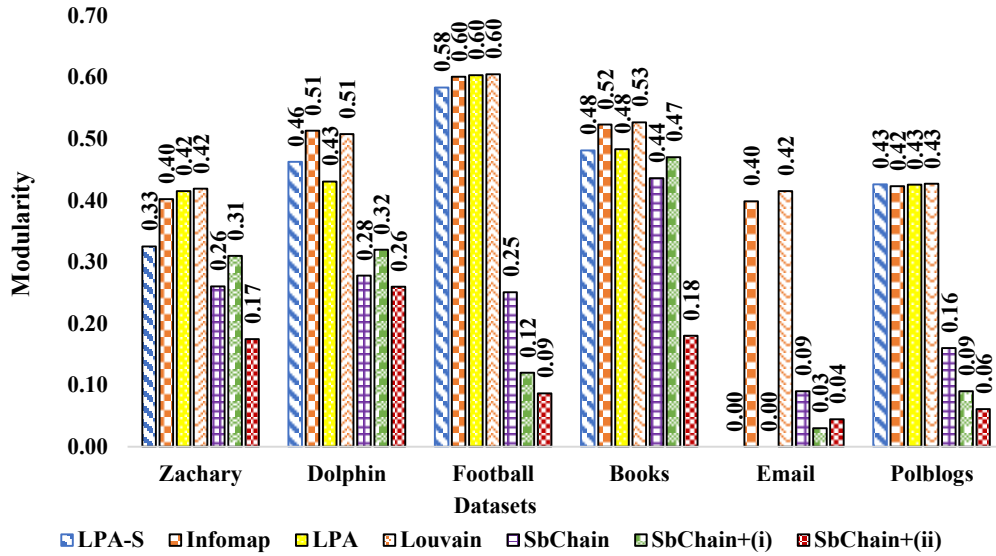


Fig. 2. Visualization of the performance comparison results of  $SbChain+$  with state-of-the-art methods over real-world datasets in terms of modularity.

TABLE IV. PERFORMANCE COMPARISON OF  $SbChain+$  WITH STATE-OF-THE-ART METHODS OVER REAL-WORLD DATASETS IN TERMS OF MODULARITY (MOD.)

Datasets	Ground truth	Community Detection Methods						
		Infomap	LPA(SS)	Louvain	LPA	SbChain	SbChain+(i)	SbChain+(ii)
Karate	0.37	0.40	0.32	0.42	0.32	0.26	0.31	0.17
Dolphin	0.37	0.51	0.46	0.50	0.41	0.28	0.32	0.26
Football	0.55	0.60	0.58	0.60	0.58	0.25	0.12	0.09
Polbooks	0.41	0.52	0.48	0.52	0.48	0.44	0.47	0.18
Email	0.29	0.39	0.00*	0.40	0.00	0.08	0.03	0.04
Polblogs	0.40	0.42	0.43	0.42	0.42	0.15	0.09	0.06

TABLE V. PARAMETERS USED TO GENERATE LFR-1K NETWORK

Parameter	Value
Nodes (N)	1000
Average degree ( $\langle k \rangle$ )	20
Minimum community size ( $c_{min}$ )	20
Maximum community size ( $c_{max}$ )	100
Maximum degree ( $k_{max}$ )	50
Community size distribution exponent ( $\beta$ )	1
Degree distribution exponent ( $\gamma$ )	2
Mixing parameter ( $\mu$ )	[0.1, 0.5]

TABLE VI. PARAMETERS USED TO GENERATE LFR-5K NETWORK

Parameter	Value
Nodes (N)	5000
Average degree ( $\langle k \rangle$ )	20
Minimum community size ( $c_{min}$ )	50
Maximum community size ( $c_{max}$ )	100
Maximum degree ( $k_{max}$ )	50
Community size distribution exponent ( $\beta$ )	1
Degree distribution exponent ( $\gamma$ )	2
Mixing parameter ( $\mu$ )	[0.1, 0.5]

TABLE VII. PERFORMANCE COMPARISON OF SbCHAIN+ WITH STATE-OF-THE-ART METHODS OVER LFR-1K DATASETS IN TERMS OF NMI

Datasets	Community Detection Methods						
	Infomap	LPA (SS)	Louvain	LPA	SbChain	SbChain+ (i)	SbChain+ (ii)
LFR-1K.1	1.00	0.08	1.00	1.00	0.19(0.4)	0.69(0.6)	0.47
LFR-1K.2	1.00	0.07	1.00	1.00	0.27(0.5)	0.65(0.6)	0.73
LFR-1K.3	0.08	0.08	0.08	0.08	0.27(0.4)	0.48(0.8)	0.28
LFR-1K.4	1.00	0.05	1.00	1.00	0.24(0.6)	0.59(0.6)	0.43
LFR-1K.5	1.00	0.00	1.00	0.96	0.31(0.4)	0.61(0.6)	0.48

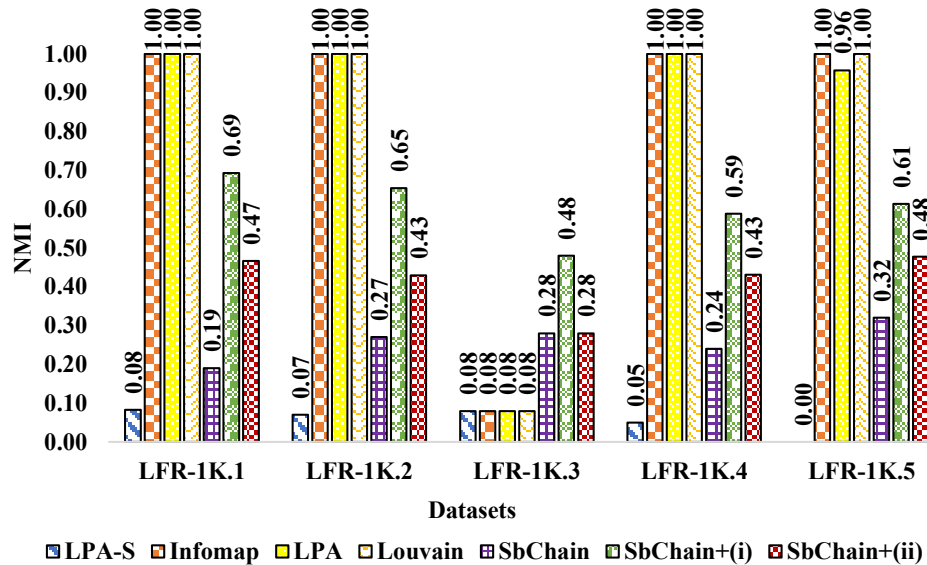


Fig. 3. Visualization of the performance comparison results of SbChain+ with state-of-the-art methods over LFR-1K datasets in terms of NMI.

TABLE VIII. PERFORMANCE COMPARISON OF SbCHAIN+ WITH STATE-OF-THE-ART METHODS OVER LFR-1K DATASETS IN TERMS OF MODULARITY

Datasets	Community Detection Methods						
	Infomap	LPA (SS)	Louvain	LPA	SbChain	SbChain+ (i)	SbChain+ (ii)
LFR-1K.1	0.83	0.83	0.83	0.83	0.66	0.22	0.19
LFR-1K.2	0.74	0.74	0.74	0.74	0.38	0.14	0.11
LFR-1K.3	0.83	0.83	0.83	0.83	0.50	0.15	0.19
LFR-1K.4	0.53	0.44	0.53	0.53	0.18	0.01	0.07
LFR-1K.5	0.45	0.00	0.45	0.43	0.17	0.00	0.05

TABLE IX. PERFORMANCE COMPARISON OF SbCHAIN+ WITH STATE-OF-THE-ART METHODS OVER LFR-5K DATASETS IN TERMS OF NMI

Datasets	Community Detection Methods						
	Infomap	LPA (SS)	Louvain	LPA	SbChain	SbChain+ (i)	SbChain+ (ii)
LFR-5K.1	1.00	0.12	1.00	1.00	0.15(0.7)	0.76(0.6)	0.55
LFR-5K.2	1.00	0.13	1.00	1.00	0.37(0.8)	0.71(0.6)	0.55
LFR-5K.3	1.00	0.13	1.00	1.00	0.38(0.7)	0.67(0.6)	0.56
LFR-5K.4	1.00	0.10	1.00	1.00	0.38(0.7)	0.66(0.6)	0.53
LFR-5K.5	1.00	0.09	0.98	1.00	0.39(0.7)	0.66(0.6)	0.53

IX and X, respectively. Although, it shows better results than LPA(SS), SbChain and SbChain+(ii). Fig. 5 and 6 show both the NMI and modularity values produced by all the techniques.

Therefore, it is seen that for real-world datasets SbChain+ is seen to perform better in terms of the identified communities as compared to the synthetic datasets. It should be seen that the average NMI produced by real-world datasets is at par with the other techniques results, and performs produces average results for LFR-1K and LFR-5K.

## VII. COMPLEXITY ANALYSIS

The best-case of the algorithm arises when all the nodes join different nodes/snowballs in each iteration, i.e., no node is left free in any iteration. This leads to a minimum of  $\log n$  iterations, where the number of nodes/snowballs also reduces to its half from the previous iteration. Therefore, a time complexity of  $O(n)$  defines the best-case. The worst-case arises when only a single node joins another node/snowball in an iteration. This leads to  $n - 1$  iterations and the time complexity goes to  $O(n^2)$ . It is also evident that SbChain+ works well on both small and large real-world datasets in terms of the identified communities. However, on LFR datasets, it

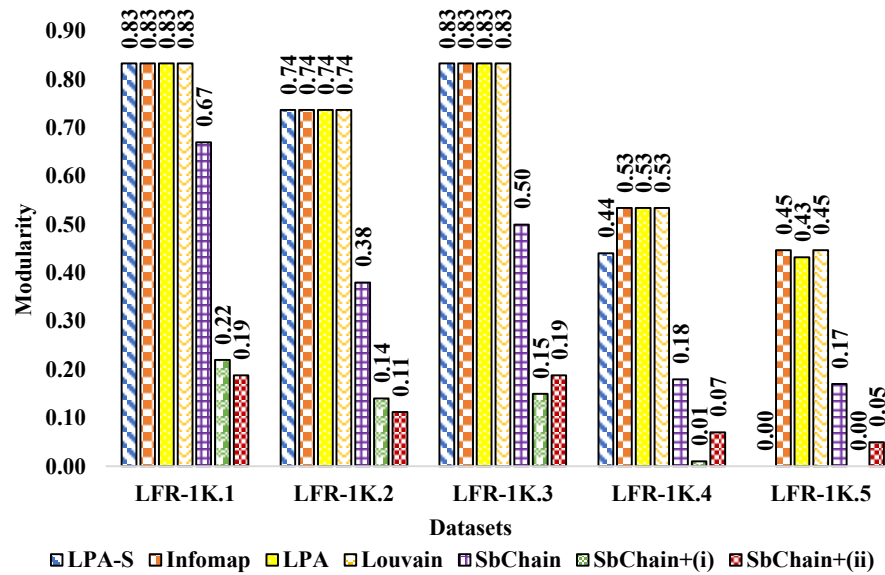


Fig. 4. Visualization of the performance comparison results of SbChain+ with state-of-the-art methods over LFR-1K datasets in terms of modularity.

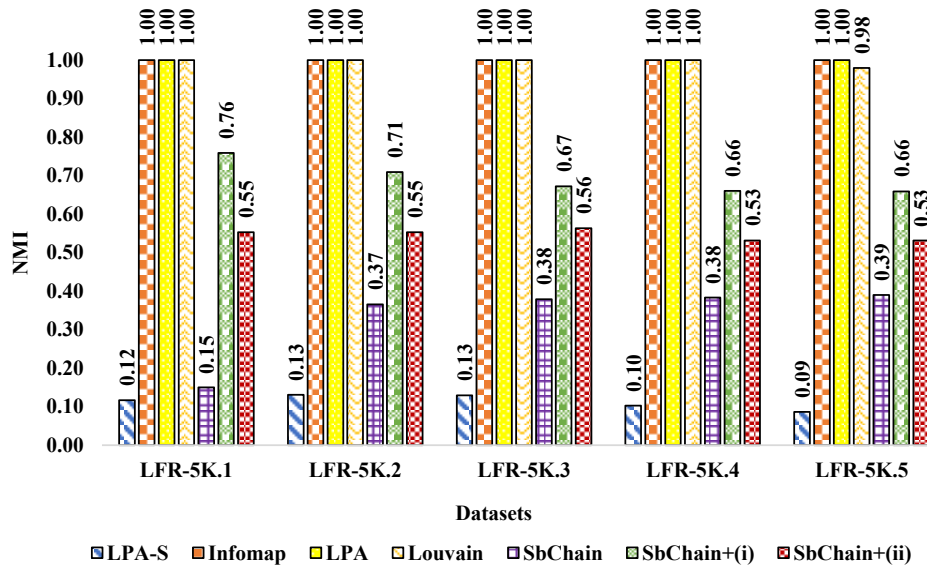


Fig. 5. Visualization of the averaged performance comparison results of SbChain+ with state-of-the-art methods over LFR-5K datasets in terms of NMI.

TABLE X. PERFORMANCE COMPARISON OF SbCHAIN+ WITH STATE-OF-THE-ART METHODS OVER LFR-5K DATASETS IN TERMS OF MODULARITY

Datasets	Community Detection Methods						
	Infomap	LPA (SS)	Louvain	LPA	SbChain	SbChain+(i)	SbChain+(ii)
LFR-5K.1	0.88	0.88	0.88	0.88	0.39	0.23	0.09
LFR-5K.2	0.78	0.78	0.78	0.78	0.20	0.09	0.09
LFR-5K.3	0.68	0.68	0.68	0.68	0.17	0.02	0.06
LFR-5K.4	0.58	0.58	0.58	0.58	0.14	0.00*	0.06
LFR-5K.5	0.48	0.44	0.48	0.48	0.12	0.00*	0.05

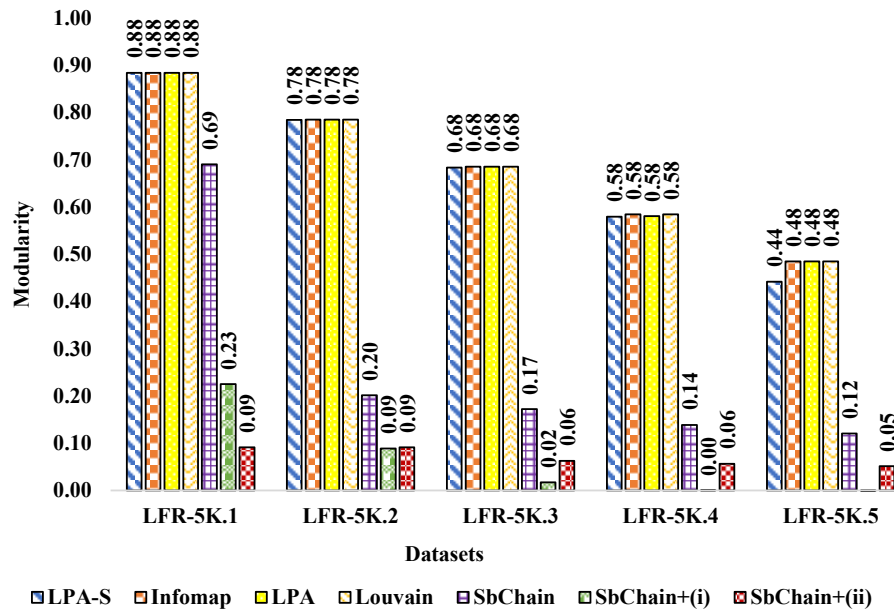


Fig. 6. Visualization of the performance comparison results of SbChain+ with state-of-the-art methods over LFR-5K datasets in terms of modularity.

TABLE XI. HYPERPARAMETER  $\lambda$  VALUES

Average degree	$\lambda$
< 5	> 0.6
> 10	$\leq 0.6$

is seen to give average performance when compared to the best performing community detection methods. It should be noted that in comparison to LPA(SS) and SbChain, both, SbChain+(i) and SbChain+(ii) show better performance in terms of the identified communities.

### VIII. CONCLUSION AND FUTURE WORK

In this paper we have presented two approaches for enhanced snowball-chain approach, SbChain+ for detecting communities in social graph. In general, SbChain+ lays emphasis on finding nodes that have a high degree of interaction with its neighbors and a densely connected neighborhood. This reveals the core nodes, i.e., the nodes that may be a part of a clique and would further contribute towards formation of snowballs and eventually a community. SbChain+ improves over SbChain in terms of cardinality of the identified communities, NMI, and modularity. In SbChain+(i), this is achieved by changing the weight function, which is based on maximizing the intersection of the neighbors between two nodes using a  $\lambda$  hyperparameter. The hyperparameter ( $\lambda$ ) which defines the minimum overlap required for two snowballs to get merged for community formation. This parameter also helps in refinement of the communities – the higher the value of  $\lambda$ , higher is the cohesion. The low value of  $\lambda$  gives higher coupling. On the other hand, SbChain+(ii) focusses on average ODF and does not use any hyperparameter and hence, detects better communities than SbChain. Whereas,

SbChain focussed on maximizing both the common neighbors as well as the score between the nodes; by relaxing this criteria, the results are seen to be better than those given by SbChain.

Further, SbChain+ method can be extended and improved upon by making it a generic framework for finding communities closer to ground truth, in both simple and weighted/directed social graphs. Also, the technique can accommodate identifying dynamic communities based on the time-varying functions. This can be seen as a promising future direction of research.

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# PaddyNet: An Improved Deep Convolutional Neural Network for Automated Disease Identification on Visual Paddy Leaf Images

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**Abstract**—Timely disease diagnosis in paddy is fundamental to preventing yield losses and ensuring an adequate supply of rice for a rapidly rising worldwide population. Recent advancements in deep learning have helped overcome the limitations of unsupervised learning methods. This paper proposes a novel PaddyNet model for enhanced accuracy in paddy leaf disease detection. The PaddyNet model, developed using 17 layers, captures and models patterns of different disease symptoms present in paddy leaf images. The effectiveness of the novel model is verified by applying a large dataset comprising 16,225 paddy leaf datasets across 13 classes, including a normal class and 12 disease classes. The performance results show that the new PaddyNet model classifies paddy leaf disease images effectively with 98.99% accuracy and a dropout value of 0.4.

**Keywords**—Image annotation; data augmentation; deep learning; paddy leaf disease detection; paddyNet

## I. INTRODUCTION

Plant disease threatens food production and disrupts food security worldwide. It was reported, for instance, that though rice cultivation was set to increase by 1.8 percent in 2021/22 to a new peak of 520.7 million tonnes [1], its supply was diminished by disease. Rice is among the most widely consumed foods globally, with a total consumption of 511.4 and 501.2 million tonnes in 2020-21 and 2019-20, respectively. These statistics highlight the relentless food shortages brought on by the devastation plant disease has wreaked on food production, turning it into a major global problem [2]. So then, increased agricultural productivity of up to 70% is required to reduce paddy leaf disease and provide food for a rapidly growing population. However, recurrent problems with infections, the improper monitoring of rice farmlands, and the regular occurrence of paddy leaf diseases destroy rice yields and result in production losses. Various diseases regularly occur in the paddy leaves, which is the reason for the production loss. Additionally, the overuse of chemicals like bactericides and fungicides in the agro-ecosystem has created conflict in the fight against plant disease [3]. For a sustained production rate, an algorithm is to be designed for predicting paddy leaf characteristics so as to detect leaf diseases. Early predictions of paddy leaf-related infections can help bolster the quality and quantity of rice production. Timely interventions help slow the rapid pace of the disease and maximize the cultivation of healthy rice leaves [4].

Paddy leaf-related disease symptoms are typically distinguished by their texture, colour, and form [5][6][7]. Artificial

intelligence-based automated identification methods are currently recognized as the best for paddy leaf disease recognition. The manual prediction of paddy leaf disease has been shown to be erroneous, expensive, and difficult to predict in advance. The condition is diagnosed far more accurately and simply using computer-based procedures. As a result, an incredible range of diseases have since been identified, the effects of which on leaves are yet to be classified. Computer-based identification methods fail to depict the effects of environmental factors on paddy leaf disease, and offer slow identification speeds as well as inaccurate information metrics. Therefore, detection techniques that identify paddy leaf diseases quickly and accurately through leaf features have been developed to enable the farming community to make appropriate decisions [8][9].

Traditional techniques such as computer vision [10], pattern recognition [11], support vector machines [12][13][14], image processing [15], and convolutional neural networks [16][17][18] have long been used to identify diseased paddy leaves with high detection accuracy and determine results rapidly. A paddy disease detection framework [19] was proposed using features from the affected parts of the leaf, which were selected from trained leaf images and classified using the support vector machine. Additionally, the SVM and Naive Bayes classifiers [20] were applied to test images using three image classes that included healthy leaves, brown spots, and leaf blast lesions. The paddy data set was captured using a Nikon COOLPIXP4 digital camera. The experimental results revealed 79.5% accuracy for the SVM and 68.1% for the Naive Bayes classifiers. The multilayer perceptron method [12] could identify six types of paddy disease, based on the texture and color of paddy images, with 88.56% accuracy. Furthermore, four classes of paddy diseases were identified with high accuracy of 92.5% using the Fractal Fourier Technique. This technique was also used to find four types of rice disease [21].

However, real-time applications of existing techniques across agriculture and other fields often involve the use of small and slow models that are specifically intended for devices with low computational power while identifying disease with good-to-better accuracy. Further, existing techniques lack noise sensitivity and produce reduced classification accuracy. The proposed PaddyNet method identifies paddy diseases quickly and classifies them from visual paddy leaf images based on deep learning models. This system utilizes a feature extraction technique that reduces noise and thereby magnifies the disease spot with no resultant loss of information.

The remaining sections of the paper are organized as follows: Section II reviews the literature on plant disease identification. Section III discusses the materials and methodologies used and describes the real-time paddy dataset in detail in Section III-A. Section IV presents the experimental findings used to determine the performance metrics of the proposed solution. Finally, Section V concludes the paper with directions for future work.

## II. RELATED WORK

Several state-of-the-art outcomes have been analyzed using image processing techniques, including computer vision and artificial intelligence, across different fields of research. The techniques are applied to images to make it easier to resolve image segmentation, feature selection and extraction, and classification using deep learning (DL) [22]. Deep learning, a sub-section of machine learning, is widely used to recognize input image patterns [23][24] by extracting parameters from paddy plant images and examining crop stress. A paddy disease identification approach was used to classify paddy image features using convolutional neural networks [25]. Ten different types of rice disease images were used for the experimental results.

In addition to diagnosing paddy leaf disease, advanced identification techniques have also been used on crops such as wheat [26], brinjal [27], pumpkin [28], tomato [29], and potato [30]. Two approaches were used to diagnose diseased leaves using the GoogLeNet and Cifar10 models [8]. With a focus on detecting disease in maize, the proposed approach achieved 98.9% and 98.8% overall accuracy for the GoogLeNet and Cifar10 models, respectively. On the other hand, the AlexNet model that was used [31] to diagnose apple leaf disease obtained the highest accuracy of 97.62%. In addition, a novel CNN was developed [32][19] to identify cucumber leaf disease with high accuracy of 94.9%. A convolutional neural network technique was used [33] for crop leaf classification to identify leaf disease. From the experimental results, four classes were correctly identified, including a normal leaf class, while the remaining constituted the affected image classes. In all, 100 images for each class were taken for the experiment and the results showed that the model achieved 92.85% overall accuracy. The proposed method obtained accuracy of 99.9%, 91%, 87%, and 93.5%, respectively, for each class [34]. A DCNN was used to diagnose rice diseases and pests. The proposed method considered 1426 images for the experimental results and achieved 93.30% accuracy [35].

The paper [36] used the proposed CNN architecture on three datasets PlantVillage, the Rice Diseases Image Dataset, and the Cassava Leaf Disease Dataset. The method extracts depth features from the images to reduce the computation cost and define the number of parameters applied on the model. This work obtained the highest performance accuracy for all three data sets. The proposed approach used deep ensemble neural networks [3] to diagnose 14 different types of crop diseases with 14 classes. The images were pre-trained using seven deep learning models such as the ResNet50, ResNet101, InceptionV3, DenseNet121, DenseNet201, MobileNetV3, and NasNet. The proposed ensemble model achieved higher accuracy than the other pre-trained models.

It is concluded from a study of the literature above that much of the research on diseased leaf detection employed deep learning methods to train the classifier models for high accuracy. This paper proposes a PaddyNet neural network model for improved leaf detection classification accuracy. The proposed model uses a large number of data images for training and testing, and classifies the images efficiently into their respective classes with high accuracy. Also, to maximize the performance of the PaddyNet model, an optimizer is developed alongside to produce optimal results. As a result, the PaddyNet deep learning model offers significant improvements overall in terms of the accuracy of paddy leaf detection classification. Real paddy plant leaf images were collected from paddy fields, using a smartphone camera, to validate the proposed PaddyNet deep learning model. The proposed approach addresses the problem of paddy disease classification and its automated identification.

## III. MATERIALS AND METHODS

Fig. 1 represents an overview of the innovative method employed for paddy leaf disease classification. An improved novel algorithm called PaddyNet is proposed to extract leaf image features and classify diseased leaf images much more accurately. The proposed method includes the three steps of dataset collection, data preprocessing, and augmentation. In the first step, dataset collection, paddy leaves are gathered from actual paddy fields. In the second step, data preprocessing, duplicate images are deleted. In the third step, augmentation, each paddy image is annotated with the help of specific agricultural officers. In addition, suitable image augmentation techniques are used to expand the data. During the data splitting stage, the final cleaned data is divided into train, validate, and test subsets, following which the proposed PaddyNet model is trained utilizing the train and validation sets for the model development process. Finally, the results are evaluated after the PaddyNet model is trained and validated using performance metrics and confusion matrices on the test set of paddy leaf images.

### A. Data Collection and Annotation

Visual images of paddy leaves were captured using the CAT S62 Pro smartphone in Tirunelveli district of Tamil Nadu, India [37]. Initially, more than 25,000 images were collected from the data set. Every sample was examined carefully and redundant data such as noisy and out-of-focus images were removed. Finally, following the cleaning process, 16,225 images were chosen with the assistance of agricultural officers. The cleaned images were labeled into 12 disease categories and 1 healthy category. Further, metadata on the age and type of paddy were collected as well [38] and the Paddy Doctor Dataset data gathered and annotated. The procedures used are shown in Fig. 2.

### B. Image Augmentation

Image augmentation in image analysis enhances both the quantum of data available and the performance of the model. This is done by generating image categories that reduce overfitting issues and enhance the model's ability for interpretation during the training phase. By applying different image data augmentation techniques, for instance, many more paddy leaf

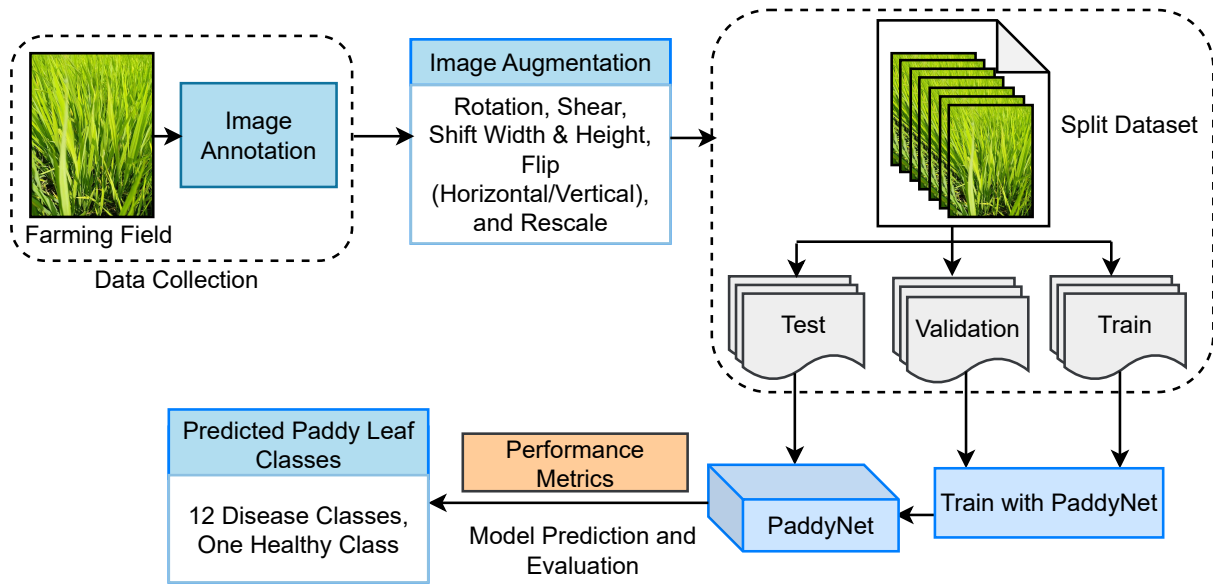


Fig. 1. An overview of the methodology for paddy disease classification using PaddyNet model.

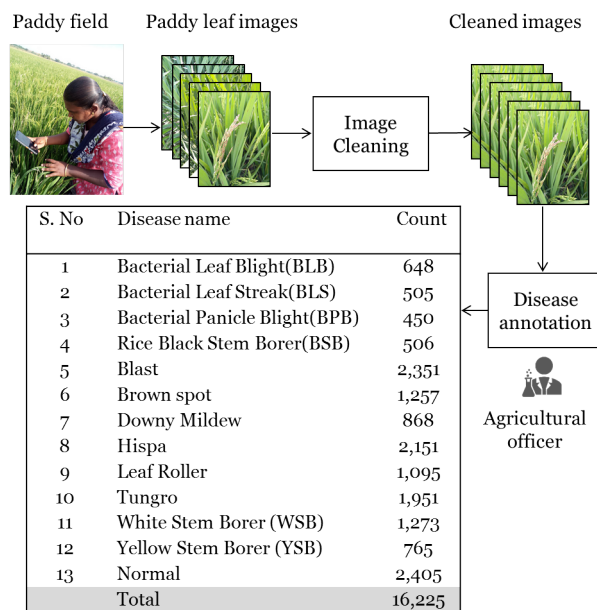


Fig. 2. Data collection and annotation process.

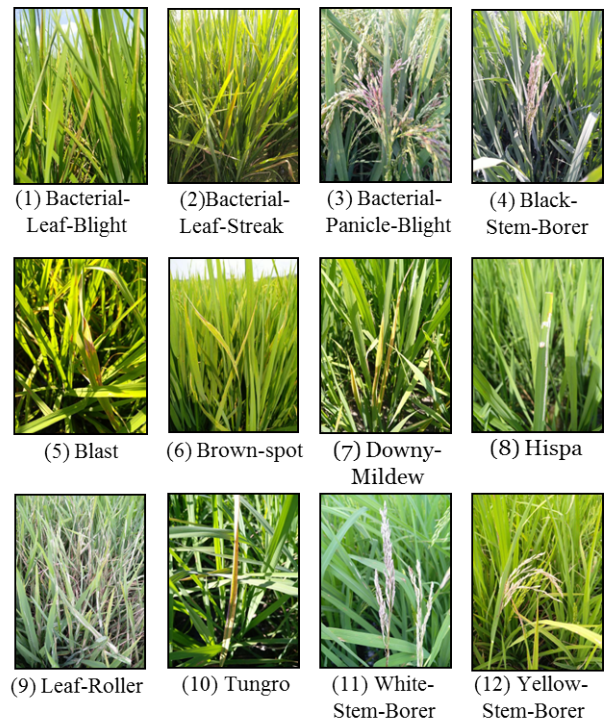


Fig. 3. Sample paddy disease images in our dataset.

images can be generated by varying image orientation and size. Common data augmentation operations include random rotation, width and height shift, horizontal and vertical flip, shear, fill mode, and rescale. Sample pictures of leaves with 12 different diseases are shown in Fig. 3.

### C. PaddyNet Model Architecture

The proposed PaddyNet model has 17 layers. Using visual images, the CNN model identifies paddy leaf disease. The proposed model has five requisite components: a convolutional layer, a pooling layer, a dense layer, a flatten layer, and an

activation function. A brief discussion of the five components follows below.

1) *Convolutional layer*: This the primary and first block of a CNN model. The proposed PaddyNet model uses seven conv2D layers. In the convolutional block, the convolution operation extracts related features from the input paddy image. To perform convolution operations using backpropagation, the model is trained using backpropagation [34] and its weight

updated, based on the error rate revealed during the preceding iteration. Forward propagation is marked by movement from the origin layer to the destination layer in the network. The loss is obtained at the end of the network, using the loss function to avoid the error. Equations (1-5) are used to calculate the convolution layers [36]. Seven 2D convolutional layers are added using Conv2D in the model. Forward propagation calculates  $Z$  based on the input value ( $X_{(i+r)(j+s)}^{[k]}$ ), weight value ( $W_{rs}^{[k]}$ ), and ( $p = i + r, q = j + s$ ).

$$Z = \sum_{j=0}^n W_{rs}^{[k]} X_{(p)(q)}^{[k]} \quad (1)$$

$$Y_{ij}^{[k]} = \sum_{i=0}^m Z + b^{[k]} \quad (2)$$

Back Propagation: to calculate the error function ( $C$ ) based on the predicted value ( $Y_{ij}^{[k]}$ ) and actual value ( $Y_{act}$ ).

$$C = (Y_{ij}^{[k]} - Y_{act})^2 \quad (3)$$

To calculate error function for weight ( $\partial W_{rs}^{[k]}$ ).

$$\frac{\partial C}{\partial W_{rs}^{[k]}} = \sum_{i=0}^{p-m} \sum_{j=0}^{q-n} \frac{\partial C}{\partial Y_{ij}^{[k]}} \frac{\partial Y_{ij}^{[k]}}{\partial W_{rs}^{[k]}} \quad (4)$$

To calculate error function for bias ( $\partial b^{[k]}$ )

$$\frac{\partial C}{\partial b^{[k]}} = \sum_{i=0}^{p-m} \sum_{j=0}^{q-n} \frac{\partial C}{\partial Y_{ij}^{[k]}} \frac{\partial Y_{ij}^{[k]}}{\partial b^{[k]}} \quad (5)$$

2) *Pooling layer*: When the feature in the image is too large, the convolutional lock employs the max pooling layer to minimize the feature map. The model uses seven max pooling layers. The three pooling layers - max, average, and sum pooling have the benefits of quick computing, limiting overfitting, and using little memory. Max pooling is applied here to determine the highest values from each region of the feature map using formulas 6 and 7. Seven 2D max pooling layers are added using MaxPooling2D in the model.

$$Y_{ij} = (0, X_{pq}) \quad (6)$$

$$\frac{\partial C}{\partial X_{pq}} = \frac{\partial C}{\partial Y_{ij}^{[k]}} \frac{\partial Y_{ij}^{[k]}}{\partial X_{pq}} \dots \left\{ \begin{array}{l} \frac{\partial C}{\partial Y_{ij}^{[k]}} \quad (Y_{ij}^{[k]} = X_{pq}) \\ 0 \quad \text{otherwise} \end{array} \right\} \quad (7)$$

3) *Flatten*: Following the application of the pooling layer, the complete matrix of generated feature maps is converted into a single volume using the flatten layer. The final fully connected neural network receives and classifies it.

4) *Fully connected layer*: Two fully connected layers are used after the flattening layer. The output of the previous layer is fed in the form of values to the last dense layer to decide which features mostly match a class. When calculating the product of the weights, a fully linked layer yields precise probabilities for the different paddy classes. The outputs are categorized using the softmax activation function.

5) *Activation function*: The softmax function  $S(Z)_i$  [39] is utilized to predict the 13 classes shown in Equation (9). Additionally, the ReLU activation function [40] employed as depicted in Equation (8) provides demonstrably high accuracy with max pooling2D:  $j = 1 \dots k$  and  $z = (z_j \dots z_k)$ .

$$ReLU(x) = (0, x) \quad (8)$$

$$S(Z)_i = \frac{e^{Z_i}}{\sum_{j=1}^k e^{Z_j}} \quad (9)$$

The proposed PaddyNet model architecture is shown in Fig. 4. The model has seven convolutional layers which include batch normalization, ReLU, max pooling2D layers, two dense connected layers, and a 13-way softmax activation in the output. In order to reduce data overfitting in each convolution block and the fully connected layer, a “dropout” method is used. The max pooling2D layer helps reduce the parameters used and surpasses average pooling in terms of performance. The Adam optimizer is used to reduce the loss as efficiently as possible and train the PaddyNet model in little time. The CNN model combines all the layers to obtain the highest accuracy. The novel model is trained and compared using several dropout values ranging from 0.2 to 0.8.

The biggest challenge of all in building the proposed PaddyNet model lay in combining all the layers, features, and optimizer values to offer excellent prediction performance. The novel model is tested by adding more layers, altering activation functions, and changing the optimizer values. While categorising 10 distinct categories, for instance, a basic 13-layer CNN model produced 88.84% accuracy. Next, the addition of an extra conv2D layer, maxpool2D, batch normalization, dropout, and activation to our 17-layer PaddyNet model resulted in 98.99% accuracy in identifying the 13 classes.

## IV. EXPERIMENTAL RESULTS

### A. Experimental Setup

We implemented the proposed PaddyNet model using Keras and TensorFlow. All experiments were conducted on the Kaggle platform with GPU kernels to improve computational performance. The list of hyperparameters used in our experiments is shown in Table I. In addition, batch size values of 32, 64, 100, and 160 were used, along with a learning rate of 0.0001. The dropout was varied from 0.2 to 0.8, and the epoch values were 25, 50, 75, 100, 125, 150, 175, and 200. Additionally, the performance of the proposed PaddyNet model was compared to that of five models (the DCNN, Xception, MobileNet, ResNet34, and VGG16), using five performance metrics [41]. The weights of the models, except the DCNN, were initialized based on ImageNet.

### B. Results and Discussion

Table II and Fig. 5 show that the PaddyNet model’s scores for all measures increase proportionately with the epoch. Epoch 200 produced the highest performance in terms of 98.99% accuracy, 98.5% precision, 98.65% recall, and 98.2% F1 score, respectively. Table III and Fig. 6 compare the accuracy of the PaddyNet model to five existing models.

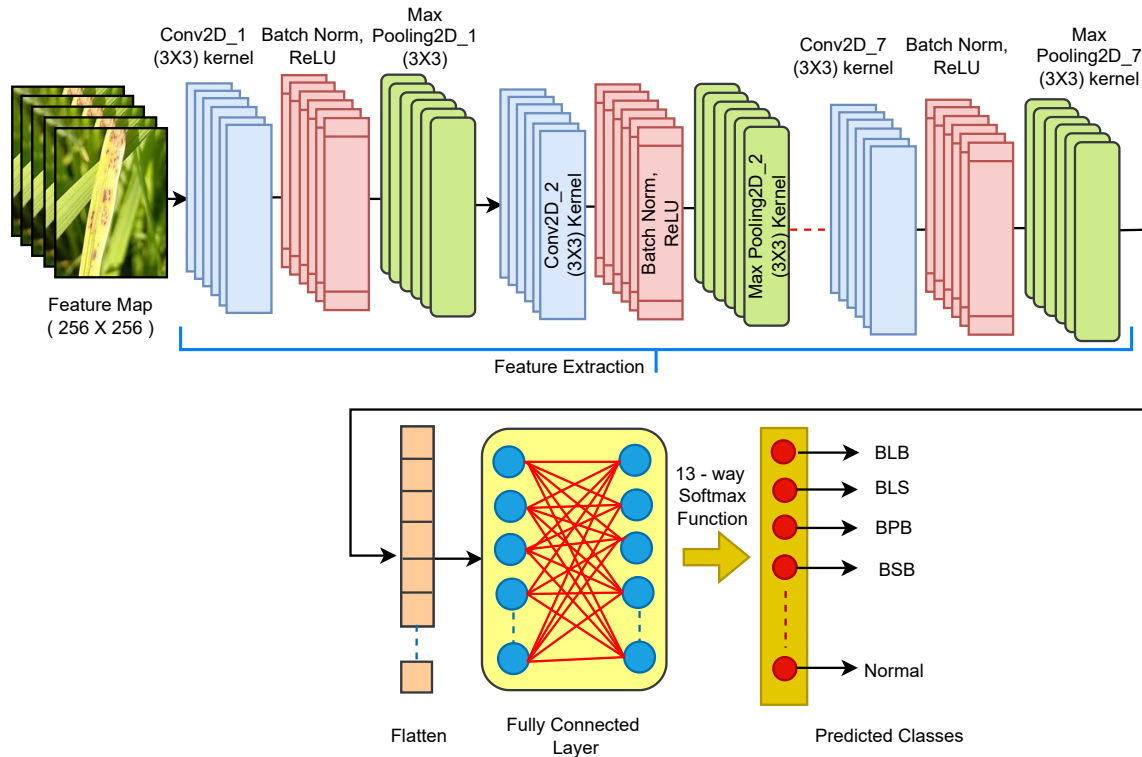


Fig. 4. PaddyNet model architecture.

TABLE I. LIST OF HYPERPARAMETERS OF THE PADDYNET MODEL

Parameters	Values
Batch Size	32, 64, 100, 160
Dropout	0.2 to 0.8
Epoch	25, 50, 75, 100, 125, 150, 175, 200
Learning Rate	0.0001
Optimizer	Adam

TABLE II. COMPARISON OF PERFORMANCE METRICS OF PADDYNET MODEL WITH DIFFERENT EPOCHS

Epoch	Accuracy	Precision	Recall	F1 Score
25	78.31	66.57	67.56	72.65
50	90.95	88.97	85.63	89.2
75	92.42	90.51	89.65	88.67
100	94.05	92.88	91.71	92.88
125	96.23	93.89	95.27	95.27
150	97.24	96.91	95.88	96.85
175	97.53	97.20	96.92	97.10
<b>200</b>	<b>98.99</b>	<b>98.50</b>	<b>98.65</b>	<b>98.2</b>

The PaddyNet model achieved the highest score, followed by Resnet34 [42][41], with 97.50% accuracy, 97.52% precision, 97.50% recall, and F1 score of 97.50%. The simple DCNN [42][41] model performed poorly with 88.84% accu-

racy, 89.22% precision, 88.84% recall, and 88.81% F score. Fig. 7 compares the performance of PaddyNet, based on five different dropout values (0.2, 0.4, 0.5, 0.6, and 0.8). The highest performance accuracy was achieved with a dropout probability of 0.4. Network weights were updated, firstly, to boost the accuracy of error estimation when training PaddyNet and, secondly, to improve efficiency. Fig. 8 compares the performance of different PaddyNet batch sizes in terms of accuracy.

Table IV and Fig. 10 show that the proposed PaddyNet model has the highest misclassification image count of 11 for the leaf blast disease class and the lowest of 1 for the BLS, BPB, yellow stem borer, and normal classes. When dealing with 13 paddy leaf disease classes, the complexity of the infected paddy images was likely to have confused the classifiers, leading to a diminished performance being displayed in the same class. A confusion matrix of the final test results is shown in Fig. 9.

When dealing with 13 classes of paddy leaf diseases, classifiers may be confused due to the complexity of infected paddy images, leading to a less performance are displayed in the same class. The final test results confusion-matrix for the paddy leaf classes is shown in Fig. 9, with correctly predicted values located along the diagonal and incorrectly predicted values located elsewhere. The confusion matrix indicates that the PaddyNet model is more successful at distinguishing certain paddy diseases, such as leaf blast, than others. The number of correctly identified test samples is 128 images in BLB, 99 images in BLS, 89 images in BPB, 94 images in black stem borer, 459 images in leaf blast, 244 images in brown spot, 168

TABLE III. ACCURACY COMPARISON OF OUR PROPOSED PADDYNET MODEL WITH EXISTING MODELS

S.No	Model	Accuracy (%)	Precision (%)	Recall (%)	F1 Score (%)
1	DCNN [41]	88.84	89.22	88.84	88.81
2	MobileNet [41]	92.42	92.63	92.42	92.39
3	VGG16 [41]	93.19	93.49	93.19	93.20
4	Xception [41]	96.58	96.61	96.58	96.57
5	Resnet34 [41]	97.50	97.52	97.50	97.50
<b>6</b>	<b>PaddyNet</b>	<b>98.99</b>	<b>98.50</b>	<b>98.65</b>	<b>98.2</b>

TABLE IV. MISCLASSIFICATION IMAGE COUNT FOR EACH CLASS OF PROPOSED PADDYNET MODEL

S.No.	Disease or class name	Count	PaddyNet	Resnet34	Xception	VGG16	MobileNet	DCNN
1	BLB	130	2	3	5	11	20	24
2	BLS	100	1	2	3	4	14	7
3	BPB	90	1	3	4	12	9	18
4	Black-Stem-Borer	101	7	9	9	13	10	10
5	Blast	470	11	13	13	30	27	57
6	Brown Spot	253	9	10	18	20	21	43
7	Downy-Mildew	174	6	8	8	15	19	27
8	Hispa	431	9	13	23	44	35	78
9	Leaf-Roller	219	3	4	19	35	45	33
10	Tungro	390	6	10	8	12	11	41
11	White-Stem-Borer	254	2	1	3	6	15	11
12	Yellow-Stem-Borer	152	1	2	1	4	10	6
13	Normal	481	1	3	7	15	10	7
	<b>Total</b>	<b>3245</b>	<b>59</b>	<b>81</b>	<b>121</b>	<b>221</b>	<b>246</b>	<b>362</b>

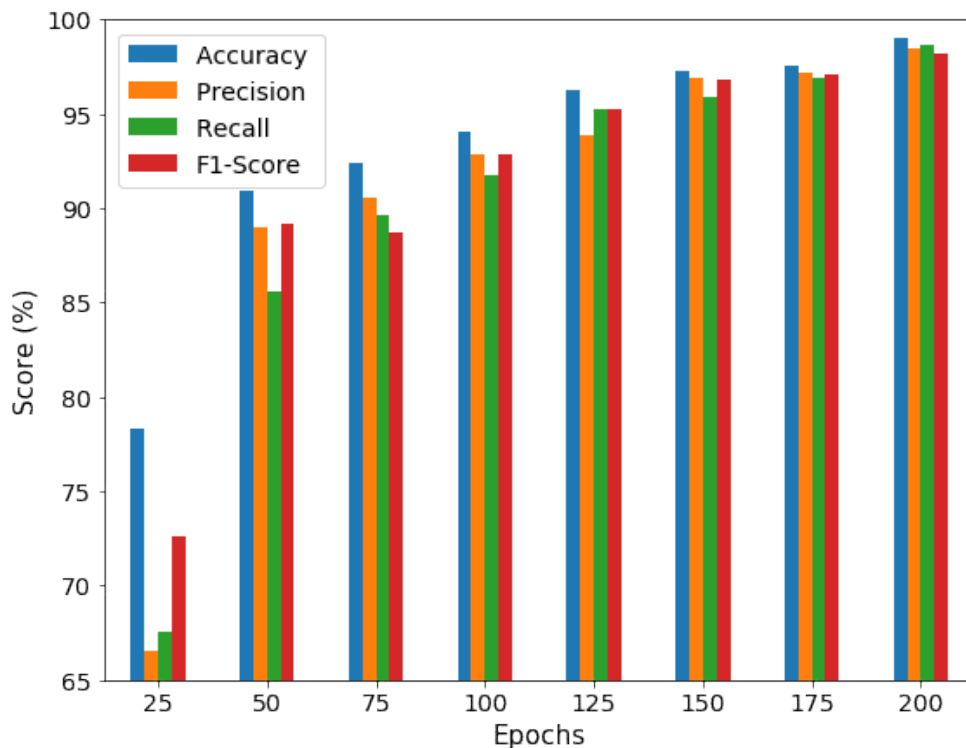


Fig. 5. Comparison of four performance metrics with different epoch. PaddyNet achieved the highest accuracy when using an epoch value of 200.



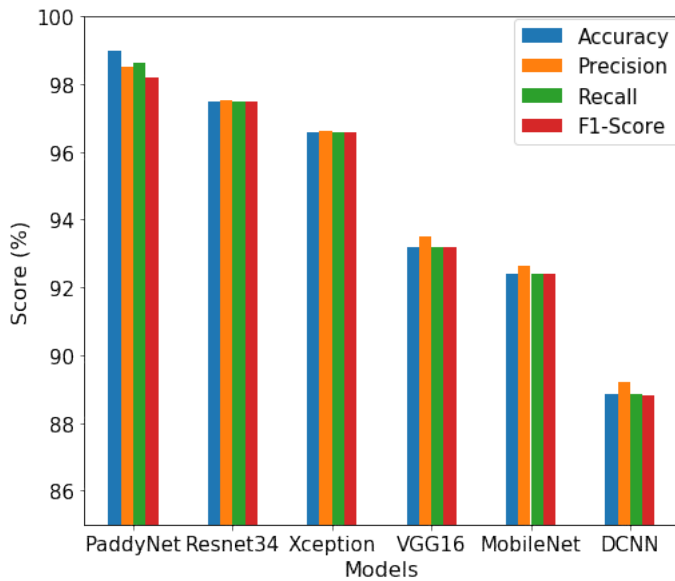


Fig. 6. Comparison of performance metrics of PaddyNet with five deep learning models.

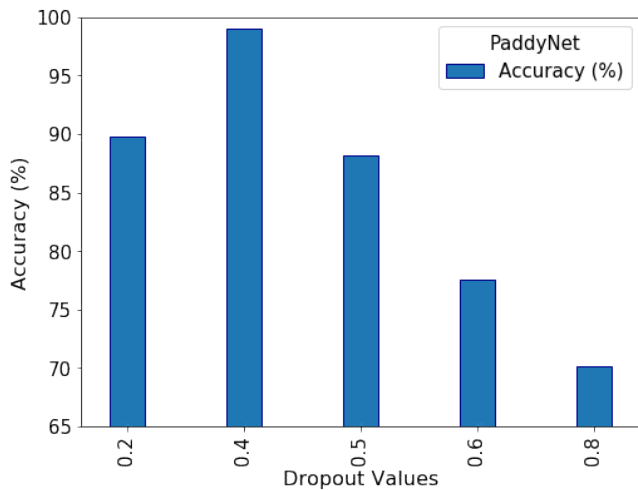


Fig. 7. Comparison of Accuracy of five dropout values used in our experiments. PaddyNet achieved the highest accuracy of 98.99% when the dropout is 0.4 and the lowest accuracy of 73.74% for dropout 0.8.

images in downy mildew, 422 images in hispa, 216 images in leaf roller, 384 in tungro, 252 images in white stem borer, 151 images in yellow stem borer, and 480 normal leaf images in the testing set, respectively. The count of incorrectly identified test samples is 2 images in BLB, 1 image in BLS, 1 image in BPB, 8 images in black stem borer, 11 images in blast, 9 images in brown spot, 6 images in downy mildew, 9 images in hispa, 3 images in leaf roller, 6 images in tungro, 2 images in white stem borer, 1 image in yellow stem borer, and 1 normal leaf image. According to Fig. 10 and 11, which exhibit the misclassification images for each class and their count for each model, the misclassification may have stemmed from the congruent feature similarities of the 13 classes. However, the remaining predicted values are well distinguished.

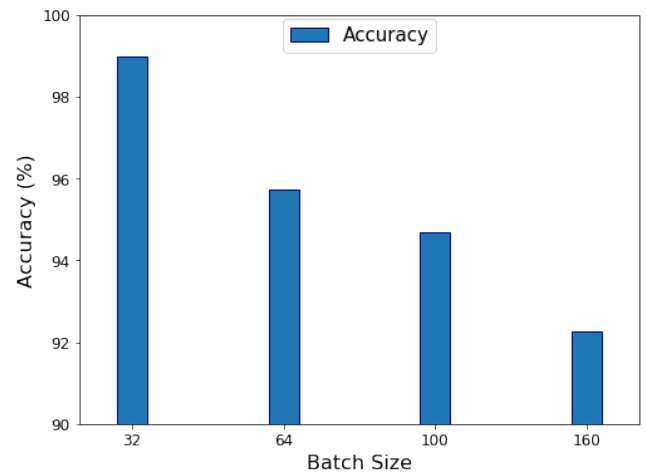


Fig. 8. Comparison of accuracy of PaddyNet using different batch size. PaddyNet achieved the highest accuracy of 98.98% when the batch size is 32.

Bacterial leaf blight	128	0	0	0	0	1	0	0	0	1	0	0
Bacterial leaf streak	1	99	0	0	0	0	0	0	0	0	0	0
Bacterial panicle blight	0	0	89	0	0	0	0	0	0	0	1	0
Black stem borer	0	0	0	94	0	0	0	0	0	0	0	1
Blast	1	1	0	0	459	0	2	2	1	0	4	0
Brown spot	0	5	0	0	0	244	3	0	1	0	0	0
Downy mildew	0	0	0	0	1	0	168	0	0	0	5	0
Hispa	4	0	0	0	3	0	0	422	1	0	1	0
Leaf roller	0	0	0	0	0	0	0	3	216	0	0	0
Normal	0	0	0	0	0	0	0	1	0	480	0	0
Tungro	0	0	0	0	2	0	4	0	0	0	384	0
White stem borer	0	0	0	1	0	0	0	0	0	0	0	252
Yellow Stem borer	0	0	0	0	0	0	0	0	0	0	0	1
												151
	Bacterial leaf blight											
	Bacterial leaf streak											
	Bacterial panicle blight											
	Black stem borer											
	Blast											
	Brown spot											
	Downy mildew											
	Hispa											
	Leaf roller											
	Normal											
	Tungro											
	White stem borer											
	Yellow stem borer											

Fig. 9. Confusion matrix of the PaddyNet model.

## V. CONCLUSION

Deep learning, a fairly recent and advanced method driving agricultural growth and development, has demonstrated that it surpasses others at identifying plant disease. Advanced computer vision technology is prompting further research worldwide in paddy leaf disease identification using different methodologies. The PaddyNet model proposed in this research detects paddy leaf disease efficiently. The infected paddy leaf image dataset includes images of healthy leaves alongside images of leaves depicting twelve different diseases. The identification process of the proposed system was improved through the use of our own collection of previously acquired paddy leaf images. Further, the collected dataset was enhanced using several image augmentation techniques to enrich the model and benchmarked using the proposed PaddyNet model. The experimental results reveal that the proposed PaddyNet outperformed the other five deep learning models, such as the simple DCNN, VGG16, MobileNet, Xception, and Resnet34 [42][41]. The PaddyNet model demonstrated superior performance with 98.99% accuracy, 98.50% precision,

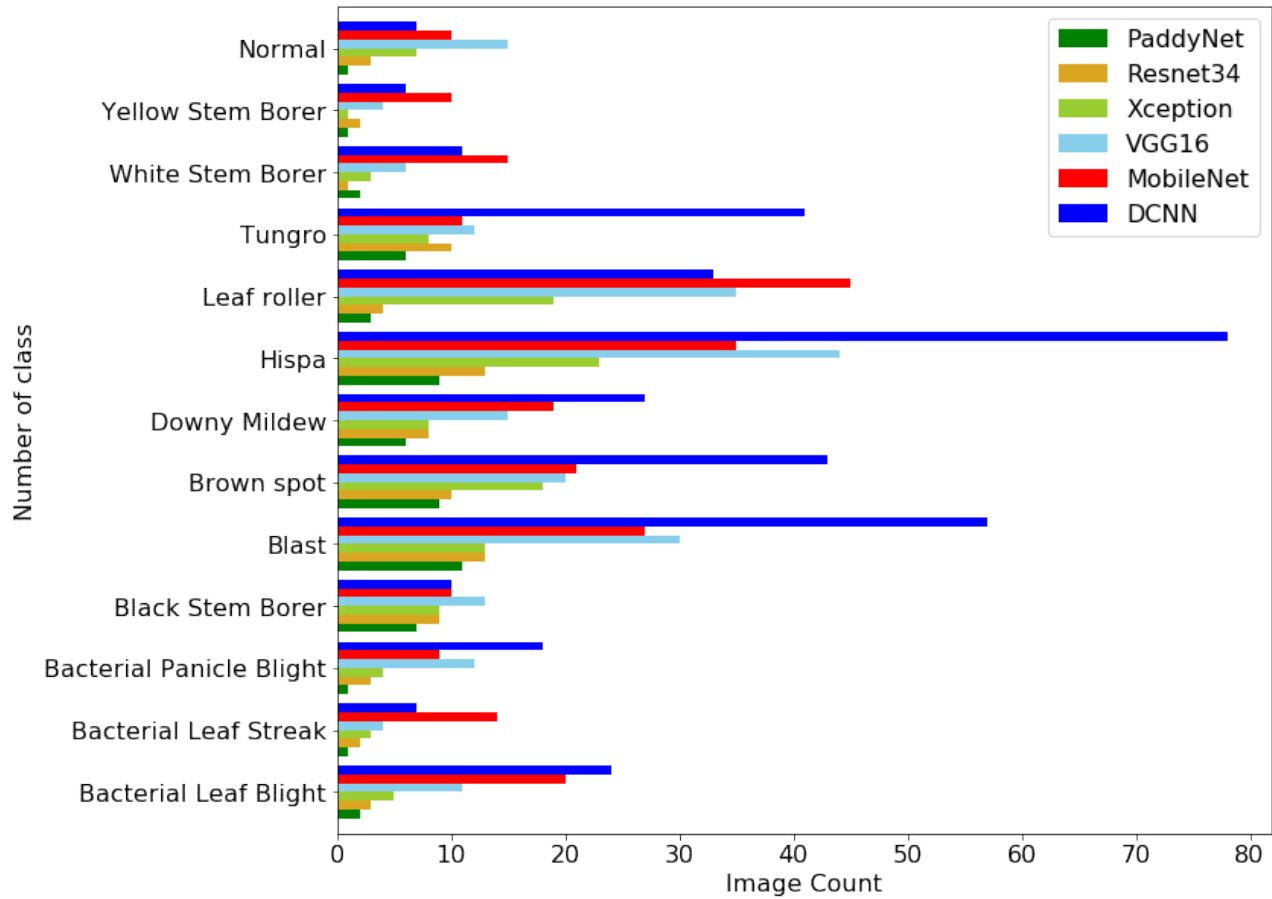


Fig. 10. Comparison of misclassification image counts for each class of PaddyNet and other five models.

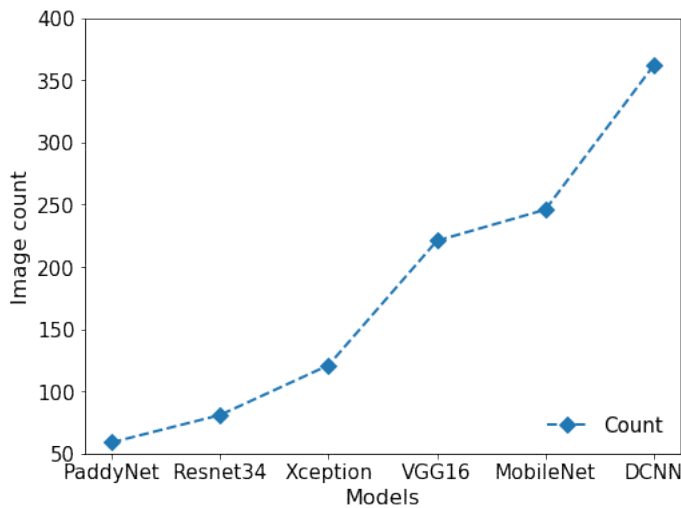


Fig. 11. Count of misclassification images for each model. In the PaddyNet model, only fewer images are not classified compared with the five models.

98.65% recall, and an F1 score of 98.20%, compared to the five state-of-the-art deep learning models. In the future, the proposed PaddyNet paradigm will be extended as a mobile phone application incorporating a deep learning model for

using farmers in real-time in their paddy fields. Next, we plan to capture real-time images taken by farmers in their fields and identify leaf disease instantaneously through the said mobile app.

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# Unmanned Aerial Vehicle-based Applications in Smart Farming: A Systematic Review

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**Abstract**—On one hand, the emergence of cutting-edge technologies like AI, Cloud Computing, and IoT holds immense potential in Smart Farming and Precision Agriculture. These technologies enable real-time data collection, including high-resolution crop imagery, using Unmanned Aerial Vehicles (UAVs). Leveraging these advancements can revolutionize agriculture by facilitating faster decision-making, cost reduction, and increased yields. Such progress aligns with precision agriculture principles, optimizing practices for the right locations, times, and quantities. On the other hand, integrating UAVs in Smart Farming faces obstacles related to technology selection and deployment, particularly in data acquisition and image processing. The relative novelty of UAV utilization in Precision Agriculture contributes to the lack of standardized workflows. Consequently, the widespread adoption and implementation of UAV technologies in farming practices are hindered. This paper addresses these challenges by conducting a comprehensive review of recent UAV applications in Precision Agriculture. It explores common applications, UAV types, data acquisition techniques, and image processing methods to provide a clear understanding of each technology's advantages and limitations. By gaining insights into the advantages and challenges associated with UAV-based applications in Precision Agriculture, this study aims to contribute to the development of standardized workflows and improve the adoption of UAV technologies.

**Keywords**—Artificial intelligence; internet of things; sensor; big data; cloud; unmanned aerial vehicle; smart farming

## I. INTRODUCTION

The agriculture industry is currently undergoing a significant transformation fueled by cutting-edge technologies, offering promising prospects for enhanced farm productivity and profitability. Precision Agriculture, which focuses on the precise application of inputs where and when they are needed, represents the third stage of the modern agricultural revolution. Advanced farm knowledge systems, empowered by the abundance of data, have further propelled the evolution of Precision Agriculture [1]. Numerous studies have demonstrated the positive impacts of adopting Precision Agriculture technologies, such as increased net returns and operating profits, as reported by the U.S. Department of Agriculture (USDA) [2]. Moreover, there is a growing emphasis on implementing these technologies in environmentally conscious ways to ensure sustainable farm production. However, effectively harnessing the vast amount of data generated by crops remains a persistent challenge [3].

To address these challenges, it is crucial to explore and integrate cutting-edge technologies in the realm of Smart Farming and Precision Agriculture. Unmanned Aerial Vehicles (UAVs), Cloud Computing, Internet of Things (IoT), Big Data

analytics, and Artificial Intelligence (AI) have emerged as key enablers of innovation in this domain [4]. UAVs equipped with advanced sensors and imaging capabilities allow for real-time data collection, including high-resolution imagery of crops. Cloud Computing provides the infrastructure for data storage, processing, and analysis, while IoT facilitates the seamless integration of various agricultural devices and sensors. Big Data analytics and AI techniques enable intelligent insights and decision-making based on the collected data [5], [6].

This paper aims to delve into the theoretical background and related work of UAV, Cloud, IoT, Big Data, and AI approaches in Smart Farming and Precision Agriculture. Additionally, authors propose a comprehensive systematic review study that investigates the current state of research and development in this area. By analyzing existing literature, in order to identify the gaps, challenges, and opportunities for utilizing these technologies in the context of Smart Farming and Precision Agriculture, Fig. 1, depicted below, offers valuable insights into the evolution characteristics and challenges of agricultural development, spanning from Farming 1.0 to Farming 5.0. This figure serves as a valuable tool to showcase the effective utilization and evolution of technologies within the realms of Smart Farming and Precision Agriculture. The problem statement of this study revolves around the lack of a standardized framework for leveraging UAVs, Cloud Computing, IoT, Big Data, and AI in Smart Farming and Precision Agriculture. This lack of standardization hinders the widespread adoption and implementation of these technologies, limiting their potential benefits for farmers, agricultural productivity, and sustainable practices. To address this problem, our proposed solution is to conduct a systematic review that synthesizes existing research, identifies key insights, and provides recommendations for the development of standardized frameworks and practices in this field.

The motivation behind this work stems from the immense potential of integrating UAVs, Cloud Computing, IoT, Big Data analytics, and AI in Smart Farming and Precision Agriculture. By leveraging these technologies effectively, farmers can make faster and more informed decisions, reduce costs, optimize resource utilization, and increase yields. Moreover, this integration aligns with the growing demand for sustainable farming practices and the need to meet the rising global food demands. The contribution of this paper lies in the comprehensive review of existing literature, which consolidates knowledge, identifies research gaps, and proposes recommendations for the future development of Smart Farming and Precision Agriculture. By providing insights into the theoretical foundations, related work, problem statement, proposed solution, and motivation,

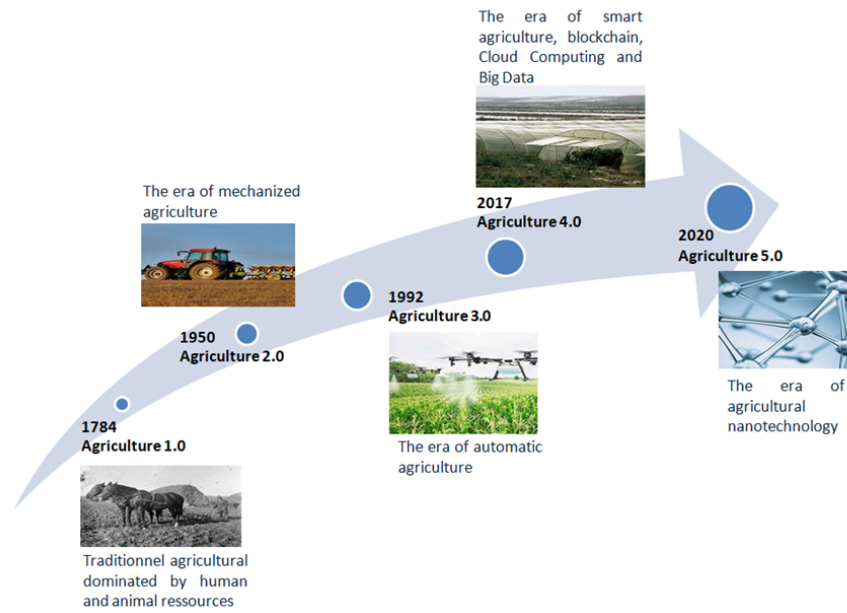


Fig. 1. Characteristics and challenges of agricultural development (from Farming 1.0 to Farming 5.0).

in order to advance the understanding and adoption of UAVs, Cloud Computing, IoT, Big Data analytics, and AI in the agricultural domain.

This paper is structured as follows. Firstly, Section 1 presents the theoretical background of UAV, Cloud, IoT, Big Data and AI approaches. Afterwards, current technical components of Smart farming and precision agriculture in the research area are specified. Within this section, a more in-depth reflection is carried out on the rising of AI and IoT in smart farming. Secondly, Section 2 describes the detailed process steps of the systematic review and the defined research methodology of this study. Then, Section 3 summarizes the research results. Section 4 describes the discussion with challenges and future directions of this research study. Finally, a conclusion is presented in the last section of this paper.

## II. BACKGROUND

### A. Unmanned Aerial Vehicles for Agriculture

Unmanned Aerial Systems (UAS), also known as drones, have become increasingly popular in agriculture due to their ability to provide a quick, cost-effective and efficient way to gather data and perform tasks on large fields and crops [7]. UAS (Unmanned Aerial Systems) indeed come in different types and can be equipped with a variety of sensors and cameras presented in Fig. 2 that can capture high-resolution images, aerial maps and thermal imagery, which can be used for a range of agriculture applications, including:

- Crop monitoring: UAS can be used to gather real-time data on crop health, growth, and yield potential.
- Irrigation management: Drones can be equipped with infrared cameras to identify areas that are in need of irrigation and to help optimize water use.

- Pest and disease management: Drones can be used to detect and map the spread of pests and diseases in crops, helping farmers to take timely action to prevent or treat these issues.
- Field mapping: UAS can produce high-resolution maps of fields, providing data on soil structure, topography, and plant populations, which can be used to make informed decisions about planting, fertilization and other aspects of crop management.
- Livestock management: Drones can be used to monitor the health and behavior of livestock, as well as to keep track of the location of animals.

Overall, the use of UAS in agriculture provides a new tool for farmers to gather data, monitor their crops and make more informed decisions, ultimately leading to improved yields, increased efficiency and reduced costs.

### B. Cloud, Internet of Things, Big data and IA

1) *Cloud*: computing plays a crucial role in smart farming, which is an application of the Internet of Things (IoT) in agriculture. The cloud enables farmers to store, process, and analyze large amounts of data generated from various IoT devices and sensors on their farms [9]. This data can include information on weather patterns, soil moisture levels, crop growth, and even the health of livestock. By analyzing this data in real-time, farmers can make more informed decisions about crop management and animal husbandry, leading to increased productivity and efficiency.

Additionally, cloud-based solutions can provide farmers with access to advanced algorithms and predictive analytics tools that can help them optimize their farming operations. For example, cloud-based machine learning models can predict

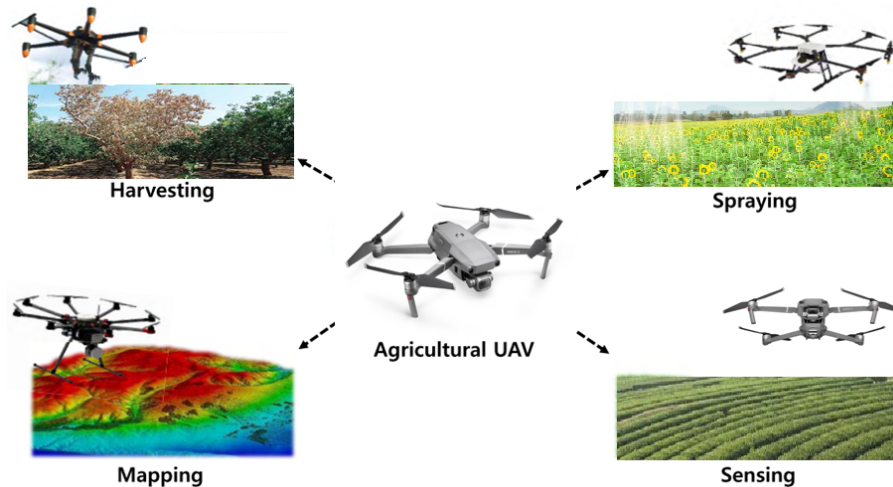


Fig. 2. Different types of agricultural UAVs (Harvesting UAV, Spraying UAV, Mapping UAV, Sensing UAV) [8].

crop yields, identify pest infestations, and suggest the most appropriate treatments. Furthermore, the cloud allows farmers to monitor their farms remotely and receive real-time updates on conditions and activities.

2) *Internet of Things*: The concept of the Internet of Things (IoT) pertains to a network comprising physical devices, vehicles, appliances, and various objects. These entities are equipped with sensors, software, and connectivity features that empower them to gather and exchange data via the internet. These connected devices can communicate and interact with each other, as well as with humans, creating a vast ecosystem of interconnected systems [10]. The IoT has the potential to revolutionize various sectors, including agriculture, healthcare, transportation, smart homes, and many others, by enabling increased automation, efficiency, and data-driven decision-making. In smart farming, IoT is used to gather real-time data from various sources such as weather stations, soil moisture sensors, and crop and animal monitoring systems.

IoT devices and sensors in smart farming can range from simple weather sensors to more complex systems such as precision agriculture systems that use Global Positioning System (GPS) to monitor the growth and health of crops. These devices can also be connected to irrigation systems, allowing farmers to control the amount of water they use based on real-time soil moisture levels. One of the key benefits of IoT in smart farming is that it enables farmers to make data-driven decisions in real-time. This leads to more efficient use of resources and improved crop yields. IoT also enables farmers to monitor their farms remotely, reducing the need for on-site visits and freeing up more time for other tasks.

In addition to its direct benefits, IoT in smart farming can also help address important global challenges such as food security and sustainability [11]. By using technology to optimize their operations, farmers can produce more food using fewer resources, reducing their carbon footprint and helping to ensure that future generations have access to safe and healthy food. Overall, the Internet of Things is revolutionizing the way farming is done and is poised to play a crucial role in the future

of agriculture.

Wireless Sensor Networks (WSNs) are networks of small, low-cost, and low-power devices that can be used to monitor and collect data from the environment [12]. These devices, called “nodes”, are equipped with sensors, microcontrollers, and wireless communication capabilities, allowing them to transmit data wirelessly to a central location for analysis.

WSNs are widely used in a variety of applications, including smart farming, where they are used to monitor soil moisture, temperature, light, and other environmental parameters that affect crop growth [13]. The data collected by the sensor nodes can be used to make informed decisions about irrigation, fertilization, and other agricultural practices, leading to increased efficiency and higher crop yields.

One of the key benefits of WSNs is that they are low-cost and easy to deploy, making them accessible to farmers of all sizes and resources. They are also scalable, allowing farmers to add more nodes as their needs grow [14]. Finally, a review of 77 research papers published between 2012 and 2022 on the implementation of IoT in various agricultural applications showed that roughly 16% focused on precision agriculture and the same percentage on irrigation monitoring. 13% of the papers delved into soil monitoring, while temperature and animal monitoring were each covered in 11% of the research. Air and disease monitoring each received 5% of attention, with water monitoring accounting for 7%. Fertilization monitoring was the least studied, with only 4% of the research papers devoted to it in [15].

### C. Big Data

Big Data plays a significant role in the context of smart farming. Smart farming involves the application of advanced technologies, such as sensors, Internet of Things (IoT) devices, and data analytics, to enhance agricultural practices and decision-making processes [16]. These technologies generate vast amounts of data from various sources, including weather conditions, soil moisture levels, crop health indicators, and machinery performance.



Big Data analytics allows for the collection, storage, processing, and analysis of large volumes of agricultural data in real-time or near-real-time. By applying advanced analytics techniques, such as machine learning and predictive modeling, valuable insights can be extracted from this data. These insights can help optimize farming practices, improve resource allocation, enhance crop yield, and enable more informed decision-making for farmers and agricultural stakeholders [17]. Furthermore, Big Data analytics can enable predictive capabilities in smart farming. By leveraging historical data and machine learning algorithms, models can be developed to forecast disease outbreaks, pests infestation, crop yield, and market demand. These predictive insights empower farmers to make proactive decisions, mitigate risks, and optimize resource allocation. In summary, the integration of Big Data analytics in smart farming allows for data-driven decision-making, optimization of agricultural practices, and the potential for increased productivity, sustainability, and profitability in the agriculture industry [18], [19].

#### *D. Artificial Intelligence*

Artificial Intelligence (AI) encompasses the creation of computer systems capable of executing tasks typically requiring human intelligence, including pattern recognition, prediction, and learning from experience. In smart farming, AI is used to automate various processes and make more informed decisions [16]. One of the key applications of AI in smart farming is precision agriculture, where AI algorithms are used to analyze data from various sources, such as weather stations and sensors, to determine the best practices for growing crops. For example, AI can be used to optimize irrigation and fertilization practices, leading to increased efficiency and higher yields. AI can also be used in animal husbandry to monitor the health and behavior of livestock. Also, AI algorithms can be used to detect signs of illness in animals, such as changes in their heart rate or behavior, and alert farmers to take action. Another application of AI in smart farming is in the detection and control of pests and diseases. AI algorithms can be used to analyze images of crops and detect signs of pests or diseases, allowing farmers to take proactive measures to address them. In conclusion, AI is a valuable tool in the development of smart farming, enabling farmers to make more informed decisions and automate various processes [20]. By using AI, farmers can improve efficiency, increase yields, and reduce waste, making a valuable contribution to the future of agriculture. However, it's important to note that while AI has the potential to greatly benefit the agriculture industry; it also presents challenges, such as the need for large amounts of data and the potential for bias in algorithms. Thus, it's important to approach the integration of AI in smart farming with caution and a focus on ethical and sustainable practices.

### III. METHODOLOGY

In recent years, the academic community has extensively analyzed numerous works related to smart farming development from various perspectives. For instance, [21] introduced a systematic review focusing on precision farming. Then, authors in [22] provided a review on technologies in precision agriculture, highlighting innovations, technologies, and applications. Also, authors in [23] explored the use of big data on smart

farming, emphasizing the primary opportunities and challenges associated with this technology. Additionally, [24] conducted a quantitative literature review, offering an overview of academic production in smart farming.

In order to enhance the existing analyses, the present study seeks to conduct a comprehensive review of UAV based applications in the field of smart farming. To accomplish this objective, we employed the Preferred Reporting Items for Systematic Reviews (PRISMA) methodology [25], a framework specifically designed to facilitate literature reports and systematic reviews. In October 2022, authors conducted a search using the available search tool on the Scopus database website. Additionally, another search was performed in April 2023 within the same database to include papers published in the year 2023. Scopus was selected due to its extensive coverage and relevance in similar bibliographic reviews mentioned in [24] and [26]. Our search strategy focused on terms related to technological applications in agriculture, such as "Precision Agriculture," "Precision Farming," "Smart Farming," and "Smart Agriculture," in conjunction with "UAV" and related terms. The publication date of articles was not a basis for exclusion. However, we restricted our research scope to journal and conference articles published in English. To ensure methodological rigor, this systematic review adhered to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), with the most recent version being 2020. In Table I, you will find a compilation of the research questions (RQ) that the Systematic Literature Review (SLR) aims to address.

In this paper, a systematic literature review (SLR) was conducted to assess recent research papers on the use of IoT, Big data, Cloud & AI techniques in the field of Smart farming. However, advancements in technology and the increasing availability of digital resources have led to the development of new systematic review process, but the traditional systematic literature review methodology remains the standard approach for conducting systematic reviews, new tools and techniques are emerging that can enhance the process and provide additional benefits to researchers and decision-makers. However, it is important to consider the limitations of these new approaches and to ensure that the results of the systematic review remain reliable and trustworthy. The following are the steps involved in the systematic literature review methodology: In this context, lookup has produced a plethora of SLR standards that should be observed to reap tremendous empirical research. In this paper, we concentrate on the SLR guidelines proposed by authors in [19], which can be classified into the following categories. There are four steps:

- Step 1: Identifying the research goal(s).
- Step 2: Research subject framing (conceptual boundaries).
- Step 3: Using inclusion/exclusion criteria to collect data.
- Step 4: Validation of the research findings is the fourth step.

TABLE I. RESEARCH QUESTIONS OF THE STUDY

Number	Research Question (RQ)
RQ1	What are the various applications of UAVs in Precision Agriculture?
RQ2	Which crops are monitored by UAV systems?
RQ3	How can UAV-based technologies be adapted for use in different types of crops or farming environments?
RQ4	What types of data can be obtained through the use of UAVs?
RQ5	Which methods of data processing can be employed to analyze the agricultural data collected by UAVs?
RQ6	What are the challenges associated with using drones for disease detection in agriculture?
RQ7	What are the potential ethical and legal implications associated with the use of drones in agriculture, and how can these issues be addressed?

### A. Research Objectives

This study attempts to systematically analyze possible future possibilities for IoT, Cloud, Big Data and AI in Smart Farming by analyzing current knowledge and the state of the research, with a focus on recent research advancements. This paper is interested in learning how this study topic has changed throughout time. Furthermore, the outcomes of the evaluation will be utilized to identify critical activities for future study as well as practical applications.

### B. Framing of the Research Subject

The goal of this study is to evaluate Big Data, Cloud, internet of things, artificial intelligence technologies for Smart Farming in a systematic way. As a result, the research subject, i.e. the conceptual boundaries, were defined in the agriculture environment using the terms “Unmanned Aerial Vehicle”, “Big Data”, “Cloud”, “internet of things”, “artificial intelligence” and related concepts “machine learning” and “deep learning.” The following Table II displays the Inclusion and exclusion criteria identified to refine the search request.

### C. Data Collection by Using Criteria

A definition of search parameters, databases, search keywords, and publication time is also required by the SLR. The selection of search resources and the choice of search phrases are both part of the search strategy. To find the papers, automated search engine from the most relevant sources were chosen: Scopus. A further examination of similar databases (ACM Digital Library and Emerald) revealed significant variations in the research studies that resulted. As a result, Scopus was used as the primary database for secondary data evaluation in this research study. The systematic research approach [24] and the inclusion and exclusion criterias, which are based on the process query depicted in Fig. 3.

Screening the article title, abstract, and keywords for relevant literature for Blockchain, IoT and AI in the subject areas of management was the first step. We included a variety of document formats in this stage and limited them to the English language. This first method was mostly utilized to obtain a sense of where research was at the time. As a result, the study was not limited intially to a specific period. In total, 536 studies were found as a result of this method. We concentrated on studies in the areas of Smart Farming and Precision Agriculture in the second step. As a consequence, we narrowed down the previously identified 536 publications to 186 papers that contained the terms Smart Farming or Precision Agriculture.

TABLE II. INCLUSION CRITERIA (IC) AND EXCLUSION CRITERIA (EC).

Number	Question
IC1	Paper published in a peer reviewed scientific journal
IC2	Works published in English
IC3	Articles on Computer Science Subject Area
IC4	Keywords on Agriculture, Unmanned Aerial Vehicles, Machine Learning
EC1	Reviews, conference papers, conference reviews, letters, books, book chapters and editorials are excluded from this study
EC2	Works that do not provide enough information on the methodology adopted and that do not report their results in a clear way are excluded.
EC3	Articles whose full text is not available are excluded

TABLE III. QUALITY ASSESSMENT QUESTIONS

Number	Question
Q1	Have the study's objectives been effectively communicated and defined?
Q2	Is the scope and context of the study clearly outlined and appropriately described?
Q3	Has the proposed solution been thoroughly explained and supported by empirical evidence?
Q4	Do the variables utilized in the study demonstrate both validity and reliability?
Q5	Is the research process adequately documented and transparent?
Q6	Have all the research questions been adequately addressed?
Q7	Are any negative findings presented or discussed within the study?
Q8	Are the main findings clearly stated, emphasizing credibility, validity, and reliability?

Furthermore, we created a ranking of all detected keywords, which was utilized to verify the meta-search query for the current database investigation. In our research strategy, no important terms were left out. To evaluate only high-quality studies, the study was limited to conference papers, conference reviews, articles, or reviews in the third step. In conclusion, the final meta-search query was as follows:

**Research Query :** (“UAV” OR “Unmanned Aerial Vehicle”) AND (“Machine Learning” OR “Deep Learning”) AND (“IoT technology” OR “IoT” OR “Internet of Things” OR “internet-of-things”) AND (“Smart Farming” OR “Smart Agriculture” OR “Precision Farming” OR “Precision Agriculture”) AND (“Cloud Computing”).

The chosen papers were evaluated using eight quality assessment questions listed in Table III [27]. Scores of 1 (high quality), 0.5 (moderate quality), or 0 (poor quality) were given to each paper. Papers that received a total score below four were removed from the study.

## IV. RESULTS

This section present the results obtained and content analysis on the complete texts of the identified papers. The initial stage of the selection process involved screening the title, abstract, and introduction of each paper to ascertain its relevance. The subsequent step was to eliminate papers that did not meet the exclusion criteria outlined in Table II. As a result, 80 papers were identified as the basis for the further research process. It is important to note that quotation marks are used to ensure that multi-word terms are searched together, preventing individual words from being considered separately. After conducting the search, the resulting articles were manually reviewed by analyzing their titles, keywords, abstracts, and texts. Duplicate articles were eliminated, and the remaining articles were assessed to determine whether

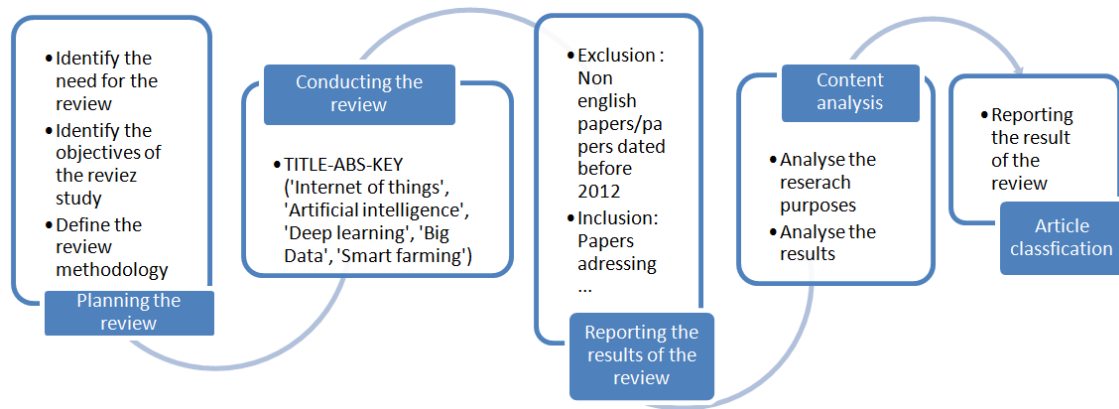


Fig. 3. Process steps of the systematic literature review.

they were relevant to the study's objectives. Valid articles were those that focused on IoT-based solutions for agricultural problems, were not literature reviews, were written in English, Portuguese, or Spanish, and pertained to agriculture rather than livestock activities. The study's search and selection process is summarized in Fig. 4. The initial search yielded 536 articles, which were then analyzed and narrowed down to 186 articles that met the study's eligibility criteria. During the screening phase, 350 articles were deemed invalid and discarded based on their lack of relevance to the study's objectives. Of these, 65% did not focus on smart farming. Additionally, almost 35% of the discarded papers were literature reviews or studies related to smart farming that did not involve IoT. A small number of papers pertained to smart farming but did not address IoT (about 5% were related to sensors), and some papers had abstracts or texts that were not available (about 2%).

In the eligibility phase, the content of the 80 remaining articles was reviewed using the same criteria as in the screening phase. Of these, 23 articles were discarded, with 27% not related to IoT and 32% not to smart farming. The remaining 41% were literature reviews or papers without available content. This research analysis conducted in 57 articles that were eligible for inclusion in the study's sample.

#### A. Description Analysis

57 papers were ultimately assigned to the topic and rated as relevant for deep analysis, out of a total of 536 papers that had been previously identified regarding the application of Cloud, Big Data, IoT, AI, within UAV Application in Smart Farming. The distribution of the selected studies' suitability, which was assessed by reading their titles and abstracts, the distribution of articles published per year is shown in Fig. 5, then the distribution of documents per year per source is provided in Fig. 6 and finally the Fig. 7 describe the distribution of documents by appropriateness.

The decrease in research on the application of drones in precision agriculture may be multiple and dependent on various factors such as funding, research priorities, technological advancements, etc. However, some possible hypotheses can be suggested: Recent technological advancements may have solved a significant portion of the issues related to drone

application in precision agriculture, thereby reducing the need for further research in this field. Funding for research in this field may have been reduced or directed towards other research areas. The scientific community may be transitioning to other agricultural monitoring technologies or methods, such as the use of remote sensors or satellites. It is also possible that the number of scientific publications on the subject has decreased, but research is still ongoing in other contexts as provided in the distribution of document by subject area provided in Fig. 8, such as in the private industry. Ultimately, it is important to realize that the decrease in research in a given field does not necessarily imply that research should be abandoned or that previous results are no longer relevant. Existing research can still be used to improve existing applications and guide future research.

Out of the 166 full texts in the field of smart farming that were found, 96 papers (58%) were rated as having high appropriateness, 53 papers (32%) as having medium appropriateness, and 17 papers (10%) as having low appropriateness in relation to the goal of this research project. Book chapters are of total of 21%, while research articles are 44%, and reviews are 23%.

Based on the 166 complete articles that were found, Fig. 8 displays the distribution of document types in the field of smart farming by subject area.

#### B. Content Analysis

The complete texts of the papers were reviewed and identified in this section. Table IV summarizes the most important clusters, primary references, to group the chosen literature into related clusters, we engaged in a thorough content analysis. In addition Table V complete this set of research documents by UAV articles analyzed by characteristics and limitations identified in the survey.

IoT (Internet of Things) technology is transforming the agricultural industry by enabling farmers to collect and analyze data from various sources to make informed decisions. However, like any technology, IoT also presents challenges and issues, particularly in the context of smart farming. Table VI provides a comparison of IoT issues and challenges in smart farming:

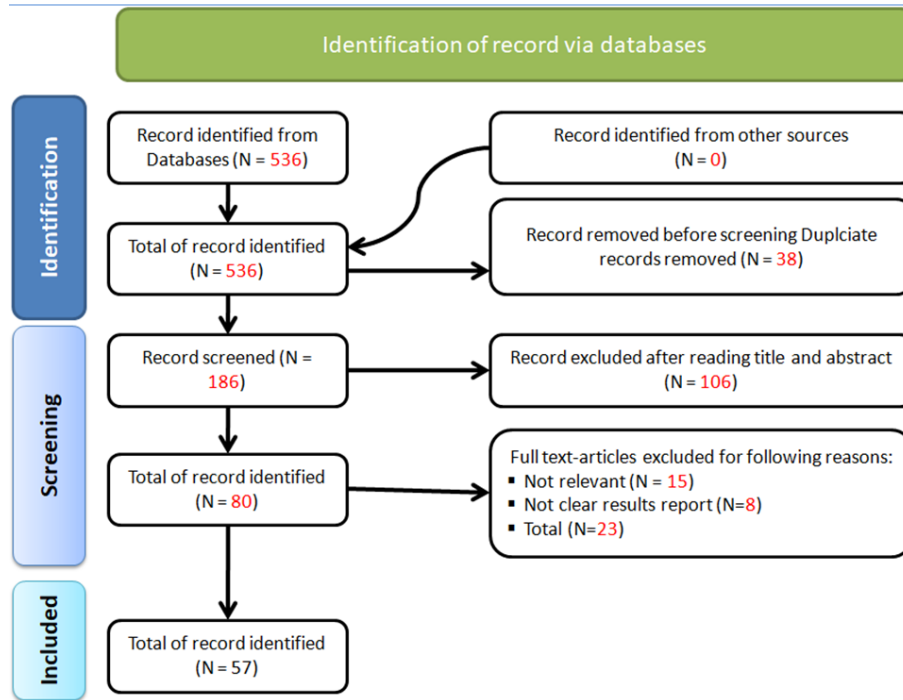


Fig. 4. Flow chart of databases search criteria and identification process of records.

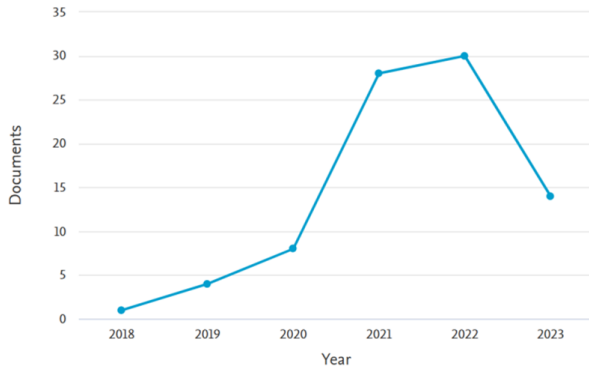


Fig. 5. Distribution of articles published per year.

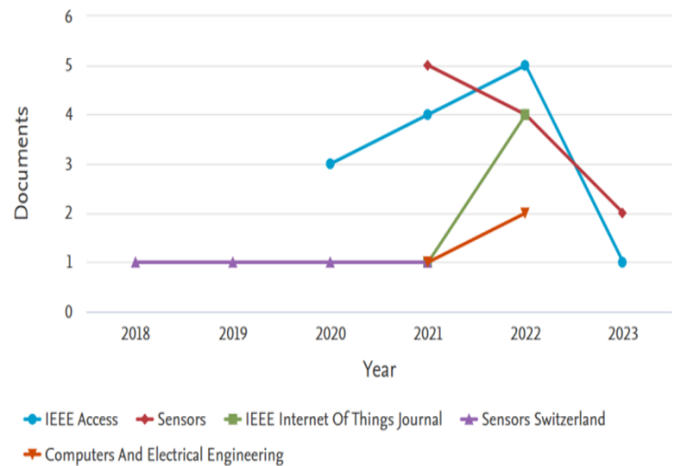


Fig. 6. Distribution of documents per year per source.

### RQ1. WHAT ARE THE VARIOUS APPLICATIONS OF UAVS IN PRECISION AGRICULTURE?

The use of Artificial Intelligence (AI) and cloud technology in Unmanned Aerial Vehicles (UAVs) has brought about significant improvements in smart farming. Here are some of the impacts:

- **Soil Analysis:** UAVs can be used to collect soil samples, analyze soil moisture levels, and assess soil quality, which can help farmers optimize fertilization and irrigation practices.
- **Planting:** UAVs can be used to plant seeds precisely and efficiently, reducing labor costs and increasing planting accuracy. **Crop spraying:** UAVs equipped with spraying systems can be used to apply pesticides, herbicides, and fertilizers accurately, reducing the en-

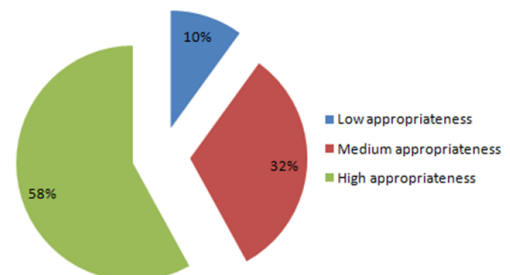


Fig. 7. Distribution of document by appropriateness.

TABLE IV. SELECTED PRIMARY STUDIES IN SCOPUS

Ref	Authors	Year	Technology and Subject Area
[28]	I. Buja et al.	2021	Plant diseases
[29]	K.A. Awan et al.	2020	Cloud based IoT
[30]	M.E. Pérez-Pons et al.	2021	Sustainable agricultural market
[20]	P. Placidi et al.	2021	Crop health monitoring
[22]	T. Kawai	2021	Agricultural systems
[12]	A.Z. Bayih et al.	2022	Sustainable Smallholder Agriculture
[[13]	T. Qayyum et al.	2022	Clustering model in smart farming
[14]	J. Bravo-Arrabal et al.	2021	The internet of cooperative agents
[9]	D. Loukatos et al.	2023	Malfunction Detection of Water Pump Equipment
[11]	N.N. Thilakarathne et al.	2022	Crop Recommendation Platform
[10]	A. Saleh et al.	2022	Edge Node for IoT-Enabled Sensor Networks
[3]	A. Cravero et al.	2022	Agricultural Big Data
[6]	G. Giray et C. Catal	2021	Sustainable agriculture
[1]	S. Pal et al.	2023	IoT-Based Smart Farming
[31]	Z. Nurlan et al.	2022	Wireless Sensor Network
[32]	F.S. Alrayes et al.	2023	Fuzzy Logic-IoT-Cloud Environment
[33]	S.S. Sarnin et al.	2019	Smart insects repeller
[15]	Y. Liu et al.	2022	Intelligent Data Management System
[34]	P. Deepika et B. Arthi	2022	Plant pest detection
[35]	K. Sharma et al.	2022	Predictive Analysis and Smart agriculture
[36]	W. Zhao et al.	2023	Smart Irrigation and Crop Monitoring
[37]	T. Sutikno et D. Thalmann	2022	Internet of things
[38]	A. Zervopoulos et al.	2020	Wireless sensor network synchronization
[39]	C.G.V.N. Prasad et al.	2022	Edge Computing and Blockchain
[40]	M.L. Rathod et al.	2022	Cloud Computing and Networking
[41]	C.H. Wu et al.	2020	Long Short-Term Memory
[42]	S. Yadav et al.	2022	Disruptive Technologies - Sentiment Analysis.
[43]	C. Bersani et al.	2022	Monitoring and Control of Smart Greenhouses
[44]	M. Junaid et al.	2021	Smart agriculture cloud
[45]	J. Almutairi et al.	2022	UAV-Enabled Edge-Cloud Computing Systems
[46]	B. Almadani et S.M. Mostafa	2021	IoT based multimodal communication model
[47]	A.S.P. Pamula et al.	2022	Real-Time Monitoring
[48]	E. Petkov et al.	2023	Smart Egg Incubation
[49]	S. Chaterji et al.	2021	Digital Agriculture
[50]	S. Katiyar et A. Farhana	2021	Artificial Intelligence and IoT
[51]	M.Z. Islam et al.	2022	QoS Provisioning
[52]	Y. Gong et al.	2022	Grid-Based coverage path planning
[53]	R. Winkler	2021	Environmental monitoring

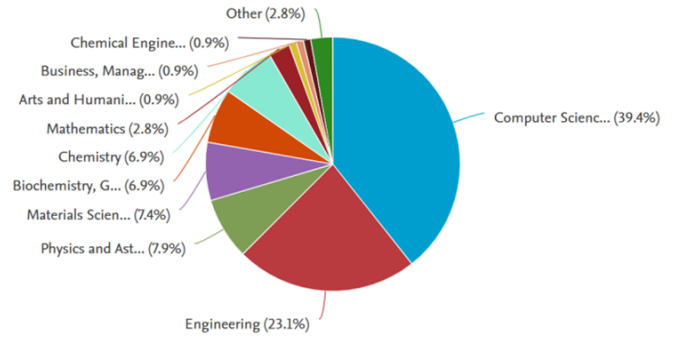


Fig. 8. Distribution of document by subject area.

environmental impact and saving time and money.

- Irrigation Management: UAVs equipped with thermal sensors can be used to identify areas of the field that need irrigation, allowing farmers to optimize water usage and reduce waste.
- Yield Mapping: UAVs can be used to generate yield maps, which can help farmers optimize crop management practices and increase overall yield.
- Livestock Monitoring: UAVs equipped with cameras can be used to monitor livestock, detect health problems, and track animal behavior.
- Crop Monitoring: UAVs equipped with sensors and cameras can be used to monitor crop health and growth, detect diseases, pests, and stress factors affecting the crop and generate crop health maps.

The integration of AI and cloud technology in UAVs has brought about significant improvements in smart farming. It has enabled precision agriculture, increased efficiency, reduced environmental impact, and enabled real-time monitoring of farm operations. Also, drones have revolutionized many industries, including precision agriculture. So the Fig. 9 provide significant UAV applications in precision agriculture using AI and Cloud Technologies. Overall, UAVs can significantly improve efficiency, accuracy, and sustainability in precision agriculture, making it a valuable tool for modern farmers.

## RQ2. WHICH CROPS ARE MONITORED BY UAV SYSTEMS?

Unmanned Aerial Vehicle (UAV) systems are increasingly being used for crop monitoring and management in agriculture. Various types of crops can be monitored using UAV systems, including different Cereals. These crops are often monitored for growth stages, yield prediction, and disease detection [63]. Fruits and vegetables: Such as grapes, citrus, apples, tomatoes, and potatoes. UAV systems can monitor the growth and health of these crops, detect pests and diseases, and assess yield. Oilseeds: Such as soybeans, sunflowers, and canola. UAV systems can be used to monitor crop growth, assess the health of plants, and predict yields. Specialty crops: Such as coffee, tea, cocoa, and tobacco. UAV systems can help monitor the health of these crops, detect early signs of disease or pest

TABLE V. CHARACTERISTICS AND LIMITATIONS OF THE RESEARCH: SET OF UAV ANALYZED ARTICLES BY PUBLICATION YEAR, SHORT DESCRIPTION, AUTHOR AND AREA OF APPLICATION

Reference	Author	Publication year	Description	Characteristics	Limitations
[54]	N. A. Sehree and A. M. Khidhir	2022	Classification of olive tree cases based on deep convolutional neural network using unmanned aerial vehicle (UAV) imagery	This paper proposes a framework that integrates UAVs with IoT and cloud computing for smart agriculture. The authors demonstrate the feasibility of the proposed framework through a case study. They conclude that the proposed framework can improve crop yield and reduce costs for farmers.	The authors primarily focus on the challenges associated with implementing UAV-based systems, rather than discussing potential solutions or strategies for overcoming these challenges. While this is an important aspect to consider, a more detailed analysis of potential solutions or strategies could be useful for practitioners and researchers in the field.
[55]	J. M. Jurado et al.	2020	Individual characterization of olive trees through multi-temporal monitoring and multispectral mapping on 3D models.	This study proposes an intelligent UAV-based system that uses deep learning and IoT for crop growth monitoring. The authors demonstrate the effectiveness of the proposed system through experiments. They conclude that the proposed system can accurately monitor crop growth and help farmers make informed decisions.	The authors used a greenhouse to conduct their experiments, which may not accurately reflect the challenges and limitations of implementing a UAV-based crop monitoring system in an outdoor agricultural environment.
[56]	P. Rallo et al.	2020	Investigating the use of UAV imagery to enhance genotype selection in olive breeding programs.	This paper proposes a novel approach to weed detection in smart agriculture using UAVs and deep learning. The authors demonstrate the effectiveness of the proposed approach through experiments. They conclude that the proposed approach can accurately detect weeds and help farmers reduce the use of herbicides.	The authors used only one type of UAV (a DJI Phantom 4 Pro drone) for their experiments. Different types of UAVs have different capabilities, such as flight time, payload capacity, and camera quality, which could impact the effectiveness and accuracy of a UAV-based weed detection system.
[57]	A. Safonova et al.	2021	Estimating the biovolume of olive trees using multi-resolution image segmentation with Mask Region-based Convolutional Neural Network (R-CNN) on UAV imagery.	The authors demonstrate the feasibility of the proposed system through experiments. They conclude that the proposed system can improve crop yield and reduce costs for farmers.	The authors do not address any potential security or privacy concerns related to the use of IoT and UAV-based systems in smart farming.
[58]	A. Di Nisio et al.	2020	Rapid detection of olive trees affected by <i>Xylella fastidiosa</i> using multispectral imaging from UAVs.	This study proposes a UAV-based smart farming system that uses machine learning and cloud computing. The authors demonstrate the effectiveness of the proposed system through experiments. They conclude that the proposed system can improve crop yield and reduce costs for farmers	The system's ability to handle varying weather conditions, crop types, and growth stages. Additionally, the authors do not discuss any potential environmental impacts of using UAVs for crop monitoring and the potential disruption to local wildlife.
[59]	A. Castrignanò et al.	2021	Development of a semi-automatic approach to detect <i>Xylella fastidiosa</i> in olive trees at an early stage. This method utilizes UAV multispectral imagery.	This study proposes a UAV-based crop monitoring system that uses IoT	The study may have only tested the UAV-based crop monitoring system in a limited range of environmental conditions, which may limit the generalizability of the findings.
[60]	Šiljeg et al.	2023	Utilizing Geospatial Object-Based Image Analysis (GEOBIA) and Vegetation Indices for extracting olive tree canopies from highly detailed UAV multispectral imagery.	This study proposes a UAV-based crop monitoring system that uses IoT	The study may have only tested the UAV-based crop monitoring system in a limited range of environmental conditions, which may limit the generalizability of the findings.



TABLE VI. CHARACTERISTICS OF THE RESEARCH: COMPARISON OF IOT ISSUES AND CHALLENGES IN UAV APPLICATIONS ON SMART FARMING (Y-YES, N-NON AND N/A-NON APPLICABLE)

Properties	[61]	[36]	[45]	[54]	[55]	[56]	[62]	[57]	[58]	[59]	[13]
Security	Y	N	N	N	N	N	Y	N	N	N	N
Control actuators Network lifetime	Y	Y	N	N	N	Y	N	N	N	N	N
Network latency Transmission reliability Quality of experience (QoE)	Y	Y	N	N	N	Y	N	N	N	N	N
Reduce risk of pesticides harming Animals or Human Semantic interoperability	Y	Y	N	N	N	Y	N	N	N	N	N
Detection of weather conditions Yes	Y	Y	N	N	N	Y	N	N	N	N	N
Preventive measures using IoT Semantic interoperability	Y	Y	N	N	N	Y	N	N	N	N	N
Architecture	Y	Y	N	N	N	Y	N	N	N	N	N
Reduce communication cost Quality of Service (QoS)	Y	Y	N/A	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sensing and actuators as a service (SaaS) Handle multi-keyword search.	N/A	N/A	N/A	N/A	Y	N/A	Y	N/A	N/A	N	N
Failure detection Prediction for IoT	N/A	N/A	N/A	N	Y	N	N	N	N/A	N/A	N/A
Increased computational time Faster detection rate for crop disease	Y	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Y	Y	N/A
Reduced the time of diagnosis of animal illness.	Y	Y	N/A	N	N	Y	N/A	N	N	N	N/A
Enhanced data transmission	N	N	N	N	N	N	N	N	N	N	N
Interactive voice response with farmers Determination of soil condition	N	N	N	N	N	N/A	N/A	N/A	N	N	N
Soil conductivity Protection of crop disease using IoT	N	N	N	N	N	N	N/A	N/A	N/A	N/A	N/A
Color-based segmentation for early detection and utilization of three-dimensional point cloud	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

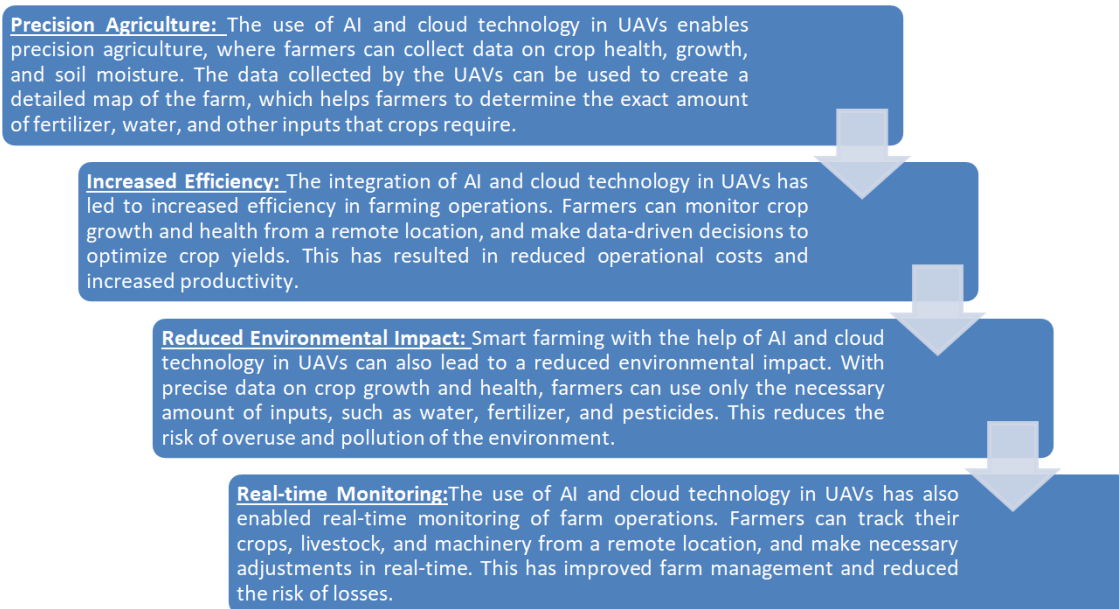


Fig. 9. Significant UAV applications in smart farming using AI and cloud.

infestations, and optimize harvest. While the use of UAV systems for crop monitoring has several advantages, there are also some limitations to the types of crops that can be effectively monitored. Here are some of the limitations collected by analyzing the following articles [64], [65], [66]. So, there are several limitations to using UAVs for crop monitoring. Firstly, UAVs can only cover a limited area in a single flight, which makes it difficult to monitor large farms efficiently. Secondly, UAVs are affected by weather conditions and may not be able to fly in adverse weather, which can impact data collection. Thirdly, UAVs require skilled operators

and specialized equipment, which can be costly and time-consuming to maintain. Then, regulations around the use of UAVs can be complex and vary between countries, which can add another layer of complexity to their use in crop monitoring. These limitations must be carefully considered when deciding whether to use UAVs for crop monitoring and when planning a UAV-based monitoring program.

In conclusion, while UAV systems can be an effective tool for crop monitoring, there are limitations to the types of crops that can be effectively monitored. Crop height, density, size, weather conditions, and sensor limitations are all factors that

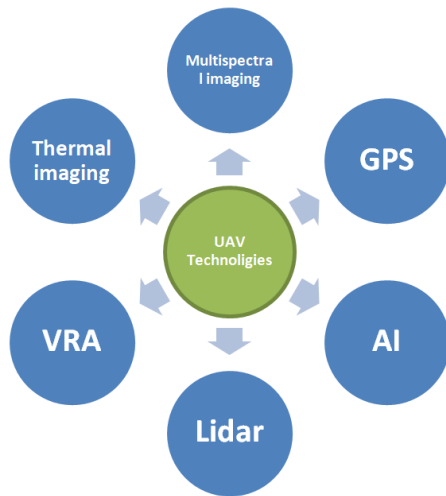


Fig. 10. UAV system technologies.

can affect the effectiveness of UAV monitoring. Generally, UAV systems can provide farmers with valuable insights and data to optimize crop management, increase productivity, and reduce the use of pesticides and fertilizers.

### RQ3. HOW CAN UAV-BASED TECHNOLOGIES BE ADAPTED FOR USE IN DIFFERENT TYPES OF CROPS OR FARMING ENVIRONMENTS?

Precision agriculture involves the use of various technologies to optimize crop management and increase yields. Unmanned Aerial Vehicle (UAV) systems are becoming increasingly popular in precision agriculture due to their ability to collect high-resolution data quickly and efficiently. Here are some UAV system technologies in Fig. 10 that are commonly adopted in precision agriculture:

- **Multispectral imaging:** UAVs equipped with multispectral cameras can capture images of crops at different wavelengths, providing valuable information on plant health, stress levels, and nutrient deficiencies.
- **Thermal imaging:** Thermal cameras mounted on UAVs can detect differences in temperature across a field, helping to identify areas of stress or water deficiency in crops.
- **Lidar (Light Detection and Ranging):** UAVs equipped with Lidar technology can create high-resolution 3D maps of crops and terrain, which can be used for crop modeling and yield prediction.
- **Global Positioning System (GPS):** UAVs equipped with GPS can precisely navigate and collect data on a field, helping farmers to monitor crop growth and identify problem areas.
- **Machine learning and artificial intelligence:** UAV systems can collect vast amounts of data that can be analyzed and processed using machine learning and artificial intelligence algorithms.
- **Variable rate application (VRA):** UAV systems can be used for VRA, where the data collected can be used to

tailor crop management practices to specific areas of a field, optimizing inputs like fertilizers and pesticides, reducing costs and environmental impact.

Overall, these UAV system technologies can provide farmers with detailed information on crop health, growth, and yield potential, helping them to make more informed decisions on crop management and increase productivity.

### RQ4. WHAT TYPES OF DATA CAN BE OBTAINED THROUGH THE USE OF UAVS?

Unmanned Aerial Vehicles are deployed in various applications, including agriculture, environmental monitoring, and infrastructure inspection. UAVs are equipped with sensors that can capture different types of data. Here are some examples of data that can be acquired by UAVs:

- **Visual imagery:** UAVs can capture high-resolution visual imagery using cameras that range from standard RGB cameras to more specialized cameras like multispectral, hyperspectral, and thermal cameras. These images can be used to monitor vegetation health, detect anomalies, and map land cover.
- **LiDAR:** LiDAR sensors can be mounted on UAVs to generate high-resolution 3D maps of the terrain, vegetation, and structures. This data can be used for precise measurements of features such as height, volume, and biomass.
- **GPS data:** UAVs can collect GPS data, which can be used to generate maps, track the drone's position, and measure distances.
- **Environmental data:** UAVs can be equipped with sensors that measure environmental variables such as temperature, humidity, and air quality. This data can be used for environmental monitoring and disaster response.
- **Magnetic and acoustic data:** UAVs can be equipped with magnetometers to measure the magnetic field of the Earth's surface. This data can be used for geological surveys and mineral exploration. UAVs can also be equipped with microphones to capture acoustic data.

Overall, UAVs can capture a wide range of data types, which can be used for various applications in fields such as agriculture, environmental monitoring, infrastructure inspection, and disaster response.

### RQ5. WHICH METHODS OF DATA PROCESSING CAN BE EMPLOYED TO ANALYZE THE AGRICULTURAL DATA COLLECTED BY UAVS?

The data acquired by UAVs in precision agriculture can be processed and analyzed using various techniques to extract useful information. Here are some examples of data processing methods that can be used to exploit agricultural data acquired by UAVs described in Fig. 11.

- **Image processing:** UAVs capture high-resolution images of crops, which can be processed using image processing techniques to extract information such as crop health, leaf area index, and crop growth stage.

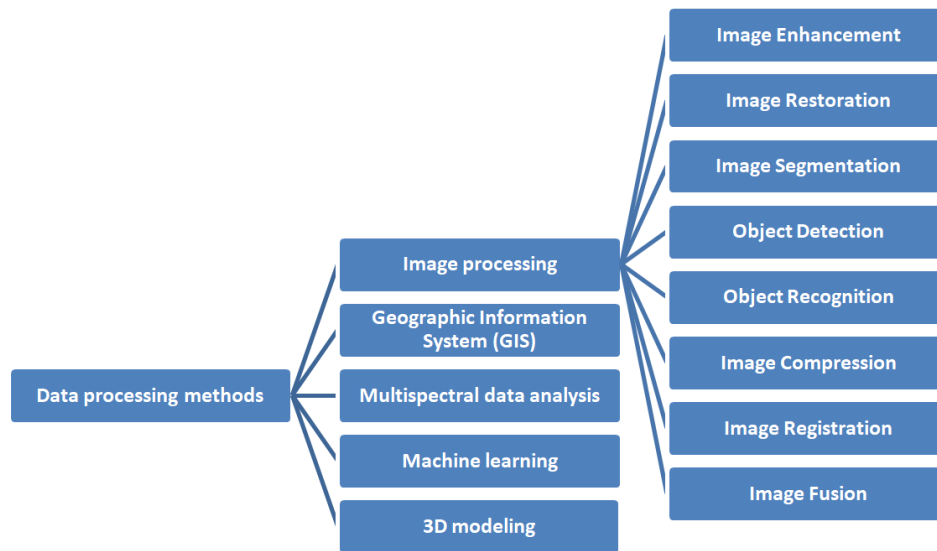


Fig. 11. Data processing methods used to exploit data collected by UAV.

- Geographic Information System (GIS): UAV data can be integrated with GIS to create maps that provide valuable information about crop health, yield, and soil properties.
- 3D modeling: UAVs can capture data in the form of point clouds using LIDAR sensors, which can be used to create 3D models of the field. These models can be used to estimate crop height, biomass, and plant spacing.

In summary, the data acquired by UAVs in precision agriculture can be processed and analyzed using various techniques to extract valuable information about crop health, yield, and soil properties. These techniques include image processing, GIS, multispectral data analysis, machine learning, and 3D modeling.

#### **RQ6. WHAT ARE THE CHALLENGES ASSOCIATED WITH USING DRONES FOR DISEASE DETECTION IN AGRICULTURE?**

The challenges can be categorized into two primary groups: dataset-related challenges and model-building challenges. Dataset-related challenges encompass deformations in the image dataset, insufficient availability of expert-labeled data, significant randomness in the data, and inadequate representation of classes in the dataset. Challenges associated with model building are the scarcity of training samples, extended training and processing times. Out of the papers analyzed, only two proposed potential solutions for these difficulties. The use of UAV in smart farming has become increasingly popular due to their ability to collect vast amounts of data quickly and accurately. However, the integration of Internet of Things (IoT) technologies into UAV applications also brings unique challenges and issues. The Table VI provides a comparison of the key challenges and issues related to IoT in UAV applications for smart farming.

#### **RQ7. WHAT ARE THE POTENTIAL ETHICAL AND LEGAL IMPLICATIONS ASSOCIATED WITH THE USE OF DRONES IN AGRICULTURE, AND HOW CAN THESE ISSUES BE ADDRESSED?**

The use of drones in agriculture presents various ethical and legal implications that need to be considered and addressed. From an ethical standpoint, privacy concerns arise as drones can capture sensitive information about individuals or their properties. There is also the potential for drones to infringe on airspace regulations, endangering other aircraft or public safety. Furthermore, the automation and autonomy of drones raise questions about accountability and liability in case of accidents or damage caused by these devices. To address these issues, several measures can be implemented. Firstly, clear regulations and guidelines should be established regarding the operation of drones in agricultural settings. These regulations should address aspects such as flight restrictions, licensing requirements, and privacy protection. Adequate enforcement mechanisms should be in place to ensure compliance.

Secondly, public awareness campaigns and education initiatives can inform both farmers and the general public about the responsible and legal use of drones in agriculture. This can help foster understanding and mitigate privacy concerns. Additionally, technological solutions can be developed to enhance privacy protection, such as implementing geofencing mechanisms that restrict drone access to certain areas or utilizing data anonymization techniques. Collaboration between stakeholders, including farmers, drone operators, regulatory bodies, and legal experts, is crucial for developing comprehensive guidelines and frameworks that address the ethical and legal implications of drone use in agriculture. Regular review and updates of regulations can also ensure they remain relevant as technology evolves. Ultimately, a balanced approach is needed that considers the benefits of drone technology in agriculture while safeguarding privacy, public safety, and legal compliance.

TABLE VII. SIGNIFICANT REVIEW STUDIES ON UAV BASED APPLICATIONS ON SMART FARMING COMPARED TO THIS SYSTEMATIC REVIEW

References	Objectives of the review	Method/Guidelines	Analysis Criteria	Results
[67]	Help potential researchers detect relevant IoT problems and, based on the application requirements, adopt suitable technologies.	SLR	Recent advancements and challenges of Internet of Things in smart farming	The upcoming studies, inventions, and initiatives mostly in field of IoT-based smart agriculture would improve the quality of living for farmers and result in significant improvements in the agricultural sector.
[68]	Pinpoints the challenges in implementing the solutions in the farmer's field in real-time.	SLR	Recent trends in computer vision such as generative adversarial networks (GAN), vision transformers (ViT) and other popular deep learning architectures.	Integration of the deep learning computer vision approaches with the UAV, and spectral data can help in building advanced-intelligent solutions.
[69]	Presents an analysis of drone technologies and their modifications with time in the agriculture sector in the last decade.	SLR	Artificial Intelligent (AI) and deep learning for the remote monitoring of crops has	There is a ramp in drone application for precision agriculture after 2017. This is due to the reduction of weight, cost of UAVs, and increment in payload capability
[26]	Suggest further research to improve the current food production globally	SLR	The application of smart farming to crop and animal production and post-harvesting	An effective Intelligent IoT system for smart farming can start the beginning of the journey toward by providing more information within the farming system for non-academics and researchers.
Proposed Systematic Review	Propose future research directions and highlight areas of improvement for the effective implementation of these technologies in agriculture.	SLR & PRISMA	Data collection and sensing technologies, AI and data analysis techniques, IoT and connectivity, Cloud computing and data management, Performance and effectiveness, Challenges and limitations	Exploration of the integration of unmanned aerial systems (UAS), AI, IoT, and cloud technologies specifically in the context of smart farming, providing an up-to-date and in-depth analysis of the benefits, challenges, and future research directions in this rapidly evolving field.

## V. DISCUSSIONS

The reason to conduct this systematic review on UAV-based applications in smart farming using AI, IoT, and cloud technologies is to provide a comprehensive overview of the current state-of-the-art in this field. This review aims to gather and analyze existing research studies, to identify gaps in the literature, and to provide insights into the potential of these technologies for smart farming.

The systematic review will contribute to the research field in several ways. Firstly, it will provide a clear understanding of the current state-of-the-art in UAV-based applications in smart farming, including the various applications, benefits, and challenges associated with the use of these technologies. Secondly, it will identify gaps in the literature and areas where further research is needed. This will help researchers to focus their efforts on areas that are most promising and where further advancements are needed. Thirdly, it will provide insights into the potential of these technologies to transform the agriculture industry, promote sustainable farming practices, and address global food security challenges.

UAV-based applications in smart farming using AI, IoT, and cloud technologies face several data challenges that must be addressed for successful implementation. These challenges include acquiring and efficiently storing the large amounts of data generated by UAVs, ensuring the quality and reliability of the data, processing and analyzing the data in real-time using AI and cloud technologies, seamlessly integrating the UAV-based applications with other systems, and ensuring data privacy and security. Overcoming these challenges will

require the development of robust data management strategies, advanced algorithms for data analysis, secure and interoperable systems, and effective policies and regulations for data privacy and security. Addressing these challenges will be crucial for the successful implementation of UAV-based applications in smart farming and the realization of their potential benefits for the agricultural industry. Meteorological conditions can have a significant impact on UAV-based applications in smart farming that use AI, IoT, and cloud technologies. For example, wind speed and direction can affect the stability and maneuverability of the UAV, which can impact the quality of the data collected. Similarly, rain, fog, and low-light conditions can affect the quality of the images and sensor readings collected by the UAV, which can impact the accuracy of the data analysis.

Extreme weather conditions such as hurricanes, thunderstorms, and blizzards can also pose safety risks for the UAV and the personnel operating it. High winds, lightning, and heavy precipitation can damage the UAV or cause it to crash, while snow and ice can affect its mobility and stability. To mitigate the impact of meteorological conditions on UAV-based applications in smart farming, it is important to have reliable weather forecasting systems in place. This can help farmers and operators plan UAV flights around weather patterns, avoiding unsafe conditions and optimizing data collection.

Additionally, it is important to use UAVs equipped with weather-resistant sensors and cameras that can operate in a range of environmental conditions. This can help ensure the accuracy and reliability of the data collected, even in adverse weather conditions. In summary, meteorological conditions can

have a significant impact on UAV-based applications in smart farming, and it is important to have reliable weather forecasting systems and weather-resistant equipment to mitigate these effects.

Overall, this systematic review will be a valuable resource for researchers, policymakers, and practitioners interested in UAV-based applications in smart farming using AI, IoT, and cloud technologies. It will help to identify areas where further research is needed, and provide insights into the potential of these technologies to address some of the most pressing challenges facing the agriculture industry today.

By validating and comparing the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) results with the presented objectives, scenarios, and analysis criteria in Table VII, this systematic review aims to enhance the existing survey methodology. It strives to provide an updated research review based on established guidelines, which can have several advantages. So, by employing a validated methodology and adhering to established guidelines like PRISMA, this work aims to provide a reliable, transparent, and up-to-date resource that can contribute to the existing body of knowledge in UAV-based applications in smart farming using AI, IoT, and cloud technologies. Despite the numerous benefits associated with the use of UAVs, AI, IoT, and cloud technologies in smart farming, there are still some limitations and challenges that need to be addressed in the future. One of the main limitations is the high cost of acquiring and maintaining these technologies, which may limit their adoption by smallholder farmers. Another limitation is the lack of regulatory frameworks and policies to guide their use, particularly in developing countries. Overall, this systematic review will be a valuable resource for researchers, policymakers, and practitioners interested in UAV-based applications in smart farming using AI, IoT, and cloud technologies. It will help to identify areas where further research is needed, and provide insights into the potential of these technologies to address some of the most pressing challenges facing the agriculture industry today. Despite the numerous benefits associated with the use of UAVs, AI, IoT, and cloud technologies in smart farming, there are still some limitations and challenges that need to be addressed in the future.

## VI. CONCLUSION

In conclusion, this paper provides a comprehensive overview of the utilization of unmanned aerial vehicles (UAS), or drones, in agriculture and the integration of AI, IoT, and cloud technologies for precision farming. The systematic review conducted following the PRISMA method highlights the potential of UAV-based applications in smart farming using these advanced technologies. The major takeaways from this work include the significant potential of UAVs in enhancing agricultural productivity and sustainability. The findings demonstrate that UAVs offer valuable capabilities for data collection, precision monitoring, and decision-making in large-scale farming operations. The integration of AI, IoT, and cloud technologies further enhances these capabilities by enabling real-time data analysis, remote accessibility, and efficient resource management. The justification for this research lies in the growing importance of technology-driven solutions in modern agriculture. By leveraging UAVs and advanced

technologies, farmers can make informed decisions, optimize resource usage, and improve crop yields. The presented work serves as a valuable resource for researchers, policymakers, and practitioners interested in understanding the potential and challenges of UAV-based applications in smart farming.

Moving forward, future research should focus on developing more advanced machine learning models to enhance accuracy in crop yield predictions and pest infestation identification. Additionally, exploring the feasibility of drones for other agricultural tasks such as irrigation management and soil analysis can provide valuable insights. Conducting empirical studies will further validate the benefits and limitations of these technologies in agriculture.

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# Advanced Night time Object Detection in Driver-Assistance Systems using Thermal Vision and YOLOv5

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**Abstract**—Driver-assistance systems have become an indispensable component of modern vehicles, serving as a crucial element in enhancing safety for both drivers and passengers. Among the fundamental aspects of these systems, object detection stands out, posing significant challenges in low-light scenarios, particularly during nighttime. In this research paper, we propose an innovative and advanced approach for detecting objects during nighttime in driver-assistance systems. Our proposed method leverages thermal vision and incorporates You Only Look Once version 5 (YOLOv5), which demonstrates promising results. The primary objective of this study is to comprehensively evaluate the performance of our model, which utilizes a combination of stochastic gradient descent (SGD) and Adam optimizer. Moreover, we explore the impact of different activation functions, including SiLU, ReLU, Tanh, LeakyReLU, and Hardswish, on the efficiency of nighttime object detection within a driver assistance system that utilizes thermal imaging. To assess the effectiveness of our model, we employ standard evaluation metrics including precision, recall, and mean average precision (mAP), commonly used in object detection systems.

**Index Terms**—Driver-assistance systems; object detection; nighttime object detection; thermal vision; YOLOv5

## I. INTRODUCTION

The rise of self-driving cars represents a significant milestone in the automotive industry, promising a paradigm shift in transportation as we know it. With the introduction of autonomous vehicles, there is a pressing need to address the alarming number of fatalities that occur in traffic accidents each year. Road traffic injuries pose a significant threat to the lives of children and young adults aged 5-29 years, making it the leading cause of death within this age group. It is worth noting that a staggering 93% of these fatalities occur in low- and middle-income countries [1]. These tragic incidents have prompted researchers and engineers to explore innovative solutions to improve road safety using machine learning (ML) and deep learning (DL) algorithms [2], [3], [4], [5]. The safety of autonomous vehicles relies on the ability to detect and classify objects correctly. Object detection algorithms need to be robust enough to differentiate between pedestrians, bicycles, cars, and other relevant entities on the road. This distinction is crucial for autonomous vehicles to assess potential risks and determine appropriate responses, such as slowing down, changing lanes, or stopping altogether. Detecting objects on the road is a crucial task for autonomous vehicles to ensure the safety of both passengers and other road users. However,

the challenge becomes even more pronounced when it comes to detecting objects at night or in low light conditions. Reduced visibility conditions make it difficult for sensors, such as cameras to capture clear and detailed information about the surrounding environment. Traditional object detection systems heavily rely on visual cues, which can be compromised in low light conditions. This poses a considerable challenge for autonomous vehicles navigating roads at night or in poorly lit environments. To address these challenges [6], [7], [8], researchers have turned to Convolutional Neural Networks (CNNs), a powerful deep learning technique that has revolutionized various fields, including computer vision. CNNs have shown great promise for object detection, providing a robust framework for training models that can learn and extract meaningful features from image data. By incorporating CNN modeling in Driver-Assistance Systems, autonomous vehicles can navigate complex environments more effectively, reducing the risk of accidents and ultimately saving lives.

The objective of this article is to provide an innovative strategy for nighttime object detection in driver-assistance systems using thermal vision and incorporating the YOLOv5 model. The primary objective is to comprehensively evaluate the model's performance by investigating the influence of different activation functions and optimizers. The findings demonstrate the efficiency of the proposed method in enhancing nighttime object detection. The results contribute to the understanding of the role of optimizers and activation functions in training the YOLOv5 model for object detection tasks. The insights gained from this research can guide future endeavors aimed at improving the efficiency and accuracy of driver-assistance systems, ultimately enhancing safety for both drivers and passengers.

The structure of this paper is outlined in the following manner: Section II provides an extensive review of the relevant literature. In Section III, we elaborate on the methodology utilized for Advanced Nighttime Object Detection, covering aspects such as Dataset and Data Preparation, Data annotations/labeling, Activation Functions, and Model Evaluation Metrics. The experimental system and results, accompanied by a comprehensive discussion, are presented in Section IV. Finally, Section V provides concluding remarks to wrap up the paper.

## II. RELATED WORKS

Ramesh Simhambhatla et al. (2019) [9] undertook a practical examination of three up-to-date meta-architectures, namely SSD, R-CNN, and R-FCN. The aim was to gauge their efficiency and precision in recognizing road objects, including vehicles, pedestrians, and traffic lights, across varying driving scenarios: daytime, nighttime, rainy, and snowy conditions. This research paper was carried out by Ruturaj Kulkarni et al. (2018) [10] introduces a robust deep neural network model that employs transfer learning for the accurate detection and recognition of traffic lights. To facilitate object detection in self-driving cars using deep learning, P Prajwal et al. (2021) [11] have selected the SSD model in conjunction with the MobileNet neural network as the foundational architecture due to its ability to produce results rapidly while maintaining a moderate level of accuracy. VD Nguyen et al. (2018) [12] presents a comprehensive framework that combines deep learning techniques, multiple local patterns, and depth information to identify, classify, and monitor vehicles and walkers on the road. Utilizing a deep CNN, H Yu et al. (2013) [13] employ a sophisticated architecture that effectively detects obstacles in complex scenes by leveraging rich and powerful learned features. P Salavati et al. (2018) [14] presents a novel approach that utilizes Deep Neural Networks (DNN) to detect obstacles using a single camera, employing unsupervised DNNs for extracting global image features and extracting local image features. P Aswathy et al. (2018) [15] explores the influence of deep convolutional layer features within an object tracking framework, showcasing the novel utilization of GoogLeNet CNN architecture's deep layer features for effective object tracking. The primary emphasis of this paper [16] is on the application of a CNN algorithm for computer vision-based object detection. The paper [17] presents a novel real-time approach for object detection in images captured by self-driving vehicles, using a unified neural network that models object detection as a regression problem on predicted bounding boxes and class probabilities, enabling simultaneous prediction of bounding boxes and class probabilities for the entire image. AA Cervera-Urbe et al. (2022) [18] introduces U19-Net, a deep encoder-decoder model designed for the detection of vehicles and pedestrians. This paper [19] introduces a novel and efficient deep learning-based detecting technique called DW-YOLO, which addresses the challenge of detecting objects in images with limited visual cues. G Rjoub et al. (2021) [20] presents a novel object detection system for autonomous vehicles, utilizing the You Only Look Once (YOLO) convolutional neural network (CNN) approach and a Federated Learning (FL) framework to enhance real-time detection accuracy, particularly in challenging weather conditions. This paper [21] demonstrates the utilization of the YOLOv5 model for real-time identification of cars, traffic lights, and pedestrians under different weather conditions, showcasing its effectiveness in typical vehicular environments. The purpose of the paper [22] is to develop a DL model, trained on the YOLOv5s and YOLOv7 architectures, to correctly classify and identify

traffic signs in diverse adverse environments. VD Nguyen et al. (2023) [23] introduces an effective feature-based approach that utilizes a sigmoid function based on a triangle pattern to encode and establish strong features of neighboring pixels in local regions, which is then integrated into advanced object detection methods to evaluate its performance.

The purpose of this article is to present an innovative and advanced approach for nighttime object detection in driver-assistance systems. The study focuses on leveraging thermal vision and incorporating YOLOv5 as the proposed method. The primary objective is to comprehensively evaluate the performance of the model, which combines SGD and Adam optimizer. Additionally, the research investigates the impact of different activation functions, such as SiLU, ReLU, Tanh, LeakyReLU, and Hardswish, on the efficiency of nighttime object detection using thermal imaging within a driver assistance system. Standard evaluation metrics, including precision, recall, and mean average precision (mAP), are employed to assess the effectiveness of the model.

## III. METHODOLOGY

### A. Dataset and Data Preparation

The FLIR Thermal Images Dataset consists of a collection of 10,228 thermal images, each hand-labeled with precise bounding boxes. The images have a resolution of 640x512 pixels. Within the dataset, there are a total of 10,228 images, and these images contain a comprehensive set of 79,297 annotated bounding boxes. The dataset focuses on three main categories, namely Person, Bicycle, and Car. In the training set, which includes 8,862 images, there are 67,618 hand-labeled bounding boxes. Specifically, the Person category has 22,372 annotated bounding boxes, the Bicycle category has 3,986 annotated bounding boxes, and the Car category has 41,260 annotated bounding boxes. In the validation set, which consists of 1,366 images, there are 11,679 hand-labeled bounding boxes. The Person category has 5,778 annotated bounding boxes, the Bicycle category has 470 annotated bounding boxes, and the Car category has 5,431 annotated bounding boxes. Details of the distribution of the data set can be seen in Fig. 1 to Fig. 4.

### B. Data Annotations/Labeling

Annotation of your training images To ensure the effective training of our object detector, it is imperative to provide supervision during the training process by employing bounding box annotations. The procedure entails outlining a box around each specific object that we intend the detector to detect, and subsequently assigning a corresponding object class label to each box, indicating the desired prediction for the detector. This crucial step allows us to train the object detector accurately. Additional details can be incorporated to provide a comprehensive understanding of the topic. The YOLO labeling format Fig. 6. utilizes a unique approach where a .txt file is generated for every image file in the directory, sharing the same name. These .txt files serve as containers for annotations

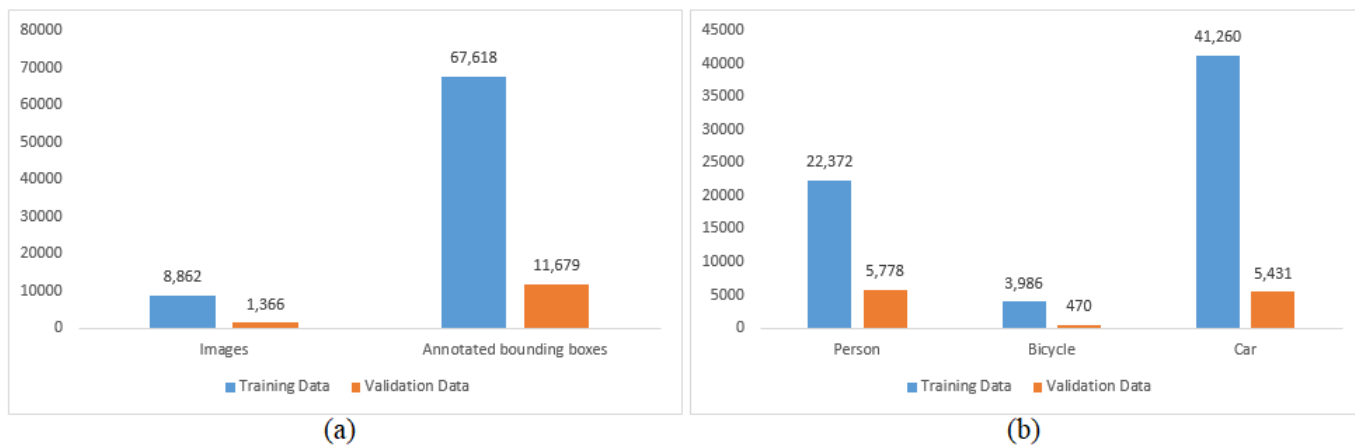


Fig. 1. (a) Total number of images and annotated bounding boxes (b) The annotations are distributed across the three main categories.



Fig. 2. Example of thermal image (left) and bounding boxes manually labeled with class person (right).

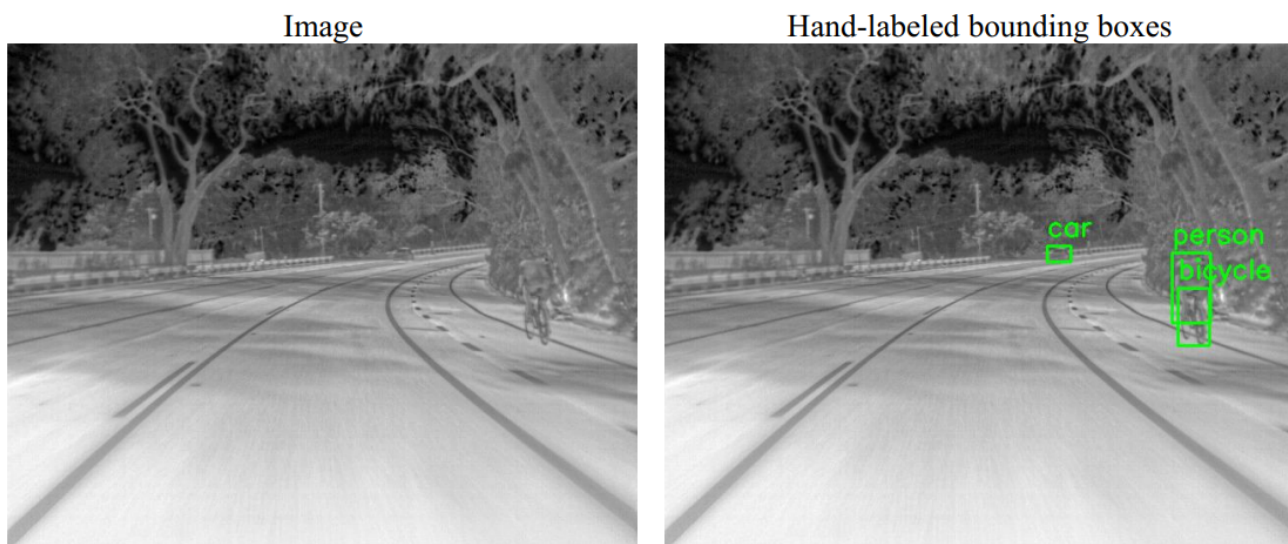


Fig. 3. Example of thermal image (left) and bounding boxes manually labeled with class Person, bicycle and car (right).

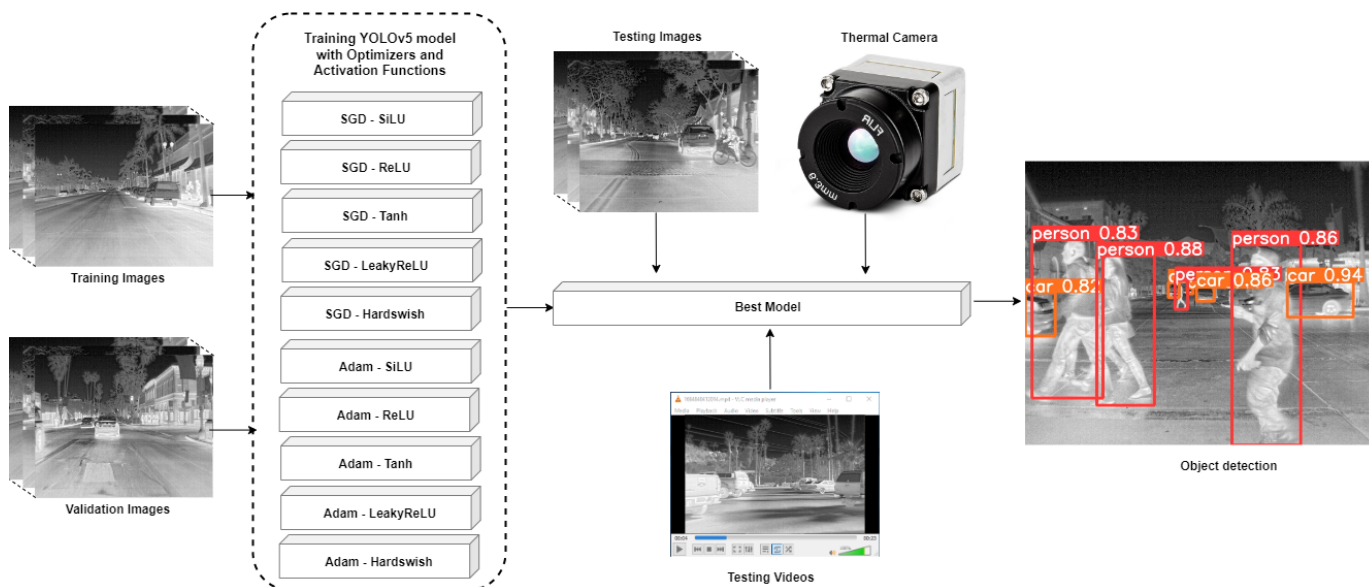
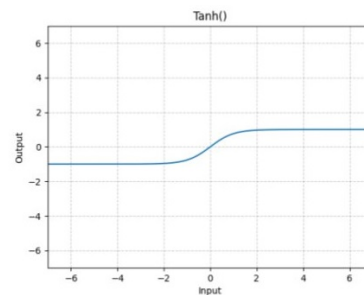
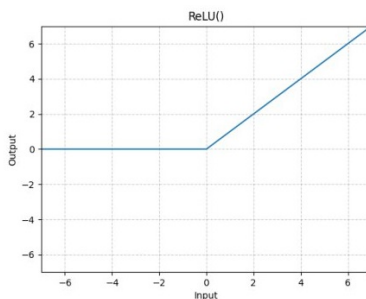
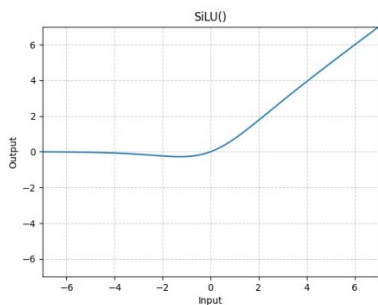


Fig. 4. Flowchart for the overall experiment conducted to train the YOLOv5 model with optimizers and activation functions.

SiLU( $x$ ) \*  $\sigma(x)$   
where  $\sigma(x)$  is the logistic sigmoid.

$$\text{ReLU}(x) = (x)^+ = \max(0, x)$$

$$\text{Tanh}(x) = \frac{\exp(x) - \exp(-x)}{\exp(x) + \exp(-x)}$$



$$\text{LeakyReLU}(x) = \begin{cases} x, & \text{if } x \geq 0 \\ \text{negative\_slope} * x, & \text{otherwise} \end{cases}$$

$$\text{Hardswish}(x) = \begin{cases} 0 & \text{if } x \leq -3 \\ x & \text{if } x \geq +3 \\ x * (x + 3)/6 & \text{otherwise} \end{cases}$$

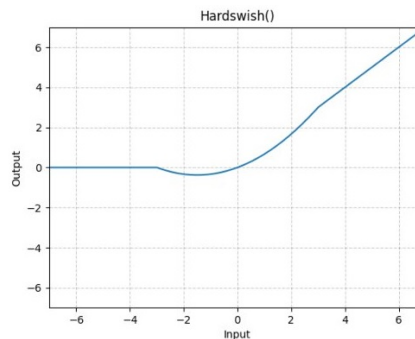
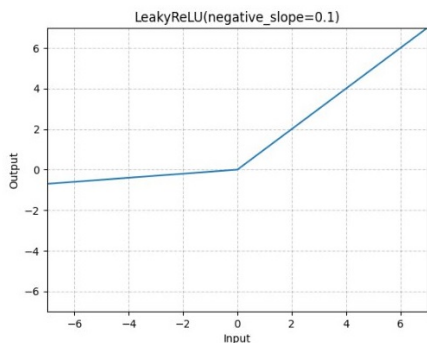


Fig. 5. Non-linear activations.





Fig. 6. (a) An example of a bounding box and (b) YOLO annotation format.

		Actual Values	
Predicted Values	True Positive TP	True Positive TP	False Positive FP
	False Negative FN	False Negative FN	True Negative TN

Fig. 7. Precision and recall.

related to the corresponding image file, encompassing object class, object coordinates, height, and width information.

### C. Activation Functions

To conduct a comprehensive assessment of the accuracy of the transfer learning network models mentioned earlier, we employ five widely recognized and extensively used activation functions: SiLU (Sigmoid Linear Unit), ReLU (Rectified Linear Unit), Tanh (Hyperbolic Tangent), LeakyReLU (Leaky Rectified Linear Unit), and Hardswish [24]. These activation functions play a crucial role in deep learning methodologies. Each function's corresponding mathematical representation is presented Fig. 5, providing a complete understanding of their functional behavior. The selection of an appropriate activation function depends on a variety of factors, such as the specific requirements of the task at hand and the desired performance outcomes. Each activation function possesses unique characteristics that can influence the learning capabilities and overall performance of the transfer learning network models. By comparing the results obtained from employing these activation functions, we will be able to draw meaningful insights and make informed decisions regarding their suitability for the given task. The findings of this comparative analysis will be shared in detail in the subsequent section, offering a comprehensive evaluation of their effectiveness.

### D. Model Evaluation Metrics

This study examined the efficiency of DL models using a range of metrics, including Precision, Recall and mAP in Fig. 7 and in equations (1), (2), and (3). Precision measured the ratio of accurate positive outcomes to all positive predictions, while recall measured the proportion of correctly predicted to all instances of positive outcomes in the dataset. mAP measures the similarity between the ground-truth bounding box and the detected box, resulting in a numerical score. This score serves as an indicator of the model's accuracy in detecting objects. A higher score signifies greater accuracy in the model's detections. By employing multiple evaluation metrics, we gained a comprehensive understanding of the model's performance and made well-informed judgments regarding its effectiveness.

$$Precision = \frac{TP}{TP + FP} \quad (1)$$

$$Recall = \frac{TP}{TP + FN} \quad (2)$$

$$mAP = \frac{1}{n} \sum_{k=1}^n AP_k \quad (3)$$

In which, TP: True Positive, TN: True Negative, FP: False Positive, FN: False Negative, n: the number of classes,  $AP_k$ : the average precision of class k.

## IV. RESULTS

This section describes the training and validation results obtained for the YOLOv5 model using the SGD and Adam optimizers, along with various activation functions. The experiments were conducted using a learning rate of 0.01 and a momentum value of 0.937. Fig. 8 and Fig. 9 present the results of training the YOLOv5 model using two different optimizers, namely SGD and Adam, along with various activation functions. The performance of the model was evaluated using three key metrics: Precision, Recall, and mAP@0.5 (mean Average Precision at an IoU threshold of 0.5). Precision measures the accuracy of the model in correctly identifying positive instances, while Recall indicates the model's ability to find all positive instances. The mAP@0.5 calculates the average precision across different IoU thresholds.

For the SGD optimizer, the activation functions evaluated were SiLU, ReLU, Tanh, LeakyReLU, and Hardswish. Among these, the SiLU activation function achieved the highest Precision of 0.85247, Recall of 0.73373, and mAP@0.5 of 0.79985. However, other activation functions such as ReLU, LeakyReLU, and Hardswish also demonstrated competitive performance, with Precision ranging from 0.82512 to 0.83494 and mAP@0.5 ranging from 0.79074 to 0.79363. Similarly, for the Adam optimizer, the model was trained with the same set of activation functions. The SiLU activation function yielded the highest Precision of 0.80156, Recall of 0.70725, and mAP@0.5 of 0.77294. The performance of the other activation functions, including ReLU, LeakyReLU, and



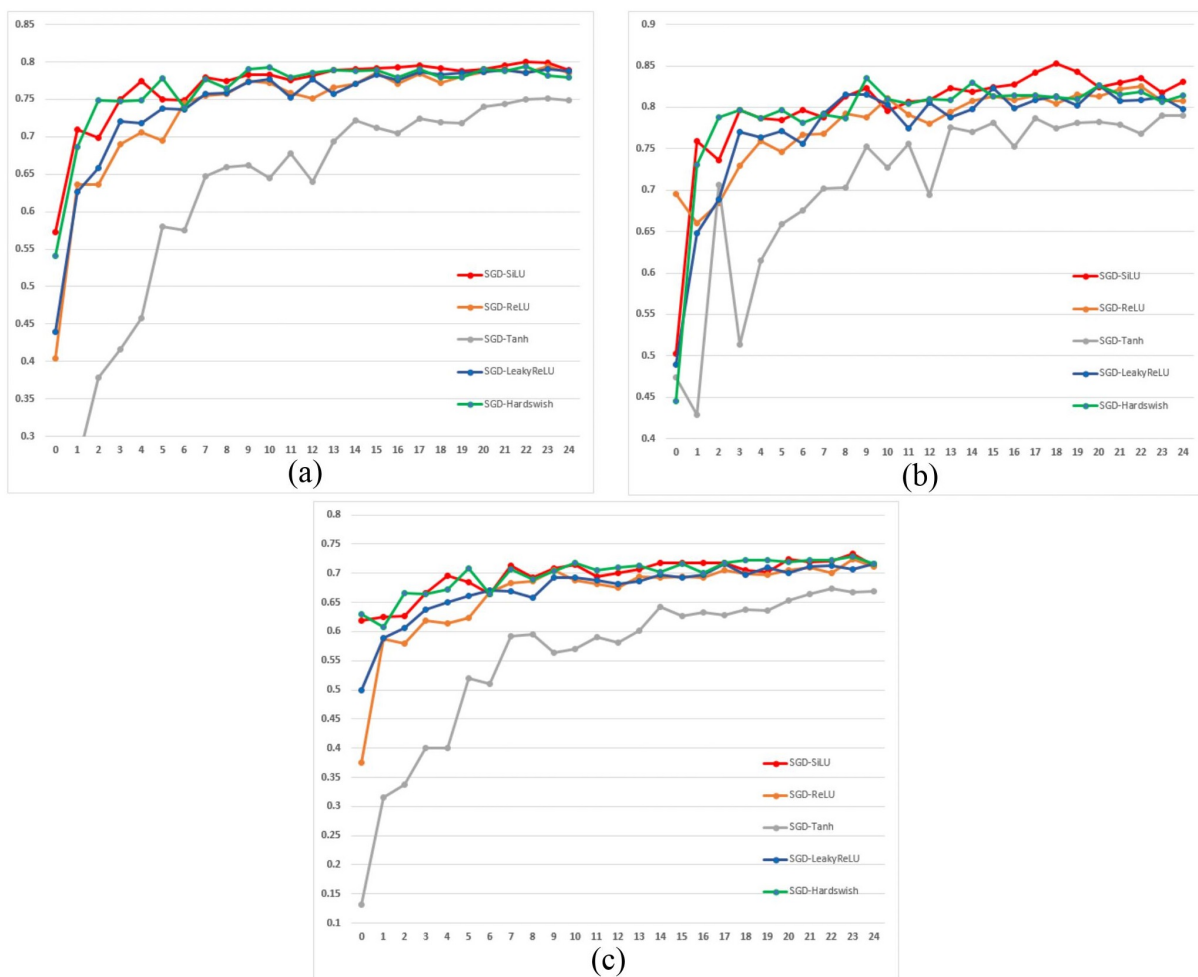


Fig. 8. Training results of YOLOv5 with SGD optimizer and various activation functions (a) The mAP@0.5 scores (b) Training precision, and (c) Training recall.

Hardswish, ranged from Precision values of 0.78057 to 0.7942 and mAP@0.5 values of 0.75974 to 0.77761.

Validation results of YOLOv5 with SGD and Adam optimizer and various activation functions are presented in Table 1. This table shows the evaluation metrics for precision, recall, and mAP@0.5. Each row corresponds to a specific combination of optimizer and activation functions. For the SGD optimizer, the SiLU activation function achieved the highest precision of 0.835, followed by Hardswish with a precision of 0.826. The highest recall was obtained with ReLU at 0.724, closely followed by SiLU at 0.722. The highest mAP@0.5 was achieved with SiLU at 0.800. For the Adam optimizer, the SiLU activation function again obtained the highest precision of 0.801, while ReLU achieved a precision of 0.782. The highest recall was obtained with ReLU at 0.703, closely followed by SiLU at 0.693. The highest mAP@0.5 was achieved with Hardswish at 0.777. Precision-Recall Curve of yolov5 model with SGD optimizer and SiLU activation function is presented in Fig. 10. These results demonstrate the performance of the YOLOv5 model with different combinations of optimizers and

activation functions (see Fig. 11). These outcomes indicate the impact of different optimizers and activation functions on the YOLOv5 model's performance. The SiLU activation function consistently exhibited strong performance across both optimizers, while ReLU, LeakyReLU, and Hardswish also showed competitive results. These findings can guide researchers and practitioners in selecting the most effective configuration for training the YOLOv5 model in object detection tasks.

## V. CONCLUSION

In conclusion, this research paper presented an innovative approach for object detection during nighttime in driver-assistance systems, utilizing thermal vision and incorporating the YOLOv5 model. The primary objective was to comprehensively evaluate the performance of the model by exploring the impact of different activation functions and optimizers. The outcomes demonstrated the efficiency of the proposed method in enhancing nighttime object detection. The experiments involved training the YOLOv5 model using two optimizers, SGD and Adam, along with various activation functions, namely SiLU, ReLU, Tanh, LeakyReLU, and Hardswish.

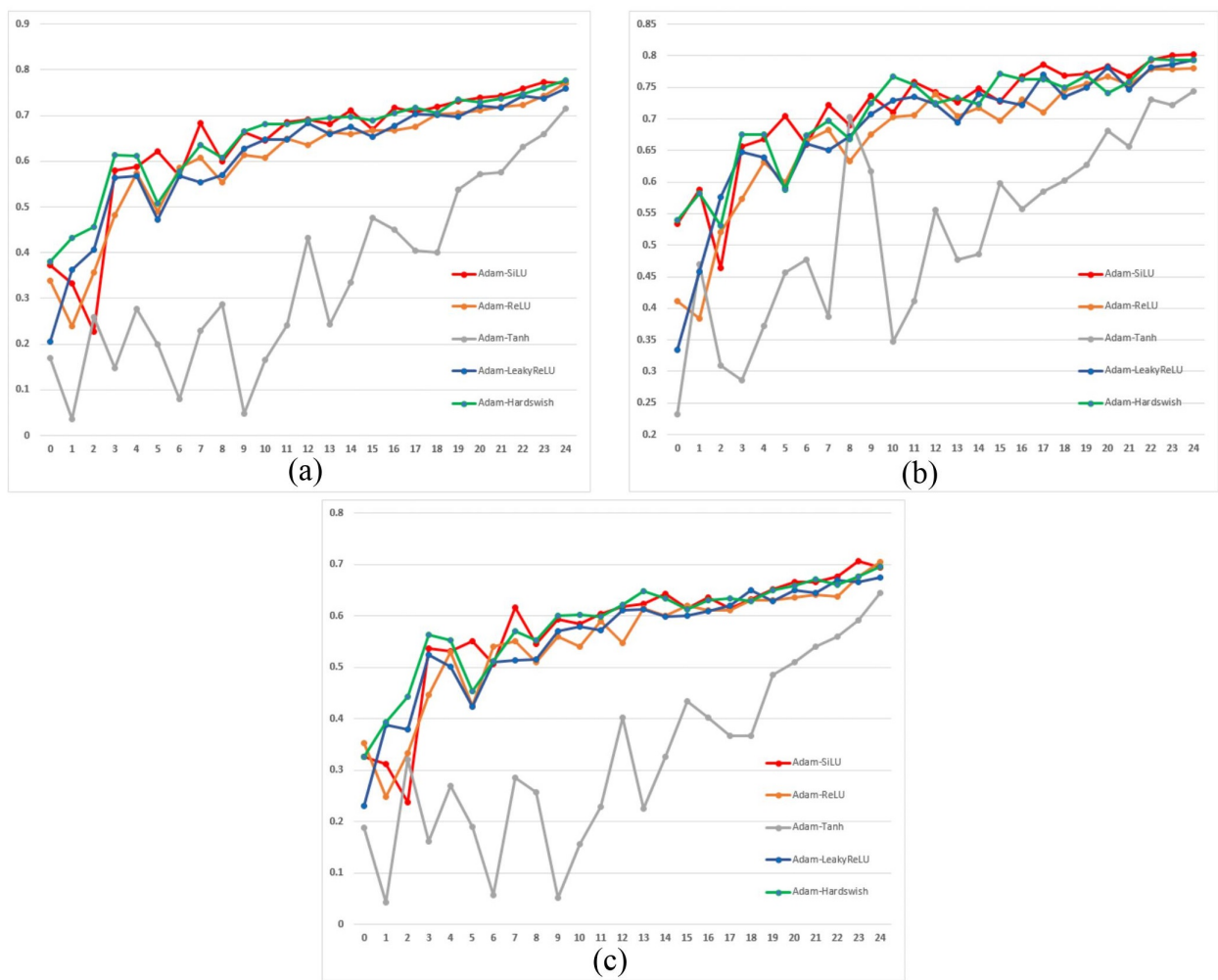


Fig. 9. Training results of YOLOv5 with adam optimizer and various activation functions (a) The mAP@0.5 scores (b) Training precision, and (c) Training recall.

TABLE I. VALIDATION RESULTS OF YOLOV5 WITH SGD AND ADAM OPTIMIZER AND VARIOUS ACTIVATION FUNCTIONS USE LEARNING RATE = 0.01 AND MOMENTUM = 0.937

Optimizer	Activation Function	Precision	Recall	mAP@0.5
SGD	SiLU	0.835	0.722	0.800
SGD	ReLU	0.807	0.724	0.793
SGD	Tanh	0.787	0.667	0.751
SGD	LeakyReLU	0.813	0.706	0.790
SGD	Hardswish	0.826	0.719	0.790
Adam	SiLU	0.801	0.693	0.771
Adam	ReLU	0.782	0.703	0.771
Adam	Tanh	0.745	0.642	0.715
Adam	LeakyReLU	0.794	0.675	0.759
Adam	Hardswish	0.793	0.696	0.777

The evaluation metrics used, including Precision, Recall, and mAP@0.5, provided insights into the accuracy, coverage, and overall performance of the model. For the SGD optimizer, the SiLU activation function achieved the highest Precision and mAP@0.5 values, indicating its effectiveness in accurately identifying positive instances. However, ReLU, LeakyReLU,

and Hardswish also demonstrated competitive performance in terms of Precision and mAP@0.5. Similarly, with the Adam optimizer, the SiLU activation function consistently yielded the highest Precision, while ReLU, LeakyReLU, and Hardswish also performed well. These results highlight the impact of different activation functions on the model's performance. Overall, the findings suggest that the YOLOv5 model, coupled with the SiLU activation function, is a promising configuration for nighttime object detection in driver-assistance systems. However, researchers and practitioners can also consider other activation functions such as ReLU, LeakyReLU, and Hardswish, which showed competitive performance in this study. These results contribute to the understanding of the role of optimizers and activation functions in training the YOLOv5 model for object detection tasks. The insights gained from this research can guide future endeavors in improving the efficiency and accuracy of driver-assistance systems, ultimately enhancing safety for both drivers and passengers.

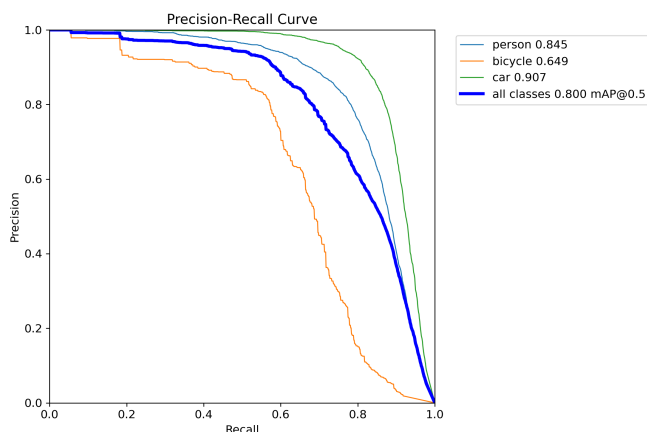


Fig. 10. Precision-Recall curve of yolov5 model with SGD optimizer and SiLU activation function.

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Fig. 11. Prediction results of the YOLOv5 model trained with SGD optimizer and SiLU activation function.



# Hate Speech Detection in Bahasa Indonesia: Challenges and Opportunities

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**Abstract**—This study aims to provide an overview of the current research on detecting abusive language in Indonesian social media. The study examines existing datasets, methods, and challenges and opportunities in this field. The research found that most existing datasets for detecting abusive language were collected from social media platforms such as Twitter, Facebook, and Instagram, with Twitter being the most commonly used source. The study also found that hate speech is the most researched type of abusive language. Various models, including traditional machine learning and deep learning approaches, have been implemented for this task, with deep learning models showing more competitive results. However, the use of transformer-based models is less popular in Indonesian hate speech studies. The study also emphasizes the importance of exploring more diverse phenomena, such as islamophobia and political hate speech. Additionally, the study suggests crowdsourcing as a potential solution for the annotation approach for labeling datasets. Furthermore, it encourages researchers to consider code-mixing issues in abusive language datasets in Indonesia, as it could improve the overall model performance for detecting abusive language in Indonesian data. The study also suggests that the lack of effective regulations and the anonymity afforded to users on most social networking sites, as well as the increasing number of Twitter users in Indonesia, have contributed to the rising prevalence of hate speech in Indonesian social media. The study also notes the importance of considering code-mixed language, out-of-vocabulary words, grammatical errors, and limited context when working with social media data.

**Keywords**—Abusive language; hate speech detection; machine learning; social media

## I. INTRODUCTION

In this digital era, social media has become an important aspect of everyday life. Not only is it a source of information, but it is also a medium of entertainment, allowing people to share content and express their feelings about anything at any time. However, social media can also be a double-edged sword. On one hand, it can provide a medium for constructive and positive communication among its users. On the other hand, the freedom of expression afforded to social media users can also create serious problems, such as the increasing prevalence of hate speech on social media. This phenomenon is often attributed to the lack of effective regulations and the anonymity afforded to users on most social networking sites [1]. These characteristics make social media the perfect medium for individual abusive users or even hate groups to spread and reinforce their views. In fact, social media platforms even

offer opportunities for violent actors to propagate their acts, potentially reaching a wider audience when their posts go viral [2]. Twitter is a popular social networking platform that provides convenient access to its users for online social interactions. The number of Twitter users has been steadily increasing, from around 100 million users in 2017 to almost 240 million in 2022. Previous studies have shown that hate speech is also a prominent challenge in the Twittersphere. Pamungkas et al. [3] conducted a study on hate speech towards women in Twitter in multiple languages, including Italian, Spanish, and English. Lingiardi et al. [4] has also explored other forms of hate speech targeted at specific groups on Twitter.

Automatically detecting hate speech from social media text is a challenging task. Several studies have been proposed to address hate speech in social media, mainly focusing on implementing machine learning models to automatically predict whether an utterance is hate speech or not. However, working with social media data is a very challenging task. Social media data often contains valuable knowledge for information extraction tasks, but it is usually very noisy and full of informal language [5]. According to the study of Baldwin et al. [5], there are several properties of social media data, including: i) the presence of code-mixed language; ii) the presence of out-of-vocabulary words; and iii) grammatical errors. Social media data also usually has very limited context, which is an important issue for abusive language detection tasks because it is difficult to classify a text as abusive or not without context. Other important clues for abusive detection tasks, such as facial expressions, gestures, and voice tones (which are recognized in face-to-face communication), are also absent in social media data. However, social media content has some signals that can be exploited to partially resolve the context of such texts, including emojis, emoticons, hashtags, URLs, and mentions. Some studies have also found that there are several issues that contribute to the difficulty of detecting hate speech in social media automatically, including the use of swear words [6], multidomain issues [7], [8], and multilingual issues [8], [7].

Similarly, hate speech phenomena also occur in Indonesian social media. According to Statista<sup>1</sup>, the number of Twitter users in Indonesia has reached almost 240 million, ranking fifth among all countries in the world. Hate speech in Indonesia has been regulated by the government since 2008, as stated in the Law of Information and Electronic Transaction (UU ITE). The Kepolisian Republik Indonesia (Indonesian Police

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<sup>1</sup><https://www.statista.com/statistics/242606/number-of-active-twitter-users-in-selected-countries/>

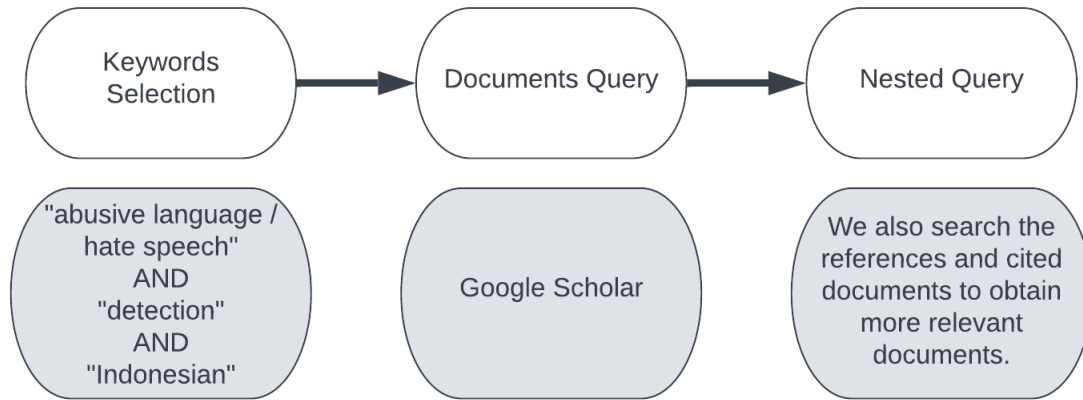


Fig. 1. Documents collection methodology.

Department) has also issued further regulations, as hate speech has the potential to have dangerous effects, not only for the victims of hate speech but also for society as a whole. Interestingly, most instances of hate speech on Indonesian social media are triggered by political events, such as elections. Several studies have also been conducted to study the hate speech phenomena in Indonesian social media [9], [10]. Most studies have focused on the automatic detection of hate speech utterances from social media data. The study by Alfina et al. [11] was one of the early studies of hate speech detection in Indonesian social media, specifically on the Twitter platform. This work proposed a novel dataset gathered from Twitter and manually annotated with two labels: hate speech and not. Another study by Ibrohim and Budi [12] proposed a more fine-grained hate speech dataset, which not only contains a binary class (hate speech vs. not), but also is annotated based on several categories, including the hate speech target, category, and level of hatefulness. More recent studies on hate speech detection in Indonesia have focused on adopting more recent technologies, such as neural-based and transform-based models [13], [14].

In this paper, we summarize the studies on hate speech detection, specifically on Indonesian social media. In this paper, we provide an overview of research conducted in this area, giving a comprehensive view of the state-of-the-art and datasets centered on this area. Our main objective is to draw a conclusion on the state-of-the-art and to provide several possible opportunities for future work based on existing open problems. After the introduction, we discuss the existing studies on hate speech detection in Indonesian social media, focusing on the approaches adopted and the available language resources in Section II. An analysis of challenges and opportunities for this particular task in future work is discussed in Section III. Finally, Section IV presents conclusive remarks for this survey.

## II. LITERATURE REVIEW

Similar to other languages, hate speech is becoming a relevant issue in Indonesian social media. Despite being regulated

by the national constitution, Indonesian social media users still use abusive language to communicate and even attack other users, often because they can hide their identities using anonymous accounts. Several studies have been conducted to address hate speech in Indonesian. Some have proposed novel corpora containing manually annotated data gathered from social media platforms such as Twitter, Instagram, and YouTube. Others have focused on developing machine learning models to automatically classify given utterances as either abusive or not. A few studies have done both, proposing a novel hate speech dataset and building a machine learning model based on that dataset. In this section, we review hate speech studies in Indonesian social media, focusing on two main aspects: (i) what datasets are available for abusive language detection in Indonesia and (ii) what has been done so far in Indonesian abusive language detection studies. We collected relevant documents using Google Scholar by searching for the keywords 'hate speech detection in Indonesian' and 'abusive language detection in Indonesian's, limited to the first five pages of results for each keyword and sorted by relevance, without a time filter. We also checked the cited documents and references on the first five pages of each search to find more relevant publications. Fig. 1 summarizes our approach to collecting relevant documents for our study.

### A. What Datasets are Available for Abusive Language Detection in Indonesia?

In this subsection, we collect information about the available datasets for abusive language studies in Indonesia. Table I summarizes the information about the available datasets for hate speech detection studies specifically in Indonesian. We gathered this information from previous studies on hate speech detection in Indonesian, using the approaches outlined in Fig. 1. We found that the two most frequently used datasets in previous work are those from Alfina et. al. [11] and Ibrohim et. al. [15]. However, these datasets are still less commonly used compared to hate speech datasets in languages with more resources, such as English, Italian, and Spanish. This may be due to the lack of a hate speech detection shared task in Indonesia, which usually attracts more researchers



TABLE I. SUMMARIZATION OF AVAILABLE ABUSIVE LANGUAGE DATASET IN INDONESIAN

Topical Focus	Sources	Annotation	Entries	Available	Ref
Hate Speech	Twitter	Expert Manual	1,100	Yes	[11]
Hate Speech	Twitter	Expert Manual	13,169	Yes	[12]
Abusiveness	Twitter	Expert Manual	2,016	Yes	[15]
Abusiveness	News Comments	Expert Manual	3,184	Yes	[16]
Hate Speech	News Comments	Expert Manual	3,614	No	[16]
Hate Speech	Twitter	Expert Manual	4,002	No	[17]
Hate Speech	Instagram	Expert Manual	1,067	No	[18]
Hate Speech	Instagram	Expert Manual	13,194	No	[19]
Hate Speech	Instagram	Expert Manual	572	Yes	[20]
Hate Speech	Instagram	Expert Manual	1,012	No	[21]
Hate Speech and Cyberbullying	Twitter	Automatic	83,752	No	[22]
Hate Speech	Facebook	Expert Manual	1,276	No	[23]
Hate Speech	Twitter	Expert Manual	35,623	Yes	[24]
Hate Speech	Twitter	Expert Manual	1,477	Yes	[25]
Hate Speech	Multiple Sources	Social Media Expert Manual	2,273	No	[26]
Hate Speech	Multiple Sources	Social Media Expert Manual	1,400	No	[27]
Abusive Language and Hate Speech	Twitter	Expert Manual	5,656	Yes	[28]
Hate Speech	Twitter	Expert Manual	20,601	No	[29]

to use available datasets for developing the best systems. In this section, we will discuss the available datasets based on their topical focus, sources, annotation approach, number of instances, and availability.

- **Topical Focuses** : As mentioned in a previous study by Pamungkas et al. [8], the topical focus of a dataset can be described as the specific abusive phenomena addressed, as well as the targets of the abusive behavior. We also agree that a hate speech dataset may cover more than one abusive phenomena. Compared to the results obtained by Pamungkas et al. [8], most abusive language datasets in Indonesia only focus on two topical focuses: abusiveness and hate speech, which are the most general terms used in abusive language studies. Only one study by Febriana et al. [22] includes the term “cyberbullying” to describe their dealt abusive phenomena. Based on these results, we argue that there are still many specific abusive phenomena that need to be addressed in Indonesian abusive language studies, such as sexism, xenophobia, offensiveness, and Islamophobia.
- **Sources** : The source of a dataset refers to the media platforms from which the data was gathered. The different characteristics of each platform can also be variables that influence the treatment and difficulty of the hate speech detection task. According to our results presented in Table I, most abusive language datasets in Indonesian were gathered from Twitter. This may be due to the convenience of scraping tweet samples using the Twitter API, and because Twitter has less strict rules regarding data sharing for research purposes compared to other platforms. This result is consistent with a survey conducted by Pamungkas et al. [8]. Additionally, we also observed that some research used Instagram posts and comments on news posts to study abusive phenomena.
- **Annotation Approach and Scheme** : Based on our manual inspection of previous studies, we found that almost all of the proposed datasets were annotated by

experts. This result differs from other studies of abusive language in other languages, where crowdsourcing is also a popular method for annotating datasets. We also observed that most proposed abusive language datasets in Indonesia use binary labels, including an “abusive” class and a “not abusive” class. However, we also found studies that propose a finer-grained annotation schema, such as the one implemented by [12], [28], [24]

- **Availability**: As presented in Table I, more than half of the datasets used for abusive language detection studies were not publicly available<sup>2</sup>. We can observe that most of the publicly available datasets were gathered from Twitter. Meanwhile, datasets sourced from other social media platforms such as Facebook and Instagram are mostly not shared publicly. This finding is also consistent with the survey results obtained by [8], where the availability of the datasets can be influenced by the regulation of the social media platforms related to data sharing policies.

### B. What has been Done so Far in Indonesian Abusive Language Detection Study?

In this subsection, we review the approaches adopted by previous studies to detect abusive language in Indonesian social media. We used a similar approach as presented in Fig. 1 to collect the available studies. We collected any publications found on Google Scholar using the defined keywords, “abusive language detection Indonesia” and “hate speech detection Indonesia”. We limited our query to the first five pages for each keyword and sorted results based on relevance, without a time filter. Furthermore, we also checked each document’s cited documents and references on the first five pages to find more relevant publications. Table II summarizes the available works in abusive language detection, specifically in Indonesian social media. We carefully reviewed each document to obtain the key information of each work. In this part, we focus on

<sup>2</sup>the link of cannot be found in the article.

TABLE II. SUMMARIZATION OF APPROACHES ADOPTED FOR HATE SPEECH DETECTION IN INDONESIAN

Model	Approach	Ref
Traditional Models	Using classical machine learning models such as SVM, Naive Bayes, Decision Tree, Random Forest, Logistic Regression, K-nearest Neighbours, Maximum Entropy and etc. coupled with several features including lexical and other structural features.	[11], [30], [17], [23], [12], [28], [27], [21], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40]
Unsupervised Approach	Using data mining technique such as clustering, classification, and association, without training process to detect hate speech instance. This approach is very beneficial when the training data is limited.	[41], [42], [43]
Neural-based Models	Using neural-based models either RNN-based model variants such as LSTM, GRU, and etc or CNN-based models coupled with language representation either using available pretrained models or self-training based on the available training data.	[26], [19], [13], [44], [45], [46], [47], [48], [49], [50], [51], [52]
Transformer-based Models	Using the recent transformer based architecture such as BERT, RoBERTa, XLM, and etc. Based on the previous studies in NLP area, these models usually provide the robust performance across different NLP tasks.	[53], [31], [14]

reviewing the adopted approach of each work to deal with the abusive language detection task. In particular, we focus on two main discussions: variants of the models and implemented approaches. Following, we provide a deeper elaboration to compare the previous work in Indonesian abusive language studies, to gain insights for further development.

- **Model Variant:** A wide variety of classification models have been adopted for the abusive language detection task in Indonesian. Table II summarizes the published studies in this topic. Based on the results, we divided the proposed models into four different variants: traditional models, unsupervised models, neural-based models, and transformer-based models. We can observe that most previous works employed traditional models to deal with abusive language detection in Indonesia. Additionally, we also found a few studies that adopt an unsupervised approach, which do not require labeled data to detect abusive language. This is an interesting finding, as unsupervised models are not popularly used for detecting abusive language in more resource-rich languages, as observed by Pamungkas et al. [8]. Similar to traditional-based models, neural-based models are also popular for detecting abusive language. This is in line with the availability of Indonesian language models that have been proposed by several recent works. Lastly, we notice that the use of transformer-based models is still not yet explored in Indonesian abusive language studies. Unlike Indonesian language models, studies focused on developing transformer models for the Indonesian language are also limited. Most of the abusive language studies in Indonesia that exploit transformer-based models are utilizing multilingual transformers.
- **Classification Models:** A wide variety of classification models were used in this task. Starting with traditional classifiers, several models such as SVM, Naive Bayes, Decision Tree, Random Forest, Logistic Regression, KNN, and Maximum Entropy have been used for this classification task. These models were the most popular approach for detecting abusive language, specifically in Indonesian data. This may be due to the limited availability of resources in Indonesian, such as language models or labeled datasets. For the unsupervised approach, a few studies have proposed using lexicon-based and straightforward string match-

ing approaches to detect abusive instances. Despite lexicon-based approaches being unpopular in common text classification tasks, this approach is still reliable when annotated data is limited. In line with the trend in other natural language processing tasks, the use of neural-based models is also gaining more attention from NLP researchers in Indonesia. Some models such as LSTM, GRU, and CNN have been widely used to detect abusive language in Indonesian, either using pre-trained language representations or without pre-training models. Lastly, the recent transformer-based technology is also starting to be used in the Indonesian research community. This may be due to the availability of multilingual transformer models such as BERT Multilingual, Multilingual GPT, and XLM RoBERTa. Some of these models were also used by a few studies [14], [53] for detecting abusive language in Indonesian.

### III. CHALLENGES AND OPPORTUNITIES

The literature review and analysis presented in previous sections provide insights into the current state of the art of abusive language studies in Indonesian. Based on these analyses, we have observed several challenges in this task, which are summarized as follows:

- **Limited Availability of Language Resources:** The adopted approach for dealing with the task of abusive language detection in Indonesian is currently limited and lags behind studies in other, more resource-rich languages. Traditional models are the most popular approach for addressing this problem in Indonesia, while in other languages, more recent transformer-based models are commonly used to achieve state-of-the-art results. We believe that this discrepancy is likely related to the limited availability of language resources, including language corpora and language models. We also note that several recent studies have proposed transformer-based models, such as IndoBERT [54] and IndoBERTtweet [55], but they are still limited in comparison to the transformer technologies available for other languages.
- **Limited Exploration of Abusive Phenomena:** Based on the abusive phenomena covered in the available datasets for abusive language detection studies, we

perceive that the explored abusive phenomena in Indonesian is still very limited. Studies in Indonesian have mostly focused on the detection of hate and abusive speech. Meanwhile, similar studies in other languages have been conducted with a broader coverage of abusive phenomena, which can include sexism, racism, misogyny, Islamophobia, and more. Some of these studies have also proposed finer-grained labels to capture more specific abusive phenomena, which is usually beneficial for differentiating the treatment for handling each phenomenon.

- **Low Awareness of Reproducibility Aspect:** Based on our review, we also notice that most of the published research in Indonesian abusive language studies do not make their code and datasets publicly available. This issue makes it difficult for other researchers to reproduce the results of previous works, which is important for better analysis of their own studies. Furthermore, reproducibility is an important aspect for maintaining continuity in research, specifically in the area of abusive language research.
- **Limited Approach for Annotation Procedure:** We observe that most studies used manual expert annotation procedures to label abusive language datasets. This approach is proven to be reliable for obtaining a high-quality dataset when the subjectivity of the annotation task is high. However, this approach is usually not feasible for annotating a large number of data, as the annotation task becomes more labor-intensive and time-consuming. Sometimes, alternative annotation approaches such as crowdsourcing scenarios can provide a wider perspective, with a diverse demographic of annotators who have different backgrounds and views to evaluate the abusive instances.
- **The Problem of Code-Mixed Languages:** Geographically, Indonesia consists of several regions, each with its own local languages. According to recent reports, there are 718 local languages used by different regions and tribes in Indonesia. Indonesians tend to use a mix of their own local language and Bahasa Indonesia to communicate on social media platforms, such as Twitter. Related to this issue, we conducted a random check on some publicly available datasets. We found a lot of code-mixed instances on the checked datasets [28], [24], which are mostly written in a mixture of Indonesian and Javanese. As in other languages and other NLP tasks, the issue of code-mixing is still a prominent challenge that needs to be tackled.

Based on these challenges, we also point out several opportunities for future studies in this research direction, which are summarized below.

- **Building Novel Language Resources in Indonesian:** Our NLP research community should also focus on studying and developing language resources in Indonesian. These resources could include novel corpora for diverse tasks or recent language model technologies. The availability of more language resources could provide more opportunities for researchers in

abusive language studies to explore more approaches to better detect abusive language in Indonesian.

- **Expanding the Study Exploration into Other Abusive Phenomena:** As mentioned in the challenges section, abusive language studies in Indonesian are still focused on a few phenomena, including hate speech and abusiveness. Based on our investigation, there are several abusive phenomena specific to Indonesia that could potentially become a focus for exploration, including islamophobia and political hate speech. There are also other more general phenomena which have been studied in other languages, such as sexism, racism, xenophobia, homophobia, and more. A broader exploration into other abusive phenomena could open more opportunities for research collaboration between NLP researchers and researchers from other communities such as the study of humanity, psychology, gender studies, and social science.
- **Exploring Other Annotation Approach to Build Abusive Language Datasets:** Most of the available abusive language datasets in Indonesian were built using expert annotation approaches. For example, crowdsourcing could be a worth-considering option to be implemented for annotating abusive language datasets. Because crowdsourcing approach has the advantage of bringing in a diverse set of annotators with different background identities, which can help to reduce bias in the dataset, which is also an important issue in this study. In addition, crowdsourcing can be particularly useful when the dataset is large and complex, and would be too time-consuming for a single person to finish.
- **Tackling the Problem of Code-Mixed Data:** Code-mixing is becoming a prominent challenge in various NLP tasks in recent years. This problem may be due to the current technology and platforms which have a multilingual environment. Similarly, Indonesians also tend to use a mix of their local languages and Bahasa Indonesia to communicate with others both in real life and on social media channels. Dealing with language-shift in code-mixed data is a challenging task. Specifically in abusive language studies, several transfer learning approaches could be applied in this task.

#### IV. CONCLUSION

This survey presents a summary of research on detecting abusive language in Indonesian social media. It covers existing datasets that could be used for this research, including datasets from multiple platforms, types of abusive behavior, and languages. The survey also examines the methods that have been proposed for detecting abusive language in Indonesian social media. Finally, it discusses the challenges and opportunities in this area of research and provides suggestions for future development.

This study found that most of the existing datasets for detecting abusive language were collected from social media platforms like Twitter, Facebook, and Instagram, with Twitter being the most commonly used source. This may be because

it is easy to obtain samples from Twitter using its public API and because of the less strict policy from Twitter for sharing data. The study also observed that hate speech is the most researched type of abusive language, compared to other types such as abusiveness and cyberbullying.

A wide variety of models have been implemented to deal with the task of abusive language detection in Indonesia. However, most studies have exploited traditional models such as logistic regression, SVM, naive bayes, and random forest to deal with this task. Several feature representations were used to train the models, which include TF-IDF, Bag of Words, and word vectors obtained from pre-trained language representations. Overall, recent deep learning architectures have obtained more competitive results compared to other models. Furthermore, we also observed that the use of transformer-based models is less popular in Indonesian hate speech studies.

Finally, we have identified some recent challenges and opportunities for abusive language detection studies in Indonesian. We observe that the availability of more language resources in Indonesian is one of the factors that contribute to the acceleration of research development, specifically in this area. We also identify that abusive language studies should explore more diverse phenomena beyond hate speech and abusiveness topics, such as islamophobia, political hate speech, and other more general phenomena which are already widely studied in other languages such as sexism and racism. Another suggestion is related to the annotation approach for labeling abusive datasets, which mostly exploit manual expert annotation procedures. We suggest exploring crowdsourcing scenarios which could produce less bias and more comprehensive datasets. Finally, we also encourage researchers who focus in this research area to consider the code-mixing issue in current abusive language datasets in Indonesia. We believe that dealing with code-mixing issue could improve the overall model performance for detecting abusive language in Indonesian data.

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# MC-ABAC: An ABAC-based Model for Collaboration in Multi-Cloud Environment

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**Abstract**—Collaborative systems allow a group of organizations to collaborate and complete shared tasks through distributed platforms. Organizations who collaborate often leverage cloud-based solutions to outsource their data and to benefit from the cloud capabilities. During such collaborations, tenants require access to and utilize resources held by other collaborating tenants, which are hosted across multiple cloud providers. Ensuring access control in a cloud-based collaborative application is a crucial problem that needs to be addressed, particularly in a multi-cloud environment. This paper presents the Multi-Cloud ABAC: MC-ABAC model, an extension of the ABAC: Attribute Based Access Control model, suitable for ensuring secure collaboration and cross-tenant access in a multi-cloud environment. The MC-ABAC introduces the notions of tenant, cloud customer and cloud service provider as fundamental entities within the model. Additionally, it incorporates multiple trust relations to enable collaboration and resource sharing among tenants in the multi-cloud environment. To demonstrate its feasibility, we have implemented the MC-ABAC model using Python technology.

**Keywords**—ABAC model; multi-tenant; multi-cloud; collaboration; trust

## I. INTRODUCTION

Nowadays, applications and IT systems are increasingly geared towards collaboration, facilitating cooperation between organizations to attain shared objectives. These collaborative efforts optimize the utilization of distributed resources among the participating entities, leading to enhanced productivity and overall benefits. Over the years, extensive research has been conducted on the design and implementation of collaborative work environments [1], aiming to fulfill the demands of collaborative activities. In this context, collaborative applications offer innovative technologies that allow a group of users to communicate, work together, and complete shared tasks using distributed platforms.

Many organizations rely on cloud-based services provided by cloud service providers to externalize their IT infrastructure, including computing, networking, and data storage [2], [21]. This enables remote access to hardware and software over the Internet. To maintain the privacy and confidentiality of these services, the cloud service provider employs a multi-tenancy approach, segregating data and customer services into distinct tenants. Each tenant is assigned to an individual or organization utilizing the cloud service.

In multi-cloud environment, collaborating tenants may be hosted in the same cloud provider or in different cloud providers. These tenants often require access to information

shared by other tenants during collaborative process. This information often contains sensitive data. Balancing collaboration and security can be challenging because collaboration aims to provide access to services and resources for those who require them, while security focuses on preserving the availability, confidentiality, and integrity of these assets and limiting access to authorized individuals only. This raises the issue of access control [25]. In order to facilitate access and collaboration across multiple tenants, a robust and fine-grained access control model is mandatory.

Traditional access control models [3], [4], [5], [6], [7] DAC, MAC, RBAC, TBAC, TMAC and others are primarily designed for defining access policies within a single organization or for specific local access control scenarios. However, they may not be adequately suitable for defining access policies in multi-tenant environments. To address the challenges of collaboration and multi-tenant access, various access control models [23], [12], [13], [14] (CTTM, MTAS, MT-RBAC, MT-ABAC, etc ) have been proposed. Nevertheless, these approaches are designed for multi-tenant environment within a single cloud. They may not effectively address the access control challenges that arise in multi-cloud environments.

In this paper, we propose MC-ABAC: Multi-cloud ABAC model, as an extended version of the ABAC [8] (Attribute Based Access Control) model. MC-ABAC leverages the capabilities of ABAC [18], [24], such as flexibility and adaptability. MC-ABAC is especially designed for securing collaboration and cross-tenant access in a multi-cloud environment. It presents the concepts of tenant, cloud customer and cloud service provider as key entities in the model. Furthermore, this model introduces many trust relations in order to support resource sharing between tenants in a multi-cloud environment. Finally, we implemented this model using Python technology to demonstrate its feasibility. To the best of our knowledge, this is the first work, that aims to extend the ABAC model to enable collaboration in a multi-cloud environment.

Our main contribution in this paper is to define a multi-cloud ABAC model, with cross-tenant trust in a multi-cloud environment. This model is suitable for supporting sharing resources between multi-cloud tenants belonging to different cloud providers. Our model takes into account the heterogeneity requirement, since cloud providers may use different and heterogeneous access control models. This is possible through the flexibility of the ABAC model, which can represent access policies defined by any model [3]. Furthermore, this model is better suited to control access to any cloud service, whether it



be IaaS, PaaS, or SaaS.

This paper is organized as follows: Section 2 presents the background of this work, focusing on a telemedicine use case and the explanation of the ABAC model. The related work is presented in Section 3. Section 4 presents the suggested MC-ABAC model. In Section 5, we introduce the trust relations. Section 6 describes the implementation architecture. Finally, we conclude in Section 7.

## II. BACKGROUND

The purpose of this section is to provide the necessary background information for this work. It primarily focuses on presenting a use case of telemedicine within a cloud-based collaborative environment. Additionally, it introduces the attribute-based access control model.

### A. Case Study

In this study, we examine the telemedicine use case, which involves Rabat's School Hospital *SH1* and Oujda's School Hospital *SH2* as two collaborating organizations that share certain resources and services to achieve a common goal. *SH1* and *SH2* utilize cloud-based services provided by Azure and Amazon, to outsource their IT infrastructure and software, including computing, networking, and data storage.

Within this particular use case, in Table I, we consider that Azure cloud offers three services, namely *s1*, *s2*, and *s3*, while Amazon cloud provides three services, namely *s4*, *s5*, and *s6*. Each customer cloud creates its own tenants using the services offered by Azure and Amazon clouds. For instance, the customer *SH1* creates tenants (*t1*, *t2*, *t3*, *t4*, *t5*) using the services (*s1*, *s2*, *s3*, *s4*, *s5*) provided by Azure and Amazon, respectively. Similarly, the customer *SH2* creates its own tenants (*t6*, *t7*, *t8*, *t9*, *t10*) from the available services (*s4*, *s5*, *s6*, *s1*, *s2*), respectively. During collaboration, users

TABLE I. MULTI-CLOUD USE CASE

Cloud customers	Cloud providers	Tenants	services
<i>SH1</i>	Azure	( <i>t1</i> , <i>t2</i> , <i>t3</i> )	( <i>s1</i> , <i>s2</i> , <i>s3</i> )
<i>SH1</i>	Amazon	( <i>t4</i> , <i>t5</i> )	( <i>s4</i> , <i>s5</i> )
<i>SH2</i>	Amazon	( <i>t6</i> , <i>t7</i> , <i>t8</i> )	( <i>s4</i> , <i>s5</i> , <i>s6</i> )
<i>SH2</i>	Azure	( <i>t9</i> , <i>t10</i> )	( <i>s1</i> , <i>s2</i> )

from one tenant require access to resources owned by other tenants. Therefore, our scenario gives rise to a set of requirements for cross-tenant access in a multi-cloud environment, which can be categorized into four cases or situations:

- **Case 1:** Collaborating tenants hosted in the same cloud provider and owned by the same cloud customer. For instance, in the Azure cloud, a user from tenant *t1* requires access to resources owned by tenant *t2*.
- **Case 2:** Collaborating tenants hosted in the same cloud provider and owned by different cloud customers. For example, in the Azure cloud, a user from tenant *t3* (owned by *SH1*) requires access to resources owned by tenant *t9* (owned by *SH2*).
- **Case 3:** Collaborating tenants hosted in different cloud providers and owned by the same cloud customer. For example, a user from tenant *t2* (hosted in Azure cloud)

needs access to resources owned by tenant *t5* (hosted in Amazon cloud).

- **Case 4:** Collaborating tenants hosted in different cloud providers and owned by different cloud customers. For example, a user from tenant *t1* (owned by *SH1* and hosted in Azure cloud) needs access to resources owned by tenant *t8* (owned by *SH2* and hosted in Amazon cloud).

Our main objective in this approach is to enable secure multi-tenant collaborations in a multi-cloud environment. For this purpose, there is a need for a comprehensive fine-grained access control model that caters to the specific requirements of the scenario.

### B. Attribute Based Access Control Model

The following section introduces the ABAC model, which has been tailored to suit the development of MC-ABAC and is not intended to be a comprehensive ABAC model. ABAC has been defined in several ways in the literature, typically for specific use cases. ABAC is an adaptive and a flexible fine-grained access control model.

**Definition 1:** The core components of ABAC model [8], [22] are:

- *U* and *O* represent finite sets of existing users and objects, respectively.
- $A = \{create, read, update, delete\}$  is a finite set of actions.
- *UATT* and *OATT* represent finite sets of user and object attribute functions, respectively.
- For each  $att \in \{UATT \cup OATT\}$ ,  $range(att)$  represents the attribute's range, which is a finite set of atomic values.
- $attType : UATT \cup OATT \rightarrow \{set, atomic\}$ , specifies attributes as set or atomic values.
- Each attribute function maps elements in *U* to an atomic value or a set
  - $\forall ua \subseteq UATT. ua : U \rightarrow Range(ua) \text{ if } attType(ua) = atomic$
  - $\forall ua \subseteq UATT. ua : U \rightarrow 2^{Range(ua)} \text{ if } attType(ua) = set$
- Each attribute function maps elements in *O* to an atomic value or a set
  - $\forall oa \subseteq OATT. oa : O \rightarrow Range(oa) \text{ if } attType(oa) = atomic$
  - $\forall oa \subseteq OATT. oa : O \rightarrow 2^{Range(oa)} \text{ if } attType(oa) = set$
- An authorization that decides on whether a user *u* can access an object *o* in a particular environment *e* for the action *a*, is a boolean function of *u*, *o*, and *e* attributes: Rule:  $authorization_a(u, o) \rightarrow f(ATTR(u), ATTR(o))$ .

### III. RELATED WORK

Several works have been in the literature to ensure access control in multiple environments. In the Task based access control [5] (TBAC), the permissions are granted according to the progress of several tasks. The TRBAC [7] model is constructed by adding the "Task" concept to the RBAC model. In TRBAC, the user has a relationship with permission through role and task. On the other hand, in the Team Access Control Model (TMAC) [6], the permissions are granted to each user through its role and the current activities of the team. These models enable fine-grained access control but they do not incorporate contextual parameters into security considerations and do not support collaboration in multi-domain environment [9], [10]. Moreover, the notion of "Team" used in TMAC model is static. Therefore, this model does not support dynamic collaboration.

Several access control approaches have been proposed to secure resources in cloud environments [11], [12], [13], [15], [16], [23]. Calero et al. [11] introduces a multi-tenancy authorization system based on hierarchical role-based access control with a coarse-grained trust relation and path-based object hierarchies. The work assumes that each issuer may utilize multiple cloud services and collaborate with other issuers.

Another model, Multi-Tenant Role-Based Access Control (MT-RBAC), is proposed by Tang et al. in [13]. This model provides fine-grained access control in collaborative cloud environments by incorporating trust relations among tenants. However, this model does not consider trust relations among issuers separately from tenants. In the MT-RBAC model, the truster exposes certain trusters roles to the trustee, who then assigns their users to these roles. This enables users to access the trusters' resources by activating the trusters' roles. The CTRBAC model [16] extends the traditional RBAC model by introducing new entities to support cross-tenant access and the concept of tasks. However, it should be noted that in this model, a tenant may utilize roles owned by other tenants, which can potentially compromise confidentiality requirements. Additionally, these models are based on the RBAC model, which may lack the necessary flexibility to define complex policy rules.

Several recent approaches have been proposed in [20], [26], [27], focusing on the concept of activity control. This concept expands the scope of traditional access control models by addressing how multiple administrative authorities can effectively collaborate to create, share, manage, and protect digital content and resources. However, these solutions are not suitable for facilitating cross-tenant access in a multi-cloud environment.

The Attribute-Based Access Control (ABAC) model has gained significant attention due to its relevance in addressing the limitations of classical access control models such as RBAC. ABAC, offers a solution that is adaptive and flexible, providing an effective means to describe intricate access control semantics, particularly in collaborative environments. The ABAC model has been extended in several works [14], [17], [28], [29], [30] to support collaboration and resource sharing.

One notable example is the Multi-Tenant Attribute-Based Access Control (MT-ABAC) model [14], which introduces

a framework for facilitating collaboration between tenants in a single cloud environment. The MT-ABAC model takes a decentralized approach, allowing each tenant to manage their own access control policies and attributes. However, the MT-ABAC model is primarily designed for multi-tenant environments within a single cloud. These extended models of ABAC may not adequately address access control challenges that arise in multi-cloud environments where users and shared resources span across different tenants in multiple clouds. In such scenario, the complexity increases as different clouds may have their own access control mechanisms and policies.

Authors propose in [19] the authorization federation approach in order to ensure collaboration among organizations whose resources are distributed across multiple cloud service providers. This study primarily focuses on facilitating collaboration among multiple homogeneous clouds, limiting its applicability to heterogeneous multi-cloud environments. Additionally, the emphasis of this approach is on collaboration and resource sharing at the Infrastructure as a Service (IaaS) level, by using openstack cloud [21], overlooking resource sharing at the Platform as a Service (PaaS) and Software as a Service (SaaS) levels.

Therefore, in this paper, we propose the MC-ABAC model, which aims to ensure secure multi-tenant collaborations in a multi-cloud environment. This approach introduces the concepts of tenant, cloud customer, and cloud service provider as key entities in the model. To the best of our knowledge, our work is the first approach that aims to extend the ABAC model to support collaboration in a multi-cloud environment.

### IV. MULTI-CLOUD ATTRIBUTE BASED ACCESS CONTROL MODEL

In this section, we introduce the MC-ABAC (Multi-Cloud Attributes Based Access Control) model, which extends the ABAC model to support cross-cloud collaboration among multiple clouds. The MC-ABAC model incorporates new entities to facilitate access control of shared resources across multiple clouds. These entities, namely tenant, cloud service provider, and cloud customer, are added to the original ABAC model. Fig. 1 illustrates the structure of the MC-ABAC model. The following sections provide a detailed description of these new entities:

**Tenant:** is a virtual partition of a cloud service provided by the cloud provider to the customer. The cloud service provider segregates the data and services into multiple tenants. A cloud service provider is defined in this approach as the 5-uplet,  $(t, U, O, ATT)$ :

- $t$ : The tenant ID;
- $U$ : Set of users belonging to this tenant  $t$ ;
- $O$ : Set of objects held by this tenant  $t$ . An object in cloud could be resource, machine, or service;
- $ATT$ : Set of user, object and environment attributes defined by this tenant  $t$ . An object in cloud could be resource, machine, or service;

**A cloud service provider (cp)** is an organization that offers computing resources, such as storage, platform, application,

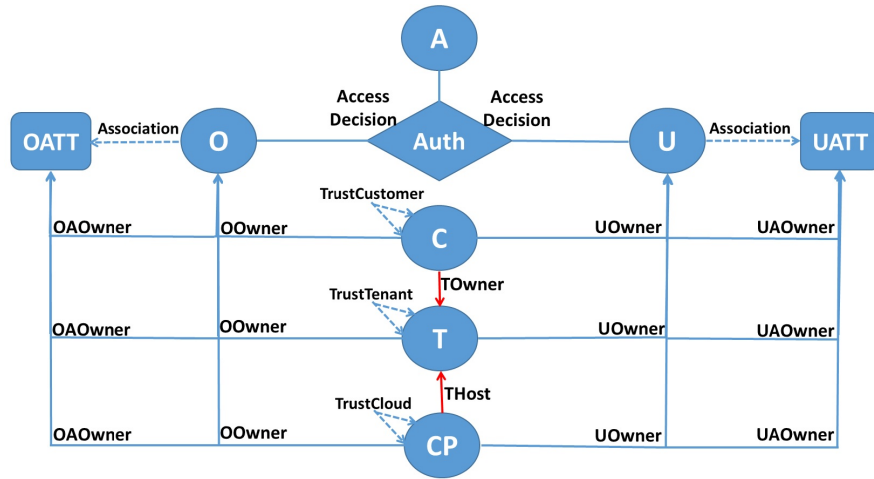


Fig. 1. MC-ABAC model.

and cloud-based compute services, that businesses can access over a network as and when required. These resources can be scaled up or down depending on the customer's needs. A cloud service provider is defined in this approach as the 5-uplet,  $(cp, U, O, ATT, T)$ :

- $cp$ : The cloud service provider  $ID$ ;
- $U$ : Set of users belonging to this  $cp$ ;
- $O$ : Set of objects held by this  $cp$ . An object in cloud could be resource, machine, or service;
- $ATT$ : Set of user, object and environment attributes defined by this  $cp$ ;
- $T$ : Set of tenants hosted in this  $cp$ .

A **cloud customer** ( $c$ ) refers to an individual or organization that utilizes cloud services. It's worth noting that a cloud customer can be a cloud itself, and that clouds may provide services to each other. A cloud customer is defined as the 5-uplet,  $(c, U, O, ATT, T)$ :

- $c$ : The cloud customer  $ID$ ;
- $U$ : Set of users belonging to this  $c$ ;
- $O$ : Set of objects held by this  $c$ . An object in the cloud could be resource, machine, or service;
- $ATT$ : Set of user, object and environment attributes defined by this  $c$ .
- $T$ : Set of tenants that this cloud customer  $c$  owns.

In the model, every user and object is associated with a unique entity: Cloud provider, cloud customer or tenant. To achieve this, the model introduces a system-defined attribute called  $UOwner$  for users and  $OOwner$  for objects. Additionally, each user attribute and object attribute is exclusively owned by a single entity. This is represented using functions  $UAOwner$  for user attributes and  $OOwner$  for object attributes.

#### A. MC-ABAC Definition

**Definition 2.** Core Multi-Cloud ABAC (Fig. 1) is defined by the basic component sets, functions and authorization policy language given below:

- $U, O, T, CP$  and  $C$  represent finite sets of existing users, objects, tenants, cloud service providers and cloud customers respectively.
- $A$  represents a finite set of actions available on objects. Typically  $A = \{create; read; update; delete\}$ .
- $UA$  and  $OA$  represent a finite sets of user and object attribute functions ( $ua$  and  $oa$ ) respectively.
- For each  $att \in UA \cup OA$ ,  $range(att)$  represents the attribute's range, which is a finite set of atomic values. An attribute  $att$  could be  $ua$  or  $oa$ .
- $attType : UA \cup OA \rightarrow \{set; atomic\}$ , specifies attributes as set or atomic values.
- Each attribute function maps elements in  $U$  to an atomic value or a set
  - $\forall ua \in UA. ua : U \rightarrow Range(ua)$  if  $attType(ua) = atomic$
  - $\forall ua \in UA. ua : U \rightarrow 2^{Range(ua)}$  if  $attType(ua) = set$
- Each attribute function maps elements in  $O$  to an atomic value or a set
  - $\forall oa \in OA. oa : O \rightarrow Range(oa)$  if  $attType(oa) = atomic$
  - $\forall oa \in OA. oa : O \rightarrow 2^{Range(oa)}$  if  $attType(oa) = set$
- $UA = GUA \cap LUA \cap CUA$ , such as:
  - $GUA$  represents a finite set of global user attribute functions which are defined by the cloud customer  $C$
  - $LUA$  represents a finite set of local user attribute functions which are defined by the tenants  $T$

- $CUA$  represents a finite set of cloud user attribute functions which are defined by the cloud service provider  $cp$
- $OA = GOA \cap LOA \cap COA$ , such as:
  - $GOA$  represents a finite set of global object attribute functions which are defined by the cloud customer  $C$
  - $LOA$  represents a finite set of local object attribute functions which are defined by the tenants  $T$
  - $COA$  represents a finite set of cloud object attribute functions which are defined by the cloud service provider  $cp$
- $UOwner : (u : U) \rightarrow E$ , required attribute function mapping user  $u$  to its owner entity. Note that an entity in this approach, could be a tenant  $t$ , a cloud service provider  $cp$  or cloud customer  $c$ ;
- $OOwner : (o : O) \rightarrow E$ , required attribute function mapping object  $o$  to its owner entity ( $t$ ,  $cp$  or  $c$ ).
- $UOwner : (ua : UA) \rightarrow E$ , attribute function, mapping user attribute  $ua$  to its owner entity ( $t$ ,  $cp$  or  $c$ ):
  - $ua \in LUA \rightarrow UOwner(ua) \in T$
  - $ua \in CUA \rightarrow UOwner(ua) \in CP$
  - $ua \in GUA \rightarrow UOwner(ua) \in C$
- $OOwner : (oa : OA) \rightarrow TE$ , attribute function, mapping object attribute  $oa$  to its owner entity ( $t$ ,  $cp$  or  $c$ ):
  - $oa \in LOA \rightarrow OOwner(oa) \in T$
  - $oa \in COA \rightarrow OOwner(oa) \in CP$
  - $oa \in GOA \rightarrow OOwner(oa) \in C$
- $TOwner : (t : T) \rightarrow C$ , required attribute function mapping tenant  $t$  to its owner cloud customer  $c \in C$ ;
- $THost : (t : T) \rightarrow CP$ , required attribute function mapping tenant  $t$  to its hosting cloud provider  $c \in C$ ;
- The authorizations that decide on whether a user  $u$  can access an object  $o$  for the action  $a$ , are a three Boolean functions of  $u$  and  $o$  attributes:
  - $LAuth_a(u; o) \rightarrow f(LUA(u); LOA(o))$ , represents local authorization that is defined by the tenant;
  - $GAuth_a(u; o) \rightarrow f(GUA(u); GOA(o))$ , represents global authorization that is defined by cloud customer;
  - $CAuth_a(u; o) \rightarrow f(CUA(u); COA(o))$ , represents cloud authorization which is defined by cloud service provider;
- Cloud administrator: The person who is responsible for defining access policies in the cloud service provider;
- customer administrator: The person responsible for defining access policies in the cloud customer;
- Tenant administrator: The person who is responsible for defining access policies in the tenant entity;

In this model, administrators are granted the ability to perform various administrative operations, with each operation having certain preconditions that need to be satisfied. In the following, we present the formal specification of several administrative operations and their corresponding preconditions:

- $\forall ua \in CUA, ua(u : U)$  is defined by the cloud administrator of  $cp$  only if ( $UOwner(ua) = UOwner(u) = cp$ ), means that the cloud  $cp$  must be the owner of both the user  $u$  and the attribute  $ua$ . The same principle applies to the subsequent operations as well;
- $\forall oa \in COA, oa(o : O)$  is defined by the cloud administrator only if ( $OOwner(oa) = OOwner(o) = cp$ );
- $\forall ua \in GUA, ua(u : U)$  is defined by the customer administrator of  $c \in C$  only if ( $UOwner(ua) = UOwner(u) = c$ );
- $\forall oa \in GOA, oa(o : O)$  is defined by the customer administrator of  $c \in C$  only if ( $OOwner(oa) = OOwner(o) = c$ );
- $\forall ua \in LUA, ua(u : U)$  is defined by the tenant administrator of  $t \in T$  only if ( $UOwner(ua) = UOwner(u) = t \cup (TOwner(UOwner(ua)) = UOwner(u))$ ), This implies that the user  $u$  must be owned by either the tenant  $t$ , who is the owner of the attribute  $ua$ , or the cloud customer who owns the tenant  $t$ .
- $\forall oa \in LOA, oa(o : O)$  is defined by the tenant administrator of  $t \in T$  only if ( $OOwner(oa) = OOwner(o) = t$ );
- $CAuth_a(u; o)$  is defined by the cloud administrator of  $cp$ . For all attributes  $ua, oa$  that are defined in  $CAuth_a(u; o)$  only if  $UOwner(ua) = OOwner(oa) = UOwner(u) = OOwner(o) = cp$ . Each authorization function needs to verify that the owner of  $ua$  is the same as the owner of  $oa, u$ , and  $o$ .
- $GAuth_a(u; o)$  is defined by the customer administrator of  $c \in C$ . For all attributes  $ua, oa$  that are defined in  $GAuth_a(u; o)$  only if  $UOwner(ua) = OOwner(oa) = UOwner(u) = OOwner(o) = c$ ;
- $LAuth_a(u; o)$  is defined by the tenant administrator of  $t \in T$ . For all attributes  $ua, oa$  that are defined in  $LAuth_a(u; o)$  only if ( $UOwner(ua) = OOwner(oa) = UOwner(u) = OOwner(o) = t \cup (UOwner(ua) = OOwner(oa) = OOwner(o) = t \cap UOwner(u) = TOwner(t))$ ). This predicate  $UOwner(u) = TOwner(t)$  means that the

### B. Administrative MC-ABAC Model

In this subsection, we focus on the administrative model for the suggested MC-ABAC. This model enables administrators to perform various administrative operations. In this approach, we distinguish three types of administrators: cloud administrator, customer administrator and tenant administrator.

user  $u$  is owned by the cloud customer who is the owner of  $t$ ;

## V. TRUST RELATIONS

MC-ABAC introduces many trust relations in order to support access between the cloud customer and the cloud service provider, cross tenant access, cross customer access and resource sharing in a multi-cloud environment. These trust relations are established between both, cloud service providers, cloud customers and tenants. In the following, we will define each trust relation used in this model.

### A. Provider to Customer Trust Relation

The Provider to customer trust relation ( $CPC$ )  $\subseteq CP \times C$  is a many-to-many relationship between the cloud service provider  $cp$  and the cloud customer  $c$ . It is defined as  $TrustCPToC(cp, c) = \cup_i(S_i)$ , such as  $S_i$  is a cloud service owned by the provider  $cp$ . This relationship means that the cloud  $cp$  provides a set of services  $\cup_i(s_i)$  to the cloud consumer  $c$ . This customer  $c$  will create its own tenants from these services.

For example, the trust relation  $TrustCPToC(Azure, SH1) = \{s1, s2, s3\}$ , means that the customer  $SH1$  could create new tenants  $t1$ ,  $t2$  and  $t3$  from these services  $s1$ ,  $s2$  and  $s3$ , in the cloud  $cp$ . Using this trust relation, the cloud consumer can establish or create their own tenants based on the services defined within this relation.

### B. Cloud Trust Relation

The cloud trust relation ( $CPCP$ )  $\subseteq CP \times CP$  is a many-to-many reflexive relation between a truster cloud  $cpr \in CP$  and a trustee cloud  $cpe \in CP$ . It is defined as  $TrustCloud(cpr, cpe : CP) \rightarrow 2^T$  means that the cloud service provider  $cpr$  authorizes  $cpr$ 's tenants to collaborate with  $cpe$ 's tenants. This implies that tenants hosted in  $cpr$  could establish tenant trust relation with  $cpe$ 's tenants, in order to ensure cross tenant access in multi-cloud environment.

This trust relation  $TrustCloud(cpr, cpe) = \bigcup_{i=1}^k t_i$  is defined with the additional required condition that:  $t \in TrustCloud(cpr, cpe)$  only if  $THost(t) = cpr$ , this implies that the cloud service provider  $cpr$  should possess ownership of the tenants which are defined in this relation. For example:  $TrustCloud(Azure, Amazon) = t1, t2$ , means that tenants hosted in *Azure* cloud, such as tenants  $t1$  or  $t2$ , can establish a trust relation with tenants from the *Amazon* cloud.

### C. customer Trust Relation

The customer trust relation ( $CC$ )  $\subseteq C \times C$  is a many-to-many reflexive relation between a truster customer  $cr \in C$  and a trustee customer  $ce \in C$ . It is defined as  $Trustcustomer(cr, ce : C) \rightarrow 2^T$ , which means that the cloud customer  $cr$  authorizes some  $cr$ 's tenants to collaborate with  $ce$ 's tenants. This implies that tenants owned by  $cr$  could establish tenant trust relation with  $ce$ 's tenants, in order to ensure cross-tenant access, where each tenant belongs to a different customer, .

This trust relation  $Trustcustomer(cr, ce) = \bigcup_{i=1}^k t_i$  is defined with the additional required condition that:  $t \in$

$Trustcustomer(cr, ce)$  only if  $TOwner(t) = cr$ , this means that the customer  $cr$  must be the owner of tenants which are defined in this relation. For example:  $Trustcustomer(SH1, SH2) = t2, t3$ , means that tenants belonging to cloud customer  $SH1$ , such as  $t2$  or  $t3$ , can establish trust relationships with tenants belonging to cloud customer  $SH2$ .

### D. Tenant Trust Relation

The tenant trust relation ( $TT$ )  $\subseteq T \times T$  is a many-to-many reflexive relation between the truster  $tr \in T$  and the trustee  $te \in T$ . It is defined as  $TrustTenant(tr, te : T) \rightarrow 2^U$  which means that the tenant  $te$  is authorized to assign values for  $te$ 's local user attributes to tenant  $tr$ 's users. This trust relation  $TrustTenant(tr, te) = \bigcup_{i=1}^k u_i$  is defined with the additional required condition that:  $u \in TrustTenant(tr, te)$  only if  $UOwner(u) = tr$ , this implies that the truster  $tr$  must be the owner of users which are defined in this relation. For example:  $TrustTenant(t1, t3) = u1, u2$ , means that the tenant  $t3$  can assign values for  $t3$ 's local user attributes to  $u1$  and  $u2$ .

This trust relation is subject to a precondition that needs to be satisfied, which depends on the four cases introduced in the case study subsection. In the following, we specify the precondition for each case:

- **Case 1:** Collaborating tenants hosted in the same cloud provider and owned by the same cloud customer.  $TrustTenant(tr, te) = \bigcup_{i=1}^k u_i$  is defined with the additional required condition that:  $u \in TrustTenant(tr, te)$  only if  $UOwner(u) = tr$ .
- **Case 2:** Collaborating tenants hosted in the same cloud provider and owned by different cloud customers. Before establishing trust between the two tenants  $tr$  and  $te$ , trust must be established between the two cloud customers  $cr$  and  $ce$  who are the owners of  $tr$  and  $te$  respectively.  $TrustTenant(tr, te) = \bigcup_{i=1}^k u_i$  is defined with the additional required condition that:  $u \in TrustTenant(tr, te)$  only if  $UOwner(u) = tr \cap te \in Trustcustomer(TOwner(tr), TOwner(te))$ .
- **Case 3:** Collaborating tenants hosted in different cloud providers and owned by the same cloud customer. Before establishing trust between the two tenants  $tr$  and  $te$ , trust must be established between the two cloud providers  $cpr$  and  $cpe$  who are the hosts of  $tr$  and  $te$  respectively.  $TrustTenant(tr, te) = \bigcup_{i=1}^k u_i$  is defined with the additional required condition that:  $u \in TrustTenant(tr, te)$  only if  $UOwner(u) = tr \cap te \in TrustCloud(THost(tr), THost(te))$ ;
- **Case 4:** Collaborating tenants hosted in different cloud providers and owned by different cloud customers.  $TrustTenant(tr, te) = \bigcup_{i=1}^k u_i$  is defined with the additional required condition that:  $u \in TrustTenant(tr, te)$  only if  $UOwner(u) = tr \cap te \in TrustCloud(THost(tr), THost(te)) \cap tr \in Trustcustomer(TOwner(tr), TOwner(te))$ .

We summarize the definition of this trust relation using the following formalism, taking into account the four cases previously discussed:  $TrustTenant(tr, te) = \bigcup_{i=1}^k u_i$

is defined with the additional required condition that:  $u \in TrustTenant(tr, te)$  only if  $[(UOwner(u) = tr) \cap [(TOwner(tr) = TOwner(te)) \cup (tr \in Trustcustomer(TOwner(tr), TOwner(te)))] \cap [(THost(tr) = THost(te)) \cup (tr \in TrustCloud(THost(tr), THost(te)))]]$ .

Utilizing this trust relation entails redefining the preconditions that correspond to the two operations  $oa(o : O)$  and  $LAuth_a(u; o)$ . Below, we provide the formal specification of these two operations:

- $\forall ua \in LUA, ua(u : U)$  is defined by the tenant administrator of  $t \in T$  only if  $(UOwner(ua) = UOwner(u) = t) \cup (Towner(UAOwner(ua)) = UOwner(u)) \cup (u \in TrustTenant(UOwner(u), UAOwner(ua)))$ ;
- $LAuth_a(u; o)$  is defined by the tenant administrator of  $t \in T$ . For all attributes  $ua, oa$  that are defined in  $LAuth_a(u; o)$  only if  $(UOwner(ua) = OOwner(oa) = UOwner(u) = OOwner(o) = t) \cup (UOwner(ua) = OOwner(oa) = OOwner(o) = t \cap UOwner(u) = Towner(t)) \cup (UOwner(ua) = OOwner(oa) = OOwner(o) = t \cap (u \in TrustTenant(UOwner(u), UAOwner(ua))))$ .

## VI. IMPLEMENTATION

### A. System Architecture

As shown in Fig. 2, we present the implementation architecture of the MC-ABAC model using python technology in order to demonstrate its feasibility. This architecture is composed of five components: Entity information, entity attributes, authorizations, trust relations and policy decision component. In the following, we provide a description of each of these components:

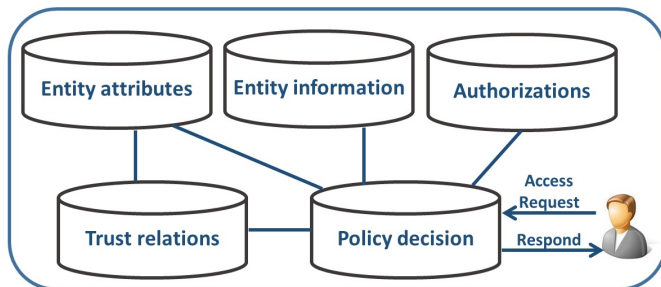


Fig. 2. Implementation architecture.

- **Entity information:** In this component, the cloud administrator, customer administrator, and tenant administrator are responsible for defining and managing various entities. These entities encompass customers, tenants, cloud users and objects, global users and objects, as well as local users and objects. Each administrator is responsible for their respective set of entities within the system;
- **Entity attributes:** Within this component, it is the administrator's responsibility to define the attributes

associated with users and objects. These attributes can be categorized as either global, local, or specific to the cloud provider. Subsequently, the administrator assigns values to the user and object attributes for their respective users and objects. This is achieved through a function that takes the user or object as input and generates a value from the range of the attribute. For instance,  $attr1(user1) = \{val1, val2\}$ : means that for the user  $user1$  the values of the attribute  $attr1$  are  $val1$  and  $val2$ ;

- **Authorizations:** In this component, the cloud administrator, customer administrator, and tenant administrator are responsible for specifying the authorizations policy  $CAuth_a(u; o)$ ,  $GAuth_a(u; o)$  and  $LAuth_a(u; o)$ . In our approach, we consider that each cloud, customer and tenant defines its own policy rules. Note that at this level, we assume that the security policy rules are valid and free from conflicts.
- **Trust relations:** Within this component, the management of trust relations is handled. These trust relations, namely  $TrustCloud()$ ,  $TrustCustomer()$ , and  $TrustTenant()$ , are established by the cloud administrator, customer administrator, and tenant administrator, respectively. Moreover, this component governs the trust between the cloud provider and the customer by using the trust relation  $TrustCPtoC()$ .
- **Policy decision:** In this component, the evaluation of access requests to objects stored in the cloud is carried out based on the collected attribute values and authorizations. When a user submits a request to access a resource within the cloud, the policy decision component assesses the request against the policy rules to determine whether the user has the authorization to access the requested resource or not.

### B. Results and Performance

The experiments were conducted on a virtual machine with the following specifications: Memory: 4096 MB, CPU: 2 cores, Hard Disk: 30 GB. For the analysis, we have used a synthetic dataset, containing up to 1000 authorizations, 200 attributes, 2000 attribute assignments and 25 tenants. We observed that the performance of our approach is influenced by various factors, including the number of authorizations and attribute assignments. The evaluation results indicate that the implementation of the MC-ABAC model for defining access control policies incurs minimal overhead.

The average time to grant the access to an object (Fig. 3(a)) with ABAC model increases with 13.1% and 28.5% for policies of 200 and 1000 rules respectively using the MC-ABAC model. The waiting time that is required to get a policy decision increases when there are too many authorizations to be collected. We attest that our implementation performs well, even for a large number of authorizations.

Furthermore, the running time for access/deny decisions to an object has been computed, using both ABAC and MC-ABAC models, for 600 authorizations and for 400 to 2000 attribute assignments. Fig. 3(b) demonstrates that the average time to access a resource with ABAC model increases with



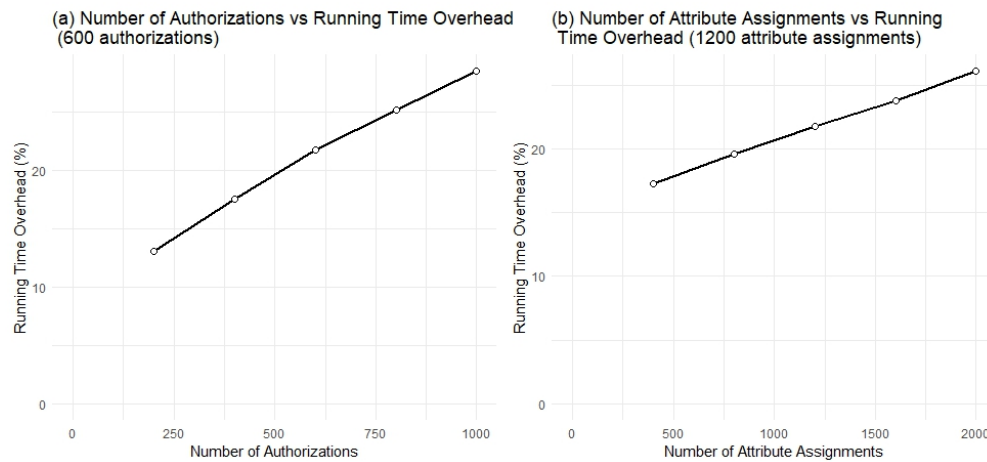


Fig. 3. Running time overhead for access/deny decisions.

17.3% and 26.1% for 400 and 2000 attribute assignments using MC-ABAC Module. We recognize that the implementation of our model demonstrates effective performance when handling a significant number of attribute assignments.

## VII. CONCLUSION

In this paper, we present a novel ABAC model called: MC-ABAC, that leverages the capabilities of ABAC, such as flexibility and adaptability. MC-ABAC enables collaboration and resource sharing among tenants, which are hosted across multiple cloud providers. This model introduces the notions of tenant, cloud customer and cloud service provider as fundamental entities within the model. Moreover, MC-ABAC integrates various trust relations to facilitate effective collaboration and cross-tenant access in the multi-cloud environment. This model is designed to address access control challenges that arise in heterogeneous multi-cloud environments where users and shared resources are distributed across different tenants in multiple clouds.

Finally, the implementation architecture of the MC-ABAC model using Python technology has been proposed to demonstrate its feasibility. The evaluation results have demonstrated that implementing this model for defining access control policies has minimal overhead. As a future work, we plan to implement and test MC-ABAC model on a real platform consisting of multiple cloud providers. Another future research involves developing a solution to detect and resolve conflicting rules in access policies that are defined using the MC-ABAC model.

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# Type 2 Diabetes Mellitus: Early Detection using Machine Learning Classification

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**Abstract**—Type 2 Diabetes Mellitus (T2DM) is a growing global health problem that significantly impacts patient’s quality of life and longevity. Early detection of T2DM is crucial in preventing or delaying the onset of its associated complications. This study aims to evaluate the use of machine learning algorithms for the early detection of T2DM. A classification model is developed using a dataset of patients diagnosed with T2DM and healthy controls, incorporating feature selection techniques. The model will be trained and tested on machine learning algorithms such as Logistic Regression, K-Nearest Neighbors, Decision Trees, Random Forest, and Support Vector Machines. The results showed that the Random Forest algorithm achieved the highest accuracy in detecting T2DM, with an accuracy of 98%. This high accuracy rate highlights the potential of machine learning algorithms in early T2DM detection and the importance of incorporating such methods in the clinical decision-making process. The findings of this study will contribute to the development of a more efficient precision medicine screening process for T2DM that can help healthcare providers detect the disease at its earliest stages, leading to improved patient outcomes.

**Keywords**—Diabetes Mellitus Type II; feature selection; machine learning methods; precision medicine

## I. INTRODUCTION

The phenomenon of urbanization in recent years has brought about significant lifestyle changes, contributing to the rising incidence of diabetes. Diabetes, also known as Diabetes Mellitus (DM), occurs when the blood sugar levels become elevated. This condition can occur due to either inadequate production of insulin by the body or the cells’ inability to respond to insulin. Insulin is a hormone that plays a crucial role in regulating glucose levels in the blood [1]. When the body fails to utilize glucose for energy production, it accumulates in the bloodstream, leading to a condition known as hyperglycemia.

The World Health Organization (WHO) has projected that by the year 2040, approximately 600 million people worldwide will be affected by diabetes. This staggering statistic underscores the urgent need to address the growing prevalence of this disease. The number of diagnosed cases continues to escalate [2], highlighting the pressing need for effective strategies to combat diabetes and mitigate its impact on global health.

Fig. 1 illustrates the significant impact of diabetes, where 90% to 95% of diabetes cases are attributed to T2D. Inadequate diabetes management affects glucose control and increases the risk of various comorbidities such as stroke, cancer,

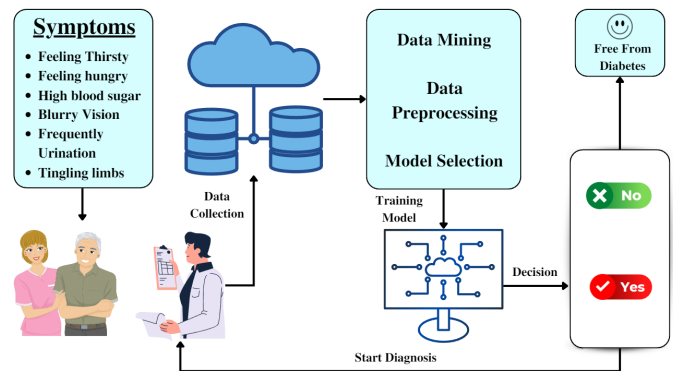


Fig. 1. Block diagram representation of precision medicine employing various data analytics and machine learning algorithms.

Alzheimer’s disease, hypertension, and cardiovascular disease. Thus, early detection plays a crucial role in predicting and managing Diabetes Mellitus or T2D effectively.

Type 2 diabetes mellitus occurs when insulin is not produced sufficiently to meet the body’s needs. On average, people are diagnosed to type 2 diabetes around the age of 40 due to Obesity, seniority, and parents’ inheritance. Apart from Obesity, other factors such as age, gender, socioeconomic class, place of residency (rural or urban), smoking addiction, liquor infusion, nutrition frequency, and so on are strongly linked with Type 2 Diabetes (T2D) [3]. Few of these characteristics are flexible and thus play a vital role in T2D management.

Since the dawn of machine learning, many researchers have suggested classification models for the prediction of diabetes mellitus (Table I). However, even though machine learning algorithms can predict diabetes early, it is not yet established for clinical operations. The proposed method constitutes of various classification of ML algorithms and attributes are chosen from the dataset using feature selection algorithm. The selected attributes are fed into various ML algorithms and results are compared with existing models.

Diabetes data analysis is a difficult task since most of the medical information is non-linear, irregular, correlation structured, and very tangled in nature. Therefore, using machine learning techniques in T2D analysis is a critical process for extracting knowledge from large amounts of available diabetes-related data and also aids in accurately diagnosing diabetes [4]. Traditional blood analysis methods may be more painful

TABLE I. TIME LINE OF VARIOUS MACHINE LEARNING METHODS FOR T2DM

Ref	Year	Methodology	Independent Variables
[6]	1993	Static and Dynamic Regression Model	Gender, Age, Frequency of diabetes
[7]	2004	Multiple Regression Analysis	Age, Usage of cigarette, Chronic pancreas history, Physical activity
[8]	2010	Pearson Partial Correlation	Age, Hyper tension status, Race, Waist Circumference
[9]	2015	Wilcoxon Signed-Rank Regression Model	Age, Diabetic state, Over weight, BMI, Obesity
[10]	2016	General Regression Networks	Diastolic Blood pressure, Two hours serum insulin, Age, Pedigree Function, triceps subcutaneous thickness
[11]	2016	Artificial Neural Network	Age, Gender, Height, Weight, BMI, High Blood Pressure History, Pregnancy history, Gestational diabetes history
[12]	2017	Dynamic Markov Model	Type-1 and type-2 Diabetes Status, Death, Undiagnosis diabetic state
[13]	2022	Ensembler Random Forest	Gender, Age, Polyuria, Irritability, Genital Thrush

and time-consuming, and because of this, physicians frequently make decisions based on a patient's current blood analysis report. Therefore, it has become a challenging task for both physicians and patients the diagnosis of diabetes mellitus. Hence, monitoring blood glucose (BG) levels plays a vital role in avoiding and relieving diabetic complications.

A portative Self-Monitoring of Blood Glucose (SMBG) device, a combination of advanced Information and Communication Technology (ICT) and biosensors, nourishes an efficient real-time monitoring administration technique for the healthiness state of diabetic patients. As a result, a patient can independently monitor the differences in his blood glucose levels [5]. In addition, using CGM (continuous glucose monitoring) sensors, users can better understand changes in blood glucose levels. Thus, many of the intelligent diabetes diagnosis systems have been designed by inspiring human biological constructors. These advanced methods predict whether or not the patient has diabetes mellitus without taking into account of any surgeon's progress [14].

Further, the paper consists of a brief description of the different sections discussed in the paper. The subsequent sections include a comprehensive Literature Survey in the second section, which examines relevant research and existing knowledge in the field. Following the Literature Survey, the experimental setup outlines the methodology and techniques to develop the diabetes diagnosis model. Finally, the paper presents the Results and Discussion section, where the performance and effectiveness of the machine learning models are analyzed and interpreted in detail.

## II. LITERATURE SURVEY

Early detection and diagnosis are paramount to effectively prevent the progression of diabetes. Several studies have found that lifestyle changes and pharmacological interventions can decrease the chance of developing diabetes. Furthermore, for recently interpreted intensive lifestyle, diabetic patients intervention, earlier short-term intensive insulin treatment, and metabolic therapy can result in prolonged glycaemic remission without additional antidiabetic treatment. As a result, identifying people at increased risk of acquiring diabetes is critical for diabetes prevention programs. These studies can be summarized as follows (Table II).

Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder, and recent studies have shown that machine learning techniques can accurately predict the early stages of the disease. For instance, Oladimeji et al. (2021) [15] work highlights

the potential of combining feature selection and classification algorithms for predicting diabetes at an early stage, Bhavya et al. (2020) [16] achieved their goal of predicting the presence of diabetes using machine learning techniques and achieved high accuracy rates, while Tigga et al. (2021) [17] developed a logistic regression model to predict the occurrence of type 2 diabetes with an accuracy of 83.3%. Moreover, Liu et al. (2022) [18] used machine learning techniques to accurately predict the risk of incident type 2 diabetes mellitus in the Chinese elderly. Boshra et al. (2021) [19] diagnosed diabetes using machine learning techniques and achieved high accuracy. Butt et al. (2021) [20] highlight the benefits of using machine learning algorithms in the healthcare industry, such as improved accuracy, faster diagnosis, and lower costs. In another study, Barik et al. (2021) [21] analyzed the prediction and accuracy of diabetes using classifiers and hybrid machine learning techniques and found that hybrid techniques provided higher prediction accuracy. Mounika et al. (2021) [22] compared the performance of different machine learning algorithms. They achieved a high accuracy rate of 95.3% in predicting type-2 diabetes. In contrast, Sneha et al. (2019) [23] used techniques like entropy and correlation-based feature selection to predict diabetes mellitus early by selecting optimal features. However, limitations such as dataset size and diversity need to be addressed in these studies to improve the generalizability of their results.

Khallel et al. (2021) [24] applied machine learning algorithms such as a support vector machine, decision tree, and k-nearest neighbor to predict the incidence of type 2 diabetes in a Korean population with metabolic syndrome. Their results showed that machine learning models could detect individuals at high risk of developing type 2 diabetes. In another study, Hernández-Lemus et al. (2022) [25] proposed a new machine-learning approach using a joint embedding of DNA methylation data and clinical variables to predict T2DM status. The authors showed a higher predictive performance of their model compared to current state-of-the-art methods. Furthermore, the authors highlighted their approach's potential to identify key methylation signatures linked to T2DM. These latest studies have shown promising results and highlight the potential of machine learning techniques to enhance early detection and improve the management of T2DM. Recent studies that demonstrate the potential of machine learning in predicting diabetes include the work of Lu et al. (2021) [26], who developed a machine-learning model to predict prediabetes and T2DM using medical claim data from a large health maintenance organization. Their model achieved high sensitivity and specificity, indicating its potential to iden-

TABLE II. LITERATURE SURVEY

Authors	Algorithms Used	Summary	Limitations
Oladosu et.al 2021 [15]	Random Forest Naive Bayes J48 KNN	The author uses the feature selection method to prevent overfitting and remove redundant data, which helps in providing an optimal model for predicting diabetes in the earlier stage by emphasizing more on feature selection	The accuracy of the output can be increased by considering body size, height and BMI attributes, which lacks in this paper.
Bhavya et.al 2020 [16]	KNN	The authors extensively explore the popular techniques in Machine Learning and uses KNN algorithm to identify the diabetes	The paper lacks in verifying the different algorithms available in Machine Learning such as Naive Bayes, SVM, Decision Tree, ID3 etc.
Neha and Shruthi 2020 [17]	LR KNN, SVM Naive Bayes DT Random Forest	The author aims to evaluate the risk of diabetes among people based on their family background and lifestyle. In this paper the model is developed by choosing 952 instances collected through online and offline questioner. The authors conclude that RF is most accurate.	The authors failed to consider biological attributes which plays an important role in predicting diabetes.
Qing Liu et.al 2022 [18]	LR DT XGBoost RF	The authors aim to make effective prediction models using machine learning algorithms for risk type of T2DM in Chinese elderly. The proposed model uses Lasso Regression for feature selection and features are applied to ML algorithms, they got best accuracy in XGBoost algorithm.	The paper fails to implement on different algorithms which might have given more accuracy because they have chosen more feature selected attributes.
Boshra et.al 2021 [19]	Logistic Regression SVM Decision Tree XGBoost Random Forest ADABoost	The author aims to implement the diagnosis of diabetes employing Machine Learning algorithms and evaluate the performance comparison of diverse models for classifying diagnosis. According to this paper the ADABoost has more accuracy.	The accuracy can be increased if authors had considered more attributes.

tify high-risk individuals and improve preventive strategies. Similarly, Alqudah et al. (2022) [27] developed a machine-learning model utilizing retinal images to predict T2DM. The authors utilized deep learning techniques to predict the presence of T2DM. They found that their model outperformed existing methods, offering the potential for an inexpensive, non-invasive approach to diabetes screening.

Yilmaz et al. (2019) [28] investigated the effectiveness of machine learning models in predicting the risk of developing T2DM using non-invasive retinal imaging. The authors utilized deep learning techniques to analyze retinal images and predict the presence of T2DM. Their findings suggest that the analysis of retinal images may provide an effective and convenient screening tool for detecting early signs of T2DM with the potential for widespread implementation. Rasmy et al. (2021) [29] developed a machine-learning model for the early prediction of T2DM using electronic health record data from a large healthcare system. The authors utilized a combination of feature selection algorithms and machine learning models to predict the risk of T2DM and achieved high accuracy rates. Their findings suggest that machine learning-based approaches improve early detection and intervention for T2DM, ultimately preventing severe complications and reducing healthcare costs. In a recent study, Wang et al. (2022) [30] developed a machine-learning model for predicting incident T2DM using electronic health record data. The authors used a large dataset of over 2 million patients, and the model achieved high accuracy rates in predicting incident T2DM up to 36 months in advance. Their model may be incorporated into clinical decision support systems to aid in the early detection and prevention of T2DM.

A study by Huang et al. (2022) [31] developed and validated a machine learning-based nomogram for predicting the risk of T2DM in Chinese adults. The authors used data from the China Health and Retirement Longitudinal Study and developed a nomogram that integrated various risk factors such as age, sex, BMI, and lifestyle factors. The results showed that the nomogram achieved high accuracy in predicting T2DM risk and could be clinically applicable for the early detection and prevention of T2DM. Another study by Wu et al. (2023) [32]

proposed a novel machine learning algorithm that combines deep neural networks (DNNs) and attention mechanisms to predict T2DM. The authors used electronic health record data from a large hospital in China and compared their model's performance to other widely used models. Their results showed that their DNN-attention model outperformed other models in predicting, indicating its potential for clinical application in early detection and personalized intervention. In a study by Lui et al. (2023) [33], the authors used a deep learning-based approach to predict T2DM using electronic health record data. The authors developed a convolutional neural network (CNN) model incorporating structured and unstructured data, such as lab test results and clinical notes. The model achieved high accuracy rates in T2DM prediction and showed improved performance compared to traditional machine learning models, suggesting its potential for clinical application in diabetes prediction and management. Finally, a recent study by Sim et al. (2023) [34] aimed to develop a machine-learning model that predicts T2DM based on lifestyle factors. The authors used data from a large cohort study and developed a model incorporating physical activity levels, diet, and sleep patterns. The results showed that the model achieved high accuracy in predicting T2DM risk based on lifestyle factors alone, demonstrating the potential of machine learning approaches to personalize diabetes prevention and management strategies based on lifestyle habits.

### III. EXPERIMENTAL SET UP

Fig. 2 shows the proposed methodology of this work. The method demonstrated incorporates feature selection as an important step in the machine learning classification process. It helps to reduce the dataset's dimensionality and eliminate irrelevant or redundant features that can lead to overfitting or reduced accuracy. Further, the proposed model helps combine multiple feature selection techniques, which also helps to identify the most important features that contribute to the T2DM detection model and improve its overall accuracy. This is a crucial advantage over other methods that do not incorporate feature selection, leading to a more robust and accurate T2DM detection model.

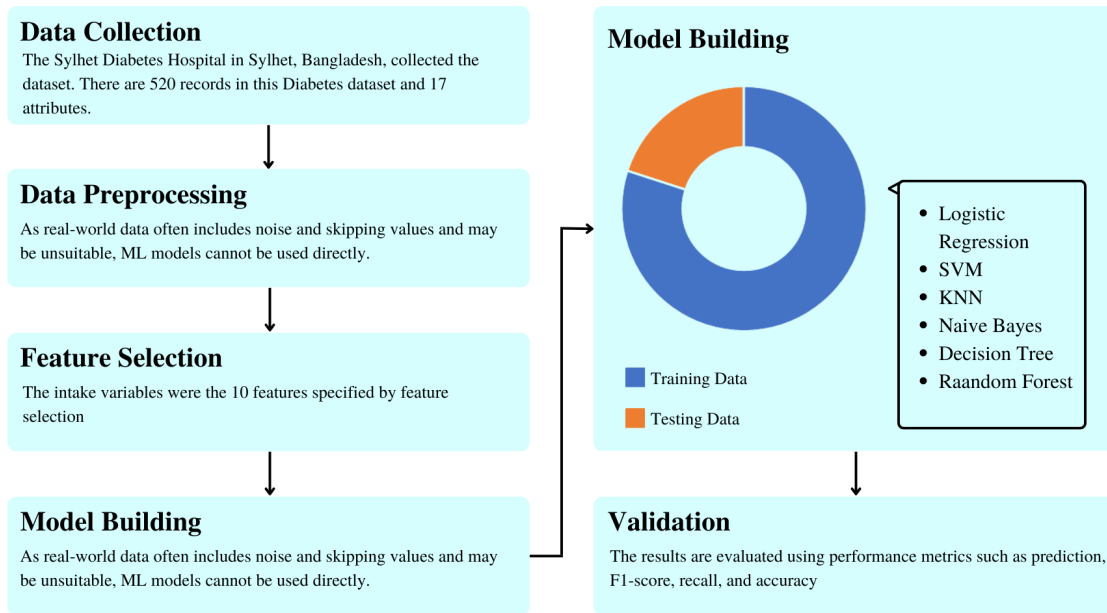


Fig. 2. Flowchart depicting the five stages of the machine learning process with data collection, data preprocessing, feature selection, and model building for validation.

The gathering and comprehension of data enable the examination of patterns and trends, which aids in outcome prediction and evaluation. The Sylhet Diabetes Hospital in Sylhet, Bangladesh, collects the dataset directly from the patients by having them complete a questionnaire, and a doctor then verifies it. Below is a description of the dataset. There are 520 records in this Diabetes dataset and 17 attributes.

As real-world data often includes noise and skipping values and may be unsuitable, ML models cannot be used directly. Instead, data cleaning and preparation for a machine learning sample are required for data pre-processing, which increases the precision and effectiveness of the machine learning model. Finding lost data, encoding categorical data, exploratory data analysis (Fig. 3), dividing the dataset into a training and trial set, feature selection, and feature scaling are some of the tasks it entails.

Every machine learning pipeline comprises Key Performance Indicators (KPIs). Since the result from classification models are discrete, we require a metric that contrasts different classes somehow. Classification Metrics evaluate a model's execution and show if the classification is valid, but they do so in various ways. It evaluates models based on their performance, time complexity, accuracy, recall, sensitivity, and the most promising metric, which is the confusion matrix. The truth labels versus model predictions are displayed in a confusion matrix using tables. An individual row of the confusion matrix defines an instance in a class label, but an individual column represents an instance in a real class. The Confusion Matrix isn't a performance indicator but provides the framework for other metrics to assess the outcomes. Therefore, a metric is required for all machine learning models to evaluate their effectiveness.

The dataset was randomly split into train and trial data

with a proportion of 80% to 20%. Since the data is extremely unbalanced, it is a good idea to use the Sklearn module in Python to standardize the dataset's input features and normalize. Using the Python Standard Scaler function from the Sklearn pre-processing library, the training cluster was standardized to have a mean of Zero and a variance of One, and the test set was normalized using the mean and standard deviation of the training dataset.

We trained the LR, DT, RF, KNN, and SVM models and implemented them using the Python Sklearn package. The intake variables were the 10 features specified by feature selection (Table III). The Primary purpose of using hyperparameters is to specify the attributes before training begins. It expresses the major characteristics of the model, such as its efficiency, robustness, and intricacy. Therefore, it has evolved to become immensely popular for adjusting hyperparameters in machine-learning algorithms. The most suitable hyperparameters for RF were as observed: max\_depth = 100, max\_features = 10, min\_samples\_leaf = 5, n\_estimators = 80, min\_samples\_split = 69, criterion = entropy and random state = 0.

TABLE III. ATTRIBUTES

SL No.	Attributes	Score
1	Age	18.845767
2	Gender	38.747637
3	Polyuria	116.184593
4	Polydipsia	120.785515
5	sudden weight loss	57.749309
6	Polyphagia	33.198418
7	visual blurring	18.124571
8	Irritability	35.334127
9	partial paresis	55.314286
10	AgeAlopecia	24.402793

Though AI and its subsets like machine learning are quite



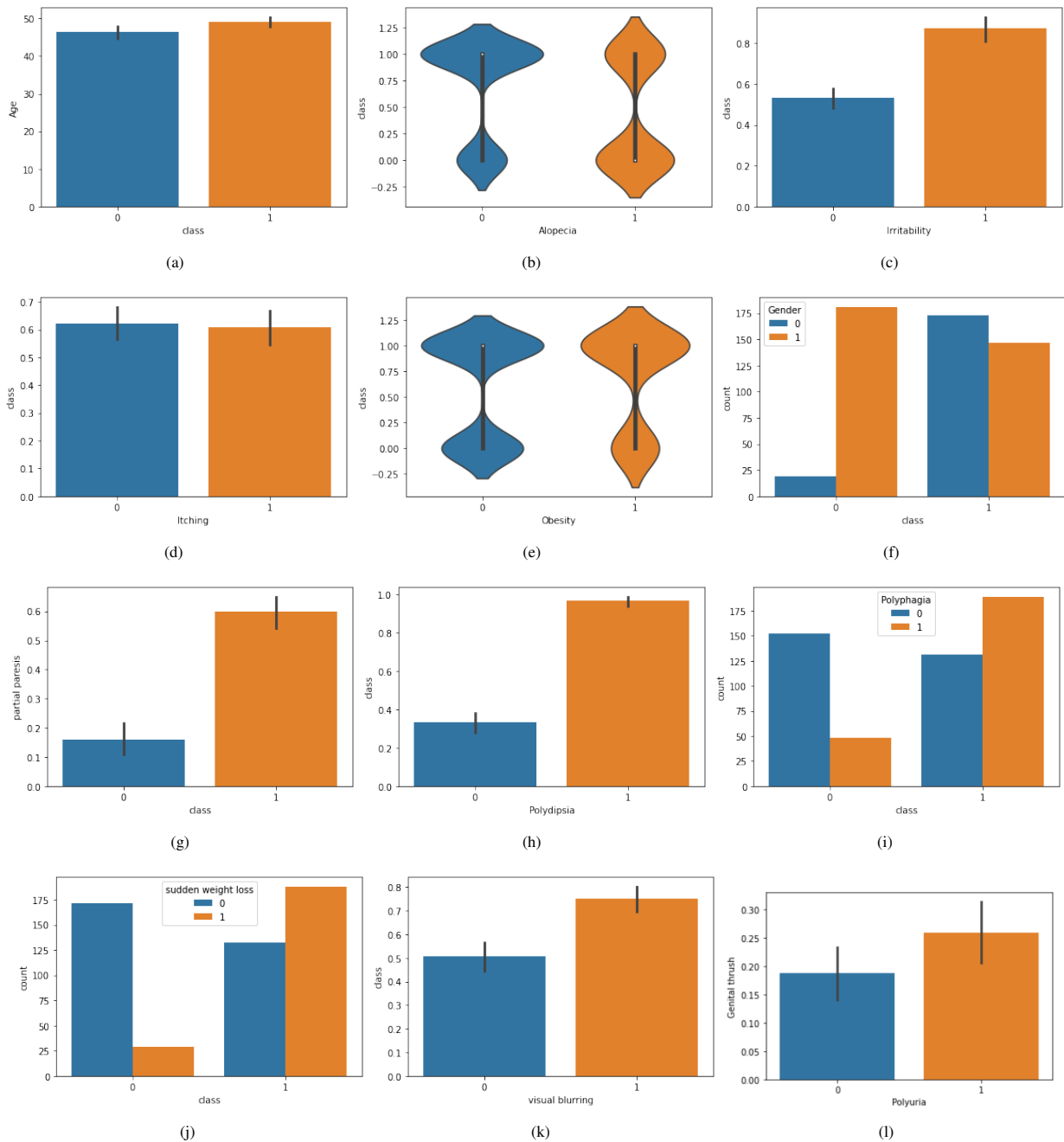


Fig. 3. Exploratory data analysis for the extracted features from the dataset - a)age-class, b)alopecia, c)irritability, d)itching, e)gender, f)obesity, g)partial paresis, h)polydipsia, i)polyphagia, j)sudden weight loss, k)visual blurring, l)polyuria Vs genital thrush.

promising with their results, it is still a challenge to practice these methods in real-time for clinical diagnosis. The main reason is that AI needs a large amount of data to work with, and this requires time. In the case of AI, this is called data transfer learning. And it means that you need a large amount of labeled data to train your algorithm with. Moreover, the results may again vary based on the data collected from a geographic location such as Asia Pacific, USA, and European regions. The datasets available on open-source platforms are outdated and don't meet the expected results as the prediction needs to be dynamic, which means based on the patient's current

reports. Also, the results will vary based on the top features or attributes selected during the process of feature selection. The challenge of building a machine learning model is that it requires extensive data, which is often not available in the medical field. Therefore, there are limitations to building a model based on the available data.

#### IV. RESULTS AND DISCUSSION

Our research presents compelling results on the detection of Type 2 Diabetes (T2D) using feature selection algorithms.

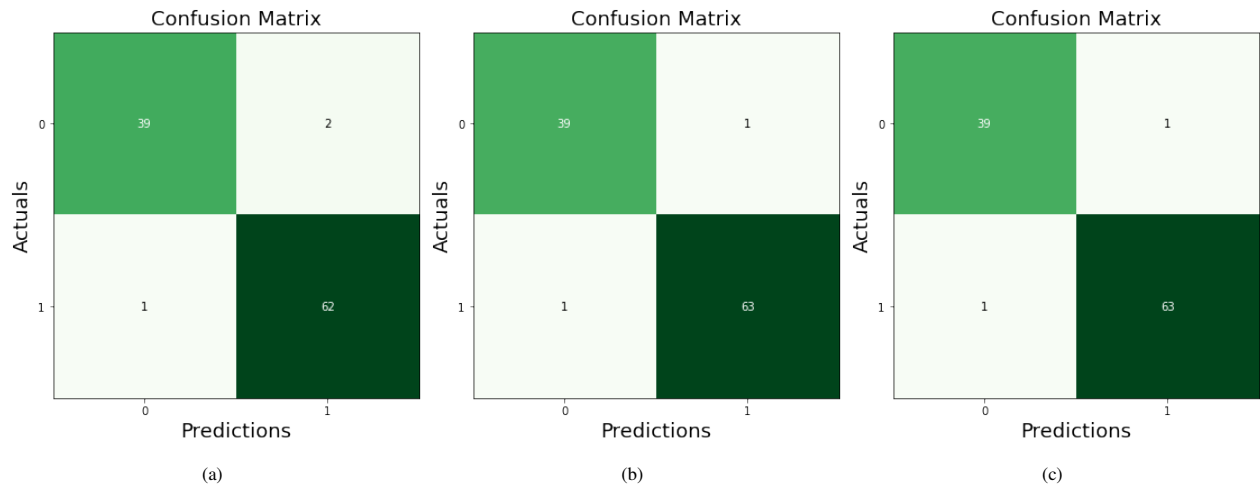


Fig. 4. Confusion matrix depicting true positive, true negative, false positive and false negative to calculate precision, recall, F1-score and accuracy for - a)decision tree, b)support vector machine, c)random forest.

Through the utilization of carefully curated datasets, we employed various algorithms to assess the probability of individuals having T2D. The evaluation of our results was based on performance metrics such as prediction, F1-score, recall, and accuracy, which are presented in Table IV.

Fig. 4 highlights the notable findings of our study, emphasizing the significant improvement in T2D prediction accuracy achieved by addressing imbalanced datasets using feature selection techniques. The Confusion Matrix visually represents the superior performance of our approach, clearly demonstrating the enhanced accuracy obtained through our methodology.

Of particular interest is the remarkable performance of the Random Forest (RF) algorithm, outperforming other algorithms examined in our study. This discovery holds great promise for the healthcare industry, as our proposed model proves to be cost-effective and efficient in terms of implementation time. Unlike traditional diagnostic tests such as Oral Glucose Tolerance Test (OGTT) and Hemoglobin A1c (HbA1c), our model eliminates the need for expensive lab reagents and specialized skills. This breakthrough paves the way for early detection of diabetes, especially in remote areas with limited access to healthcare facilities.

Looking ahead, the integration of 5G and Artificial Intelligence (AI) technologies offers even more potential for improving healthcare outcomes. By leveraging deep learning algorithms, the latency at the edge can be significantly reduced, enabling real-time data analysis and decision-making. This cognitive system architecture represents the inception of a smart healthcare system, empowering remote areas and underserved communities with access to timely and accurate diabetes detection.

Moreover, the potential impact of our research extends beyond the realm of T2D detection. The application of feature selection algorithms and the success of the RF algorithm in this study open avenues for exploring similar approaches in the diagnosis and prediction of other medical conditions. By leveraging the power of data analysis and machine learning, we

can unlock new insights into various diseases and develop efficient and accessible diagnostic models. This not only has the potential to transform healthcare delivery but also contributes to the advancement of personalized medicine, where early detection and targeted interventions can significantly improve patient outcomes and overall population health. Our research lays a solid foundation for future investigations into leveraging feature selection and algorithmic techniques to enhance medical diagnostics across diverse healthcare domains.

TABLE IV. THE ML ALGORITHMS WITH THE KPI AFTER BEING TRAINED WITH THE PROPOSED MODEL

SL No.	Algorithms	Precision	Recall	F1-score	Accuracy
1	Logistic Regression	92%	91%	91%	89%
2	SVM Linear	94%	91%	92%	90%
3	SVM Radial	98%	98%	98%	98%
4	KNN	98%	98%	98%	98%
5	Naive bayes	89%	88%	88%	86%
6	Decision Tree	97%	97%	97%	97%
7	Random Forest	98%	98%	98%	98%

The dataset used in this research was obtained from the Sylhet Diabetes Hospital in Bangladesh. It consists of 520 records with 17 attributes. The data was collected through patient questionnaires, verified by medical professionals. However, the dataset's regional specificity may limit generalizability. The sample size, though substantial, should be considered for its representativeness. Potential limitations include self-reporting bias and missing variables. Despite these considerations, the dataset provides a valuable foundation for studying the relationship between urbanization and diabetes.

In summary, our results demonstrate the effectiveness of feature selection algorithms, with the RF algorithm standing out as a powerful tool for T2D prediction. The cost-effectiveness, efficiency, and accessibility of our proposed model present exciting opportunities for revolutionizing healthcare and fostering the development of smart healthcare systems.

tems.

## V. CONCLUSION

Our research on early detection of Type 2 Diabetes Mellitus (T2DM) using machine learning classification has yielded significant findings. By employing feature selection techniques and effective data management, we have developed an innovative model for diagnosing diabetes at its early stages. The combination of various feature selection methods with machine learning algorithms has proven to be highly effective in predicting the presence of T2DM, with the Random Forest algorithm achieving an impressive accuracy of 98%. This research highlights the importance of early identification of diabetes due to its widespread prevalence and impact on individuals' health. Furthermore, the application of machine learning classification in the healthcare sector not only facilitates more efficient decision-making but also lowers the cost of diagnosis, making it more accessible to a broader population. Our contribution lies in the significance of feature selection and appropriate data management techniques, which greatly improve the predictive power of the model. However, further validation is necessary through larger sample sizes and diverse populations to ensure the model's robustness and generalizability. Future research should explore the impact of variables such as body size, height, and body mass index (BMI) in the early identification of diabetes, potentially enhancing the accuracy of the diagnostic model. Continued advancements in machine learning algorithms and refinement of the feature selection process can further enhance the model's performance and applicability. Overall, our study demonstrates the promising potential of machine learning classification with feature selection in early T2DM detection, aiding in better management and prevention of this prevalent disease.

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# A Novel Classification Approach for Grape Leaf Disease Detection Based on Different Attention Deep Learning Techniques

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**Abstract**—Preventing and controlling grape diseases is essential for a good grape harvest. With the help of “single shot multi-box detectors”, “faster region based convolutional neural networks”, & “You only look once-X,” the study improved grape leaf disease detection accuracy with effective attention mechanisms, which includes convolutional block attention module, squeeze & excitation networks, & efficient channel attention. The various attention techniques helped to emphasize important features while reducing the impact of irrelevant ones, which ultimately improved the precision of the models and allowed for real-time performance. As a result of examining the optimal models from the three types, it was found that the Faster (R-CNN) model had a lower precision value, while You only look once-X and SSD with various attention techniques required the fewest parameters with the highest precision, with the best real-time performance. In addition to providing insights into grape diseases & symptoms in automated agricultural production, this study provided valuable insights into grape leaf disease detection.

**Keywords**—Grape leaves; faster region-based convolutional neural networks; you only look once (x); single shot detection attention techniques

## I. INTRODUCTION

Preventing and controlling crop diseases is crucial for producing safe and healthy vegetables, minimizing losses, and reducing the use of pesticides in the production of crops [1]. Thus, early detection & prevention of diseases are crucial. Grape plants can be affected by various diseases, such as powdery mildew, brown blotch, and anthracnose, which can significantly impact the yield and quality of the fruit. Traditional methods of detecting grape diseases rely on the experience of the growers or the guidance of experts, which can be slow, inefficient, and lack real-time performance. Images of grape leaves are used to detect, identify, and provide guidance about diseases infected with grape leaves [2] because disease-infected grape leaves often have visible spots.

Grape leaf disease detection is crucial for several reasons. Firstly, it allows growers to monitor the health of their grapevines and take appropriate actions to prevent or

manage diseases effectively. Early detection enables timely interventions, minimizing potential damage and crop losses. Different grape leaf diseases require specific treatments, and accurate identification helps growers implement targeted control measures. This optimizes the use of pesticides, reduces environmental impact, and ensures effective disease management.

Grape leaf diseases can significantly impact the yield and quality of grapevine production. Some diseases cause defoliation, reducing the vine’s ability to photosynthesize and produce energy, leading to decreased fruit quality, delayed ripening, and reduced yield. Early disease detection enables growers to protect the crop and implement measures to minimize yield losses. Early identification of grape leaf diseases is essential for preventing their spread within vineyards. Prompt isolation and treatment of infected vines help prevent diseases from affecting healthy plants. Additionally, preventive measures such as pruning, canopy management, and cultural practices can be implemented to reduce the likelihood of disease occurrence and spread. Economically, grapevines are valuable crops, and detecting diseases in grape leaves allows growers to make informed decisions on disease management, optimizing resource utilization, and reducing unnecessary costs. This helps preserve the economic viability of vineyards and sustain profitability in grape production.

Efficient disease detection and management practices also contribute to sustainable agriculture. Early identification minimizes the use of broad-spectrum pesticides, reducing their negative impact on the environment and non-target organisms. Targeted treatments based on accurate disease detection help reduce chemical inputs, promote ecological balance, and support sustainable cultivation practices for grapevines. In summary, grape leaf disease detection is vital for crop health monitoring, disease management, yield protection, disease prevention, economic considerations, and sustainable agriculture. Early detection allows for timely interventions, optimization of disease control measures, minimization of crop losses, and the long-term sustainability of grapevine production.

Due to the rapid development of artificial intelligence technologies, a wide variety of vision approaches are utilised in the processing of photos for various crop diseases [3][4][5]. Research into classifying agricultural diseases uses a wide range of approaches, including “genetic algorithms” [6], “support vector machines” [7], “K-means clustering” [8], “ensemble learning” [9], “Bayesian classification” [10], “radial basis functions” [11], & “filter segmentation” techniques [12]. Unfortunately, conventional approaches to crop disease classification and identification rely on labour-intensive, environment-dependent manual feature selection. In particular, the development of deep learning’s Convolutional Neural Network (CNN) has led to vast improvements in the field of autonomous detection and identification of agricultural diseases.

An object detection system that uses a convolutional neural network (CNN) has made great strides recently. Several applications make use of this technique, including recognition of faces [13], navigation [14], detection of road obstacles [15], detection of pedestrians, abnormal activity recognition [16], monitoring of physical activity [17][?], [18] detection of fruits, and detection of weeds [19]. Despite complex backdrops, crop leaf diseases can be detected using object detection algorithms due to CNN’s ability to extract high-dimensional properties from object images.

As a result, scientists in China and others have studied object detection algorithms to develop models for detecting crop diseases. For instance, Some authors have applied various models for object detection to the tomato disease dataset, including the Faster(R-CNN), and the Single Shot Multibox Detector. Faster (R-CNN) as well as VGG16, produced the best disease detection results. Dynamic identification of grape leaf illnesses was accomplished by using Faster (R-CNN) on time-series images of grape leaves. Using an enhanced Faster (R-CNN) model, the authors of [20] detected diseases in bitter melon leaves with excellent results. Using an in-house dataset, The authors of [21] trained the SSD model to identify agricultural diseases with an overall accuracy of 83.90%. An enhanced model based on MobileNetv2 & YOLOv3 was proposed by the authors [22], which allowed for the early detection of grey speck disease in tomatoes. This refined model benefits from a number of desirable characteristics, including a low memory size, outstanding detection accuracy, and lightning-fast identification.

Previous studies have shown that using object detection technology to detect grape leaf diseases is feasible. Existing grape detector models, however, operate slowly and have low detection precision, which severely limits their application. This research included the attention methods of “convolutional block attention module,” “efficient channel attention,” & “squeeze & excitation attention” into the models of “Faster(R-CNN),” “SSD,” & “YOLO-X” to boost their accuracy and speed. The goal was to boost the feature extraction network’s efficiency and put more emphasis on health issues. Experiments were run on a plant village dataset of grape diseases, and the findings revealed that models based on diverse attention mechanisms, such as “Faster(R-CNN),” “SSD,” & “YOLO-X,” significantly improved detection accuracy and operation performance with only little parameter tweaks. The findings of this study can be used as a foundation for future work on grape disease control measures. The main objectives of the

paper are to enhance the accuracy and speed of grape leaf disease detection, improve the efficiency of feature extraction networks, validate the performance improvements on a grape disease dataset, and provide a foundation for future grape disease control measures.

However, the existing literature lacks research on incorporating attention mechanisms, such as the “convolutional block attention module,” “efficient channel attention,” and “squeeze & excitation attention,” into grape detector models like “Faster(R-CNN),” “SSD,” and “YOLO-X.” There is a gap in knowledge regarding the potential impact of attention mechanisms on improving detection accuracy and processing speed for grape leaf diseases. The main objectives of the paper are:

- Enhance the accuracy and speed of grape leaf disease detection: The purpose of this work is to enhance the efficiency of previously developed grape detection models by incorporating attention mechanisms such as “convolutional block attention module,” “efficient channel attention,” and “squeeze & excitation attention” into the models of “Faster(R-CNN),” “SSD,” and “YOLO-X.” The objective is to achieve higher detection accuracy and faster processing speeds, addressing the limitations of slow operation and low detection precision in existing models.
- Improve the efficiency of feature extraction networks: By integrating attention methods into the models, the paper aims to enhance the efficiency of the feature extraction networks. The attention mechanisms help to prioritize relevant features and emphasize health issues related to grape leaf diseases, leading to more effective and accurate detection.
- Validate the performance improvements on a grape disease dataset: The research conducts experiments using a dataset specifically focused on grape diseases. By evaluating the models based on diverse attention mechanisms, such as “Faster(R-CNN),” “SSD,” and “YOLO-X,” the paper aims to demonstrate significant improvements in detection accuracy and operation performance. The experiments involve minimal parameter tweaks, ensuring that the observed enhancements are primarily attributed to integrating attention mechanisms.
- Provide a foundation for future grape disease control measures: The findings of this study serve as a basis for future work on grape disease control measures. By demonstrating the effectiveness of attention mechanisms in improving detection accuracy and speed, the paper offers valuable insights and guidance for the development of advanced and efficient techniques for managing and controlling grape leaf diseases.

## II. RELATED WORK

Detecting plant diseases in a timely manner is crucial for effectively managing plant losses. However, relying on manual diagnosis by humans is a time-consuming process that is prone to errors and can be costly. To address these challenges, researchers have been actively exploring automated



techniques for disease detection and classification in plants. The utilization of automated equipment and methods has emerged as a promising approach for monitoring crop fields. In this section, we will delve into the specifics of computer vision methods employed to identify and diagnose diseases in plant leaves.

The authors of [23] conducted a study focusing on detecting black rot in grape leaves using a YOLOv3-SPP-based deep learning method. The researchers employed a combination of super-resolution image enhancement and convolutional neural network techniques to identify the disease in grape leaves. The initial step involved upsampling the input image through bilinear interpolation. After enhancement, the processed inputs were fed into the YOLOv3-spatial pyramid pooling model, resulting in a remarkable detection accuracy of 95.79%. However, when tested in real field conditions, the precision of this method dropped to 86.69%. In a separate study, The authors of [24] proposed a deep learning approach specifically for accurately detecting black rot spots on grape leaves. They employed the DeepLab V3+ model, which incorporates feature maps from different levels and utilizes ResNet 101 as the backbone network. The test results demonstrated that the improved DeepLab V3+ model outperformed conventional methods.

The authors of [25], [26] developed a novel support vector machine & image processing-enabled technique for identifying and categorizing grape leaf disease. The authors of [27] employed a CNN-SVM-based approach to classifying five different species of grapevine leaves. They utilized the MobileNetv2 CNN model for leaf-type classification. Initially, features were extracted from the pre-trained MobileNet2 logits layer, and classification was performed using SVM with various kernels. The Chi-squares method was applied for feature selection, resulting in an impressive classification accuracy of 97.60%. The use of feature selection techniques significantly contributed to the improved accuracy of classification.

The authors of [28] focused on detecting grape black measles disease. They utilized the ResNet-50-based DeepLabV3 segmentation model in combination with fuzzy logic to determine the severity of the disease. The input image provided region of interest features and the percentage of infections. A fuzzy rule-based reference system was developed based on each feature, which was then used to grade the grape disease. The grading system allowed for the classification of healthy, mild, medium, and severe cases, specifically for measles disease.

### III. MATERIALS AND METHODS

#### A. Image Acquisition

The plant-Village dataset provides 4,062 images of grape leaves displaying common symptoms. In this dataset, 1,180 images were found to be affected by Black Rot, 1,383 by Esca measles, 1,076 by Leaf spot, and 423 by healthy leaves, all with a resolution of  $256 \times 256$  pixels. A leaf with black rot, a leaf with black measles, a leaf with blight, and a healthy leaf is displayed in Fig. 1.

The data set contains varying quantities of images for each category, indicating significant imbalances. Esca is the most

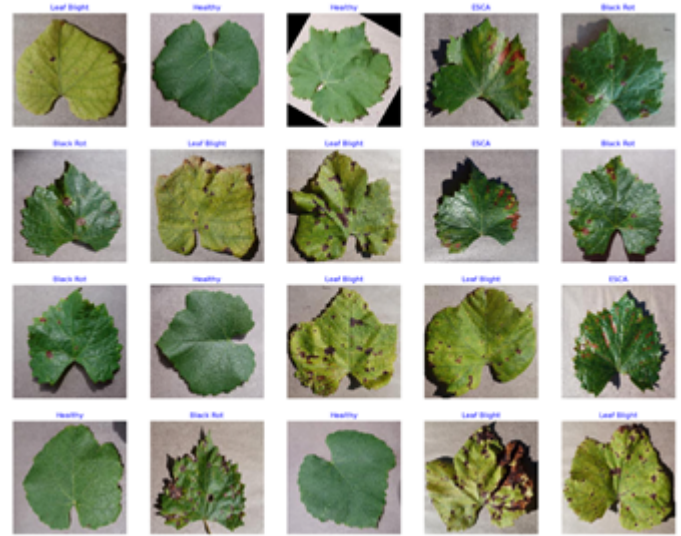


Fig. 1. Sample images from dataset.

TABLE I. LIST OF PARAMETERS USED FOR IMAGE ENHANCEMENT

Enhancement method	Parameters
gaussian filter	sigma-range(0.4,1.3)
mean filter	kernel-size-range(3,5)
median filter	kernel-size-range(2,5)
image acutance	alpha-range(0,0.2)
brightness	gamma(2.0)
contrast	alpha(1.0)

common classification, accounting for roughly 34% of the images, while Black Rot and Leaf Blight make up 29% and 26% respectively. There are also 1076 Healthy images and 10.4% Normal images in the collection.

#### B. Image Pre-processing and Augmentation

The size of the dataset must be increased by using data augmentation techniques in order to prepare grape leaves disease images for disease identification. Training the recognition model in this way ensures that it will be more resilient and can generalize more effectively. Using standard data augmentation methods, the experiment compared the effectiveness of the data augmentation method proposed in this study. The traditional methods included flipping the image horizontally and vertically, rotating the image, applying different types of filtering (Gaussian, mean, and median) with a probability of 0.2, enhancing image contrast, sharpening images with a probability of 0.3, and adjusting image brightness. According to Table I, the parameters used for each image enhancement method are listed. Table II provides more details about the dataset and can be accessed at <https://www.kaggle.com/datasets/rm1000/augmented-grape-disease-detection-dataset>.

#### C. Proposed Methodology for Grape Leaf Disease Detection

This study focuses on the detection of grape leaf diseases using three specific models: faster-rcnn, YOLOx, and SSD. The training process for these models to detect diseases in grape leaves is depicted in Fig. 2. The process begins with inputting

TABLE II. INFORMATION ABOUT THE DATASET

Class	No of images without augmentation	No of images with augmentation
Healthy	423	3000
Esca measles	1383	3000
Leaf spot	1076	3000
Black rot	1180	3000
Total	4062	12000

the selected grape leaf disease images. Next, classification features are extracted from the input images. Output is then derived from the findings of disease identification using the faster-rcnn, YOLOx, and SSD models.

A loss function is used throughout to quantify the degree to which the projected disease species deviates from the true disease species. This enables the models to learn and improve their detection accuracy over time. The optimization of the final output result is achieved through the utilization of the Adam optimizer, a widely used optimization algorithm in deep learning.

By following this approach, the study aims to leverage the capabilities of faster-rcnn, YOLO:x & SSD models to detect grape leaf diseases effectively. The training flow chart provides a systematic framework for the feature extraction and disease detection process, facilitating the accurate identification of different disease species in grape leaves.

#### D. Attention Mechanism Models

The study utilizes three attention mechanisms: “Squeeze & Excitation”, “efficient channel attention”, and “Convolutional Block Attention” spatial attention mechanism. We chose the SE attention mechanism because it is simple and adds only a few new parameters. With ECA attention, models become more accurate without significantly increasing model complexity. It is an enhanced version of the SE attention mechanism. Finally, the CBAM attention mechanism is useful because it connects the spatial domain and the channel domain, leading to more effective improvement in network performance.

1) *Squeeze & Excitation Attention*: In order to extract features, the SE channel attention mechanism employs the CNN channel. It requires re-calibrating features so that the model can pick up and remember relevant details from all of the available feature channels. Fig. 3 depicts the two steps involved in this mechanism: squeezing and excitement. After the feature image has been spatially compressed using the squeeze technique, the feature channel’s relative relevance can be determined using the excitation technique; a model is created based on the correlation between the channels. In doing so, the original feature images are excited into matching channels. The SE mechanism has few additional parameters and is computationally simple.

The “efficient channel attention” attention mechanism is utilized to enhance cross-channel interaction and reduce model complexity, while the Squeeze & Excitation attention mechanism is used to prioritize the most informative channel features for disease identification. For end-to-end training of the grape leaf disease detection model, the “Convolutional Block

Attention Module” attention mechanism is introduced to take into account the importance of pixels in different places. All three attention methods contribute significantly to improving the model’s efficiency and precision.

2) *ECA Attention Module*: It uses local cross channel interaction methods without reducing the magnitude of the dimensionality can be accomplished without using reduced-dimension SE. The functionality of the attention module is enhanced while its complexity is decreased thanks to this mechanism. In Fig. 4 we can observe the construction of the efficient channel attention mechanism.

3) *CBAM Attention Module*: The “CBAM Spatial Attention Module” is made up of 2 modules, first one is the “spatial attention module”, second one is the “channel attention module” and is designed to optimize input feature maps by inferring attention maps on both channel and spatial dimensions. These attention maps are then multiplied with the input feature map, resulting in self-adaptive feature optimization. The CBAM mechanism is effective in enhancing useful features while suppressing those that are not useful, making it a popular tool in practical applications. Fig. 5 illustrates the network structure of CBAM.

#### E. Decton Models for Disease Detection in Grape Leaves with Attention Mechanism

CNN-based object detection can be categorized into two main types. The first type uses a regional proposal to detect objects. This involves identifying candidate regions in the image, which are then divided to detect objects. This two-stage approach is exemplified by methods such as “R-CNN”, “Fast(R-CNN)”, & “Faster(R-CNN)”. The second type of object detection does not use a regional proposal and is referred to as one-stage object detection. An image is analyzed based on a CNN prediction of an object’s position & properties. There are a variety of algorithms available for this type of detection, such as SSDs and YOLOs.

The study used three models, namely the “Faster R-CNN model”, “YOLO-X model”, & “SSD model” for detecting grape leaves disease. The input of the selected grape leaf disease images, extraction of classification features, and use of the three disease detection models were involved in the process. The output was an analysis of the disease detection results. For optimizing the final output, an Adam optimizer was used to predict the difference between reality and the prediction of disease species.

Researchers found that the “Faster(R-CNN)” model boosts high detection accuracy and can detect targets end-to-end. However, its running speed is relatively slow. On the other hand, the “YOLO-X” model runs quickly, but it doesn’t detect small objects. The “SSD” technique has faster running speed and higher detection accuracy than the “YOLO-X” model, but its training process heavily relies on prior experience, and its performance in detecting small targets is not as good as the “Faster(R-CNN)” model. The characteristics of these models are elaborated as follows:

1) *Grape Leaves Disease Detection using Faster (R-CNN) Model*: This model is comprised of three main components: the “Extraction of features”, the “Region Proposal Network”

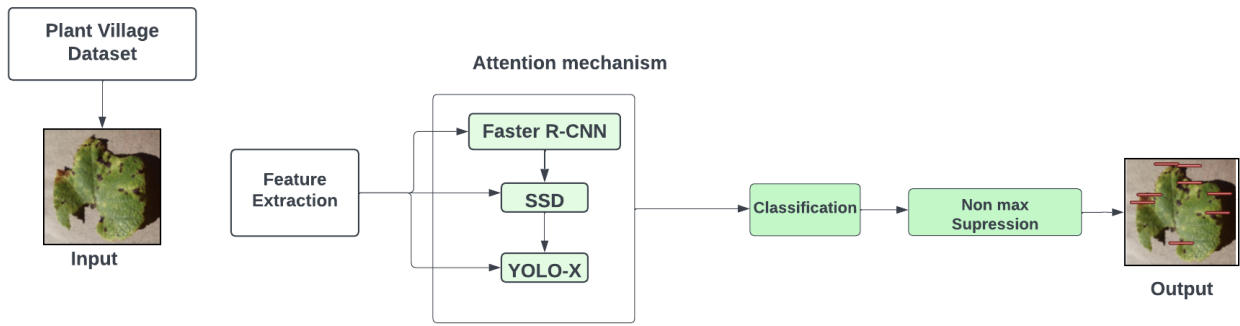


Fig. 2. Proposed attention model for grape disease detection.

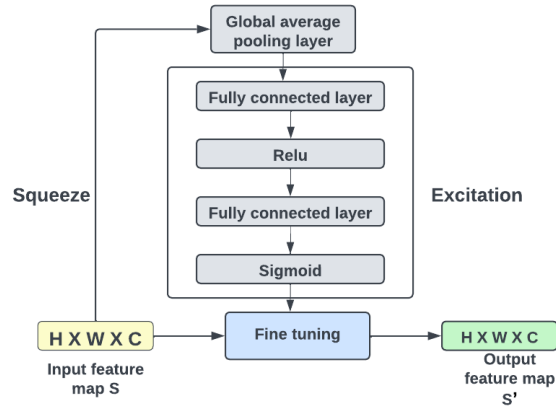


Fig. 3. SE attention mechanism.

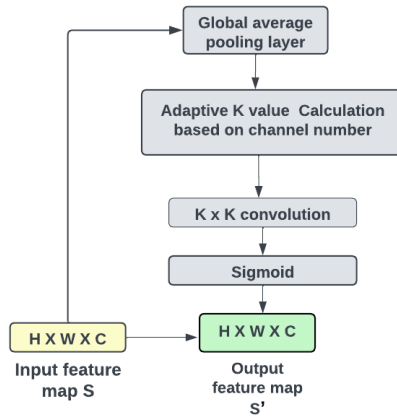


Fig. 4. ECA attention mechanism.

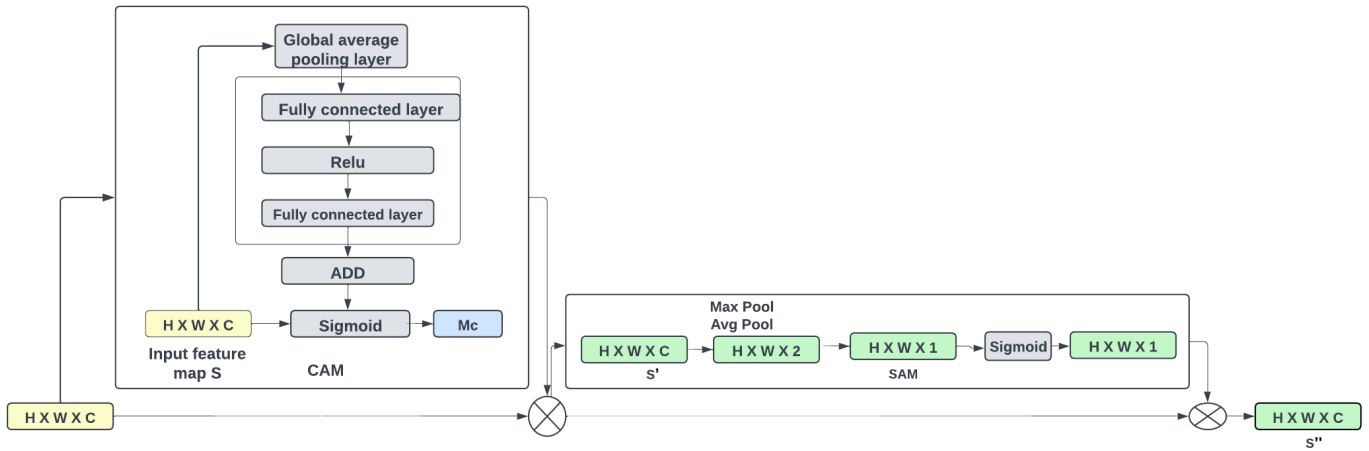


Fig. 5. CBAM attention mechanism.

, and the “Region with Convolutional Neural Network Features”. Fig. 6 depicts the Faster (R-CNN) model with attention techniques. A Faster (R-CNN) method is used to detect grape leaf diseases in four primary steps: generating candidate disease regions, extracting disease characteristics, categorizing the disease, and performing bounding box regression. The Faster (R-CNN) model utilizes convolutional neural networks for the extraction of features and then generates feature maps for corresponding images. However, the convolution kernel’s inherent locality means that only local information of disease images is retained, leading to information loss and reduced detection accuracy. To address this issue, the study introduced attention mechanisms, namely SE, ECA, and CBAM, without changing the feature extraction network’s structure or backbone features. As a result of forward propagation after the last identity block, these mechanisms were introduced to enhance the model.

2) *Grape Leaves Disease Detection using YOLO-X Model::*  
The YOLO-X with Darknet53 network is a model with high operational speed and flexibility. It includes four primary components: the input end, Backbone network, Neck, and Prediction. Fig. 7 illustrates the YOLO-X model based on various attention mechanisms. In the YOLO-X model, the YOLO Head has been changed to a decoupled head in the prediction section, the anchor-based approach has been replaced with an anchor-free method, and the SimOTA method has been introduced for dynamic matching with positive samples. The model’s detection accuracy and speed have both been enhanced by these revisions, and the models’ parameter sizes have been significantly decreased. The YOLO-X model is known for its high detection speed and precision, but it has some limitations when applied directly for disease detection in different environments. For instance, its backbone lacks the ability to extract features and integrate high-quality contextual feature information, leading to a reduction in the model’s detection precision. Therefore, in this study, the Darknet53 network structure of the YOLO-X model remained unchanged, allowing pre-training weights to be directly loaded into model training. The YOLO-X model can selectively strengthen key features while suppressing irrelevant ones based on the branches of the backbone network, namely “Darknet53”, “convolutional block

attention module”, “efficient channel attention” and “squeeze & excitation attention mechanisms.

3) *Grape Leaves Disease Detection using SSD Model::*  
Using a tiny convolution kernel and multi-dimensional feature prediction, the model combines the anchor mechanism of Faster (R-CNN) with the regression mechanism of “YOLO” for fast and accurate detection. Fig. 8 depicts the SSD model that includes attention mechanisms. The first component is an enhanced capability for disease detection based on the deep learning network model used to collect baseline disease features. The multi-scale feature detection network is the second part, and it uses cascaded-neural-networks to categorize features at various scales in order to learn about the disease’s category and location, as well as low-layer convolutional layer features to enhance detection precision and Non-Maximum suppression to generate the final detection results. Using a multi-dimensional prediction strategy, the SSD model is able to distinguish between small and large objects; the front-end deep-learning models are responsible for the former, while at the back-end multi-dimensional feature detection models handle them. Although the front-end network delivers precise coordinates and geometry, it has a limited range of perception and isn’t great at representing abstract concepts. Whereas the frontal network has a narrow receptive field and poor representational capacity for geometric data, the posterior network has a wide receptive field and excellent representational ability for semantic data. Because of this, the SSD model may overlook some diseases or incorrectly identify others. Six feature images of varying sizes were collected from the “SSD” model and supplied into the various attention modules in order to better represent critical feature information and identify disease object features. With this method, the SSD model is better able to recognize diseased items.

#### IV. RESULTS AND EXPERIMENTS

##### A. Evaluation Metrics

Results were evaluated based on standard measures for evaluating target detection. One class of targets will be evaluated using “Precision,” “Recall,” “Average Precision,” and

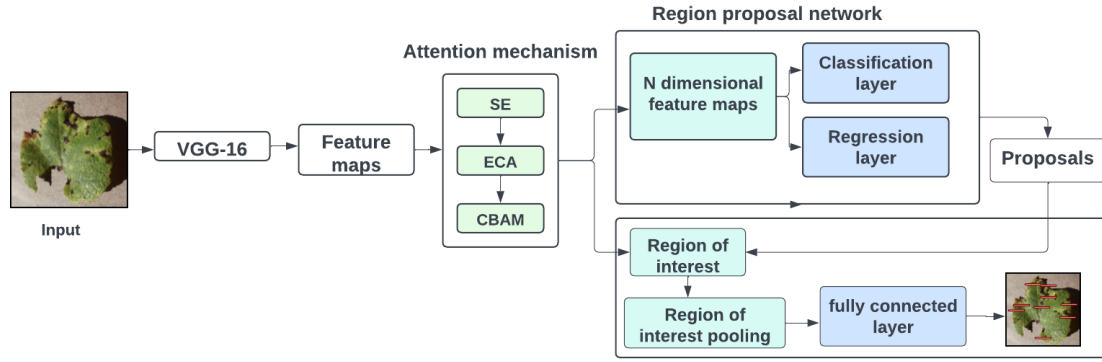


Fig. 6. Faster (R-CNN) model with attention techniques.

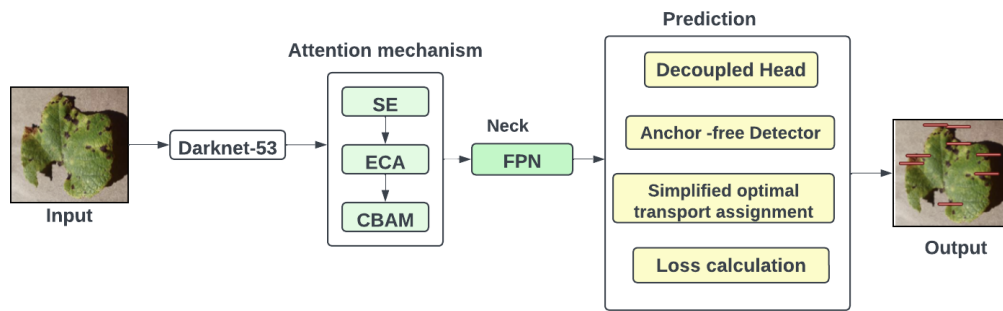


Fig. 7. YOLO-X model with attention mechanism.

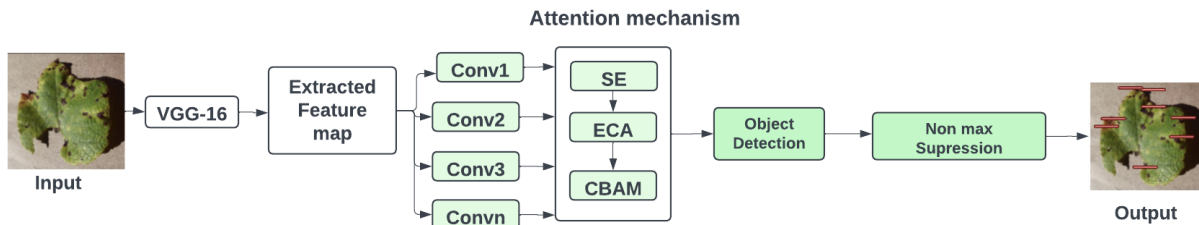


Fig. 8. SSD model with attention mechanism.

”Mean Average Precision,” while all targets will be evaluated using ”Mean Average Precision.” However, in this study, we evaluated the grape leaf disease detection model’s performance on a wider set of metrics, including the mean absolute percentage (mAP), the frame rate (FPS), the parameters, and the precision (P) and recall (R) values. The Eq. 1,2 and 3 were used to calculate P, R, and F1.

$$Precision = \frac{TruePositives}{TruePositives + FalsePositives} * 100 \quad (1)$$

$$Recall = \frac{(TruePositives)}{(TruePositives + FalseNegatives)} * 100 \quad (2)$$

$$F1score = \frac{(2 * Precision.Recall)}{(Precision + Recall)} \quad (3)$$

In Eq. 4, the variables P, TP, FP, R, FN, and F1 represent various metrics used to evaluate the performance of a model. P is the precision, which measures the percentage of correct positive predictions. The probability that grape disease leaves are accurately detected is denoted by true positives (’TP’), whereas the probability that they are mistakenly categorised as positive is denoted by false positives (’FP’). Recall, or the proportion of true positives that were correctly detected, is denoted by the letter R. The likelihood of mislabeling a positive sample as negative is known as the ”Fasle negatives” (’FN’) rate. F1 is a measure of accuracy that is the harmonic mean of two other metrics, recall and precision.

$$\int_0^1 PRdR \quad (4)$$

TABLE III. COMPARISON ANALYSIS OF FASTER (R-CNN) MODELS WITH DIFFERENT ATTENTION TECHNIQUES FOR DETECTING GRAPE DISEASES

Model	Precision	Recall	F1-Score	mAP
Faster (R-CNN) model	75.06	74.42	74.74	79.12
Faster (R-CNN) with SE Attention	79.80	84.23	81.96	85.39
Faster (R-CNN) with ECA Attention	76.54	78.71	77.61	81.93
Faster (R-CNN) with CBAM Attention	75.75	75.89	75.82	79.65
Faster (R-CNN) with SE, ECA,CBAM Attention	84.52	86.32	80.79	84.31

A higher value for TP indicates a more accurate prediction & better performance of the model. A model's performance can be measured using mAP, which is a metric that averages the average precision of all diseases. Eq. 5 defines mAP as the average of all AP values. FPS stands for the number of pictures handled each second. The algorithm's ability to recognize items improves as the FPS increases.

$$mAP = \frac{1}{N} \sum_{m=1}^N AP \quad (5)$$

A computer with 16 GB of RAM is used for this research, which runs Windows 10. Model parameters and hardware configuration are considered in Pytorch 1.10.1.

### B. Experiment Results and Analysis

The grape disease dataset was utilized to compare the Faster(R-CNN), YOLO-X, and SSD models with the classical versions based on different attention mechanisms. The models were all trained and detected with the same configuration information and training platform.

1) *Faster (R-CNN) Result Analysis:* The "Faster(R-CNN)" model can be combined with different attention mechanisms to create different versions. Also we have combined the three attention mechanisms i.e. Faster (R-CNN) with SE, ECA,CBAM Attention. To test their performance in detecting grape diseases, all these versions were used in the same experimental setup, and the results are presented in Table III and in Fig. 9. Table III presents a comparison between the Faster (R-CNN) model and four modified versions: "Faster (R-CNN) with SE Attention", "Faster (R-CNN) with ECA Attention", and "Faster (R-CNN) with CBAM Attention". The results indicate that the Faster (R-CNN) with SE Attention model outperformed the original model with an increase in P, R, and F1 values by 4.74%, 9.81%, and 7.22% respectively, and an increase in mAP by 6.27%. Similarly, the Faster (R-CNN) with ECA Attention model showed improvements over the original model with an increase in P, R, and F1 values by 1.48%, 4.29%, and 2.87% respectively, and an increase in mAP by 2.81%. Finally, the "Faster (R-CNN) with CBAM Attention" model showed slight improvements over the original model with an increase in P, R, and F1 values by 0.69%, 1.47%, and 1.08% respectively, and an increase in mAP by 0.53%.

Based on the analysis above, it is evident that the performance of Faster (R-CNN) improved after the inclusion of attention mechanisms, despite a slight increase in parameters for "Faster (R-CNN) with SE Attention and Faster (R-CNN) with CBAM Attention". Enhanced precision and accelerated

TABLE IV. COMPARISON ANALYSIS OF YOLO-X MODELS WITH DIFFERENT ATTENTION TECHNIQUES FOR DETECTING GRAPE DISEASES

Model	Precision	Recall	F1-Score	mAP
YOLO-X model	82.35	74.85	78.42	83.22
YOLO-X with SE Attention	82.46	82.21	82.33	84.02
YOLO-X with ECA Attention	87.77	86.07	86.91	88.66
YOLO-X with CBAM Attention	85.81	77.91	81.67	84.21
YOLO-X with SE, ECA,CBAM Attention	89.77	86.97	85.91	88.96

speed of detection are achieved through the attention mechanism for grape leaves images. Among the various models, "Faster (R-CNN) with SE, ECA, CBAM Attention" displayed the best detection effect when compared with "Faster (R-CNN) with SE Attention". The "Faster (R-CNN) with SE Attention" model demonstrated a 3.26%, 5.52%, and 4.35% increase in P, R, and F1 values, respectively, with an increase of 3.46% in mAP. In comparison with "Faster (R-CNN) with CBAM Attention", "Faster (R-CNN) with SE Attention" increased P, R, and F1 by respectively 4.05%, 8.34%, and 6.14%. When precision is considered, the "Faster (R-CNN) with SE, ECA, and CBAM Attention" model shows optimal results. It focuses on channel features with the most significant information while suppressing un-important features, making it ideal for detecting grape diseases in the dataset.

2) *YOLO-X Result Analysis:* The YOLO-X model has been enhanced with different attention mechanisms: SE, ECA, and CBAM. To compare their performance, all the models (including the original YOLO-X model) were tested on the dataset under the same configuration. The results are shown in Table IV and in Fig. 10. Table IV shows that the "YOLO-X with SE Attention" model has improved performance compared to the YOLO-X model. Specifically, the precision, recall, and F1 values of the "YOLO-X with SE Attention" model increased by 0.11 %, 7.36 %, and 3.91 %, respectively, while the mAP increased by 0.8%. Similarly, the "YOLO-X with ECA Attention" model also outperformed the YOLO-X model, with increases of 5.42%, 11.22%, and 8.49% in precision, recall, and F1 values, respectively. The mAP also increased by 5.44% respectively. The "YOLO-X with CBAM Attention" model also showed improvements, with increases of 3.46%, 3.06%, and 3.25% in precision, recall, and F1 values, respectively, and a 0.99% increase in mAP. Based on the analysis above, it was found that the detection performance of the YOLO-X model was improved with the introduction of attention mechanisms, despite a slight increase in the parameters of the "YOLO-X with SE Attention" and "YOLO-X with ECA Attention" models. Models were able to identify disease objects more accurately due to the attention mechanisms that allowed them to extract more comprehensive and rich features. Out of all the models, the "YOLO-X with SE, ECA,CBAM Attention" model had the best detection performance. Compared to the "YOLO-X with SE Attention" model, the "YOLO-X with ECA Attention" model had a 5.31%, 3.86%, and 4.58% increase in P, R, and F1 values, respectively, a 4.64% increase in mAP, a 4.8 increase in FPS value, and a 0.49 MB expansion in parameters. Compared to the "YOLO-X with CBAM Attention" model, the "YOLO-X with ECA Attention" model had a 1.96%, 8.16%, and 5.24% increase in P, R, and F1 values, respectively, a 4.45% increase in mAP, a 1.8 increase in FPS value, and a 0.66 MB expansion in parameters. Compared to other models YOLO-X with SE, ECA,CBAM Attention



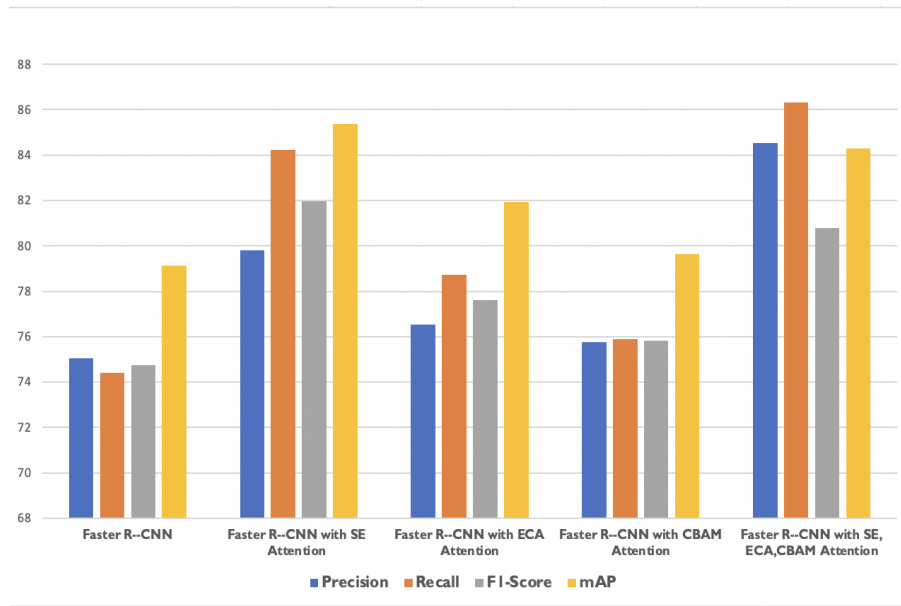


Fig. 9. Comparison analysis of Faster (R-CNN) models with different attention techniques.

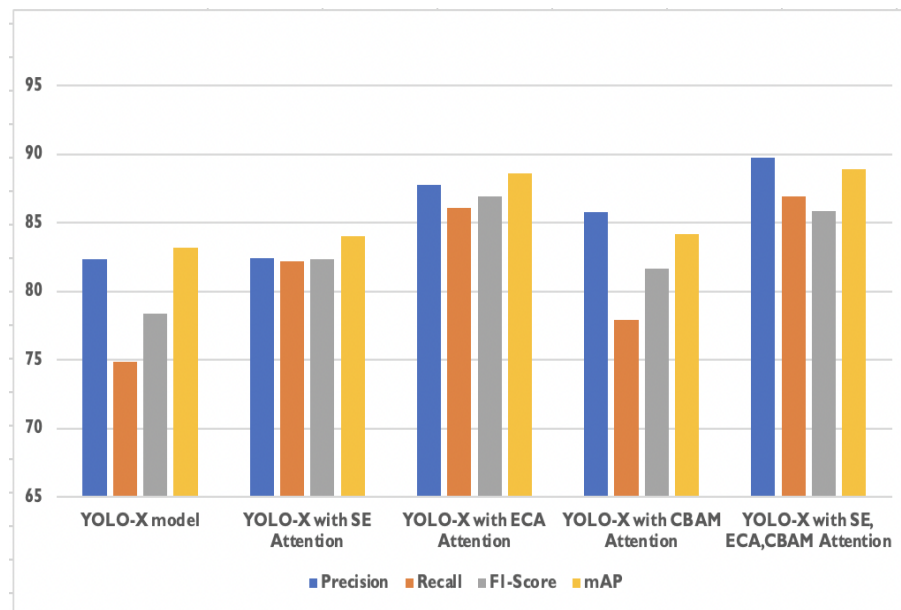


Fig. 10. Comparison analysis of YOLO-X models with different attention techniques.

models had outperformed than previous models. In conclusion, even though the “YOLO-X with SE, ECA, CBAM Attention” model had more parameters than the other three models, it achieved the best detection results with fast operation speed on the grape disease dataset, partially due to its ability to achieve cross-channel interaction.

3) *SSD Result Analysis*: Under the same experimental conditions, all the models were utilized to detect diseases on the plant village dataset, & the results of the experiment can be found in Table V and in Fig. 11.

Table V displays the results of various different models. The comparison is based on various metrics, including precision (P), recall (R), and F1 values, mean average precision (mAP).

Compared to the SSD model, the SSD with SE Attention model showed significant improvements in P, R, and F1 values by 2.72%, 15.23%, and 9.45%, respectively.

The SSD with ECA Attention model also showed improvements over the SSD model, but to a lesser degree. A relative increase of 1.35%, 8.77%, and 5.47% in P, R, and F1 values was experienced, while a relative increase of 6.67% was seen in mAP.

The SSD with CBAM Attention model showed the smallest improvements over the SSD model. There is an increase of 0.94 %, 3.61 %, and 2.48 % in P, R, and F1 values, respectively, as well as a 4.91% increase in mAP and a

TABLE V. COMPARISON ANALYSIS OF SSD MODELS WITH DIFFERENT ATTENTION TECHNIQUES FOR DETECTING GRAPE DISEASES

Model	Precision	Recall	F1-Score	mAP
SSD model	80.74	68.87	74.33	76.23
SSD with SE Attention	83.46	84.10	83.78	86.96
SSD with ECA Attention	82.09	77.64	79.80	82.90
SSD with CBAM Attention	81.68	72.48	76.81	81.14
SSD with SE, ECA, CBAM Attention	85.46	84.90	84.78	83.96

3.38 MB increase in the model parameters. "SSD with SE Attention", "SSD with ECA Attention", and "SSD with CBAM Attention" models were all enhanced by the incorporation of attention modules in the network architecture. However, the three models were able to effectively identify important information in feature images while filtering out irrelevant information based on feature importance. As a result, the detection performance of the three attention mechanisms with SSD was superior to that of the SSD model.

We have applied the different attention mechanism but, the "SSD with SE, ECA, CBAM Attention model" demonstrated the best detection performance with significantly faster real-time processing than the other three models. Compared to the "SSD with ECA Attention" model, the "SSD with SE Attention" model showed a 1.37%, 6.46%, and 3.98% improvement in P, R, & F1 values, respectively. Compared to the "SSD with CBAM Attention" model, the "SSD with SE Attention" model showed a 1.78%, 11.62%, and 6.97% improvement in P, R, and F1 values, respectively.

These experimental results demonstrate that the SE attention mechanism optimized feature images, resulting in significantly better detection performance and real-time processing compared to the other three models. Therefore, the "SSD with SE, ECA, CBAM Attention" model can be effectively applied in the detection of various grape diseases with superior comprehensive performance.

4) *Comparison Analysis* : After screening, the three optimal disease detection models were compared to present their disease detection performance. The analysis above showed that "Faster(R-CNN)", "YOLO-X", and "SSD" models when combined with multiple attention mechanisms were the optimal models of their respective detection methods. Fastest R-CNN models exhibited the lowest overall detection accuracy, the slowest operating speed, and the most parameters. The "SSD" models' rapid operation speed and great accuracy made them ideal for near-instantaneous disease diagnosis in vineyards. Strong robustness was demonstrated by the "YOLO-X" models, which achieved the maximum detection precision with the fewest parameters and performed well while identifying both small objects and items hidden by background clutter.

## V. CONCLUSION

After initial screening, three top disease detection models were selected and their performance was compared. The results of the foregoing investigation demonstrated that the "Faster(R-CNN)", "YOLO-X", and "SSD" models, when enhanced with numerous attention mechanisms, provided the most accurate detection results. Overall, "Faster (R-CNN)" models exhibited the lowest detection precision, the slowest operating speed, and the most parameters of the three types of models. Due to its excellent accuracy and quick processing speed, the

"SSD" model was found to be ideal for monitoring field grapes in real time. The "YOLO-X" models demonstrated the highest detection accuracy with the fewest parameters, and they performed well while recognising both small objects and items that were partially obscured.

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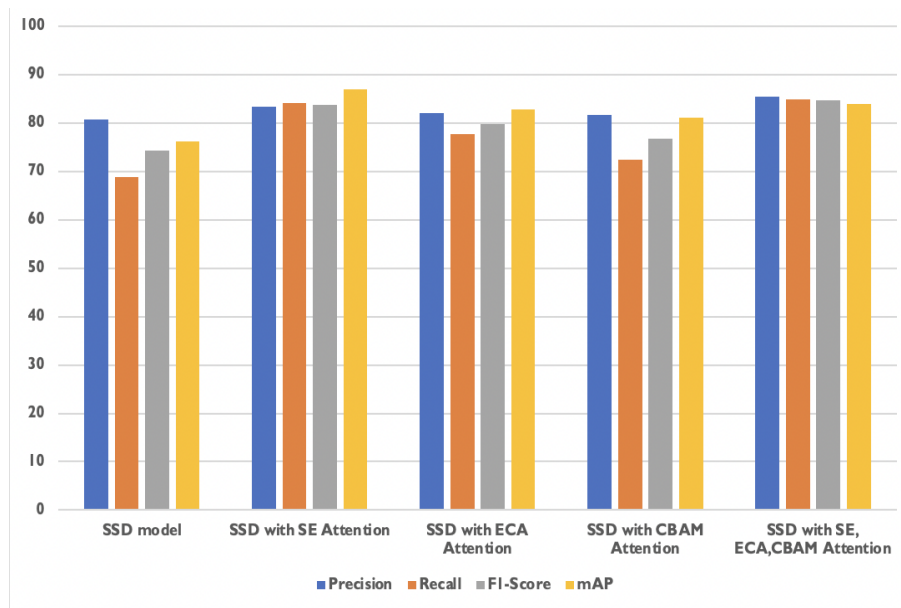


Fig. 11. Comparison analysis of SSD models with different attention techniques.

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# Predicting At-Risk Students' Performance Based on LMS Activity using Deep Learning

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**Abstract**—It is of great importance for Higher Education (HE) institutions to continuously work on detecting at-risk students based on their performance during their academic journey with the purpose of supporting their success and academic advancement. This is where Learning Analytics (LA) representing learners' behaviour inside the Learning Management Systems (LMS), Educational Data Mining (EDM), and Deep Learning (DL) techniques come into play as an academic sustainable pipeline, which can be used to extract meaningful predictions of the learners' future performance based on their online activity. Thus, the aim of this study is to implement a supervised learning approach which utilizes three artificial neural networks (vRNN, LSTM, and GRU) to develop models that can classify students' final grade as Pass or Fail based on a number of LMS activity indicators; more precisely, detect failed students who are actually the ones susceptible to risk. The three models alongside a baseline MLP classifier have been trained on two datasets (ELIA 101-1, and ELIA 101-2) illustrating the LMS activity and final assessment grade of 3529 students who enrolled in an English Foundation-Year course (ELIA 101) taught at King Abdulaziz University (KAU) during the first and second semesters of 2021. Results indicate that though all of the three DL models performed better than the MLP baseline, the GRU model achieved the highest classification accuracy on both datasets: 93.65% and 98.90%, respectively. As regards predicting at-risk students, all of the three DL models achieved an = 81% Recall values, with notable variation of performance depending on the dataset, the highest being the GRU on the ELIA 101-2.

**Keywords**—Predict at-risk student; artificial neural network; learning management system; and educational data mining

## I. INTRODUCTION

Educational Data Mining (EDM) is currently an exciting field of Data Mining (DM) which deals with investigating Educational Big Data and Learning Analytics (LA) with the purpose of conceptualizing models that can be effectively used in enriching the learners' experiences and augmenting educational institutions' academic offerings and efficiency. Traditionally, EDM applies DM, Machine Learning (ML), and statistical methods to identify patterns in large educational data [1]. Many researchers established the effectiveness of using DM techniques in the educational field, especially, in domains that are crucial to learners' progress, engagement and performance [2] [3].

The previously cited metrics of the students' learning journey, and others, are closely connected to how decision-makers and educators are preoccupied with proactively identifying at-risk students based on their behaviours and performance in educational environments. Currently, EDM, in combination with ML and Deep Learning (DL) techniques have greatly

impacted academic decision-making in terms of robustness, accuracy, and sustainability because mining LA to discover information about students' learning have led to many preemptive measures that support learners' success and advancement [4] [5].

In E-learning environments, LA is oftentimes representative of a user's behaviour inside an institutional Learning Management System (LMS). Theoretically, and in educational contexts, users' behaviour denotes the interactions performed by users inside a website, a mobile app, or a system which can be monitored through analytics tools. The detection of a user's behaviour is often dependent on features which demonstrate the amount, continuation, and emphasis of user activities [6]. These behaviours are significant factors in the evaluation of why a certain user interacts with the system in a specific way, how to proactively predict these behaviours; consequently, detect their impact on the endpoint of the process. In an educational setting, students' behaviour data represent the activities and learning interactions; ideally, within an E-learning platform such an LMS, where there are tools that can help in collecting and storing such data for further analysis. The features of this data can be, for example, course accesses, submissions, clickstream, time-series data, videos, lectures, assessments, discussion forums, and even live video discussions through the internet [7]. The features of this data are usually analysed to predict students' academic achievement, develop recommendation systems, analyse students' behaviour, re-design courses, and identify at-risk students.

Using LA with a combination of EDM, ML and DL to detect at-risk students in Higher Education (HE) Institutions has become the focus of contemporary research, where identifying at-risk learners is often, if not always, associated with demographic, social, psychological, or cultural factors both inside and outside the institution and their impact on final grades in courses and GPAs, or outcomes in programs [8] [9]. Attention to LA is, as well, crucial to a rounded understanding of learners who are susceptible to risk. Since the early 2000s, we discern a change in demarcating the scope of at-risk students, which is motivated by the mainstream use of online environments where LA has become another indicator of learners' behavioural activity in educational settings, as well as the possibility of utilizing ML, generally EDM, techniques to determine risk factors and outcomes [10]. We observe, however, the scarcity of research that addresses practical methods for detecting at-risk students based on DL algorithms in HE contexts.

The current study is primarily motivated by the need for prior discovery of at-risk students through examining their user behaviour in an online learning offering during COVID-

19 in King Abdullaziz University (KAU), which is originally delivered in the same format even before the transformation to Distance Education throughout the pandemic lockdown. The ELIA 101 course is designed and taught in a blended format to Foundation-Year students in KAU including a number of assessments that are submitted via the official LMS, Blackboard. The ultimate aim of at-risk learners' identification is to improve their performance by giving them the opportunity to enhance their achievement and avoid dropout or being academically dismissed from the programs. We assume that, based on the automated predictive modelling of Foundation-Year students' online interactions data, KAU can progressively improve the engagement of low-performing learners, predict students' final grade indicative of their Pass/Fail performance, and prevent their dropout from the course.

Therefore, the aim of this study is to 1) create two datasets which represent the main features of assessment design in ELIA 101 alongside other meaningful online activity attributes, 2) develop three Artificial Neural Networks models that classify students based on their final grade; consequently, detect at-risk students enrolled in the ELIA 101 English course, and 3) evaluate the performance of the models focusing on their accuracy and effectiveness. Generally, we will be investigating answers to the following research questions:

- 1) Which DL network achieves the highest accuracy in detecting students' at-risk status (Fail)?
- 2) Which DL network achieves the highest accuracy in classifying students Pass/ Fail status in the course?

Ideally, this study's contributions can be outlined as follows:

- The collection and pre-processing of two datasets for training the at-risk students prediction models.
- The development of three neural networks, i.e., vanilla Recurrent Neural Network (vRNN), Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), to predict at-risk students in ELIA 101 Foundation-Year English course at KAU.

The rest of this paper is organized as follows: Section II is a literature review of ML and DL methods used in students' performance, and at-risk status prediction. Section III, describes the research methodology. Section IV, presents the findings, discussion and limitations of our research. Section VI, is the conclusion with reference to future work.

## II. REVIEW OF LITERATURE

Predicting students' final grade (including the identification of their at-risk status) is representative of their course performance, and help academic institutions support their students' success, as well as encourage learners to change their study patterns and get better grades.

From an ML perspective, there has been numerous research which experimented with various techniques to predict learners' final grade, and detect their at-risk status using supervised learning methods with a specific implementation of binary classification. Among the studies which considers ML methods is Macarini in which thirteen datasets have been created from 89 students' activity on the Moodle LMS. The

classification algorithms used to classify these datasets are K-Nearest Neighbors (K-NN), Multilayer Perceptron (MLP), Random Forest (RF), AdaBoost, and Naive Bayes. Results show that a combination of the AdaBoost with dataset2 and dataset5 have performed better than the rest of the models [11].

Similarly, Kumari, assessed the behavioural features which could be effective in enhancing students' performance. The data is collected from the LMS for 500 students using the experience API (xAPI). Their model utilized ML algorithms like Iterative Dichotomiser 3 (ID3), K-NN, naive Bayes, Support Vector Machine (SVM). The algorithms have been implemented on the Waikato Environment for Knowledge Analysis (WEKA), where the ID3 achieved a higher accuracy than the other methods (=90%) [12].

Besides, Karthikeyan have assessed students' performance by proposing a Hybrid Educational Data Mining (HEDM) model. This model combines the effectiveness of naive Bayes and the J48 Classifier classification technique. The model has been tested against an online dataset and achieved an 98% accuracy [13].

The investigation of at-risk students' activity metrics and impact on their final grade have been also studied with a combination of ML and basic DL techniques like ANNs. ML and DL algorithms have been developed in Howard, on a dataset consisting of 136 students' LMS activity, the researchers implemented RF; XGBoost; Bayesian Additive Regression Trees (BART); Principal Components Regression (PCR); SVM; Multivariate Adaptive Regression Splines (MARS); neural network; and K-NN. They used the actual final grade as the main variable to which they compared the predicted one. The Mean Absolute Error (MAE) was calculated; and they reported that PCR had the lowest MAE value 6.5. The researchers found that the best time to expect at-risk students was during weeks 5/6 [14].

In Hung the data representing 12,869 students has been collected from a K-12 virtual school in the northern USA. The algorithms used for the model are SVM with the sigmoid kernel, SVM with polynomial kernel, SVM with gaussian radial basis function, RF, and ANN. The DL model achieves better performance than the ML ones by correctly identifying 51% of at-risk students with 86% accuracy [15].

Besides, Altabrawee, utilizes both ML and DL models to predict students' performance in a computer science subject at Al-Muthanna University, which is tested on data representing the user behaviour of 161 students. The researchers design an ANN, Naïve Bayes, decision tree, and logistic regression models. As indicated by results, the ANN model achieved a 77% accuracy, higher than the other models [16].

The early at-risk detection of students' performance enables them to improve their learning strategies. For example, Sultana, develop models to warn learners who have low performance issues based on their cognitive and non-cognitive competences to decrease their dropout. The non-cognitive features include: Time-management, Self-concept, Realistic-Self-appraisal, and Community support. The dataset used in this research represent the user activities of 778 students collected from different universities and online repositories. The researchers have applied logistic regression, decision tree,

naive Bayes, and an ANN. Results indicate that certain combinations of cognitive and non-cognitive features improved the model performance. For example, a combination of cognitive features, Leadership and Realistic-Self-appraisal data trained with a naive Bayes model has resulted in the highest accuracy value, 65%. Similar cognitive, non-cognitive combinations have achieved the same accuracy with the naive Bayes model as well [17].

With a specific focus on DL methods, Aydođdu uses an ANN for student final performance prediction. The dataset, used in this research, comes from the activity stream of 3518 students. The model achieves an accuracy of 80% [18]. In the same manner, the researchers in Hussain, design a method to predict students' results, which is tested on a dataset representing the user behaviour of 10140 students. The results demonstrate the effectiveness of the RNN which achieves an accuracy of 95% [19]. Utilizing an RNN as well, He, proposed a novel joint RNN-GRU neural networks that predicts at-risk students using OULAD. Three algorithms are considered as baseline models: vRNN, GRU, and LSTM. The findings show that simple techniques such as GRU and vRNN have better outcomes than the relatively complex model of LSTM. The joint model successfully predicted at-risk students at the end of the semester and obtained over 80% accuracy [7].

Prior studies examining student behavior mainly on an online or MOOC dataset, this study uses real students' datasets from the Blackboard LMS, the adopted LMS in most Saudi higher education institutions.

Moreover, the extracted LA data in the rest of the studies, which use a real student's dataset, is for a limited number of students except in [19], which has 10,140 learners. This study worked with two datasets created from data values representing 3,529 learners.

Therefore, this study extends previous research by providing an effective solution for predicting students' pass/ fail status and identifying at-risk students (fail) by implementing DL models based on individual student behavior in LMS.

### III. METHODOLOGY

The methodology adopted for this research consists of four key phases: data collection, data pre-processing, development of prediction models, and evaluation (see Fig. 1).



Fig. 1. Methodology pipeline.

More specifically, the process of the proposed models' pipeline could be illustrated in Fig. 2.

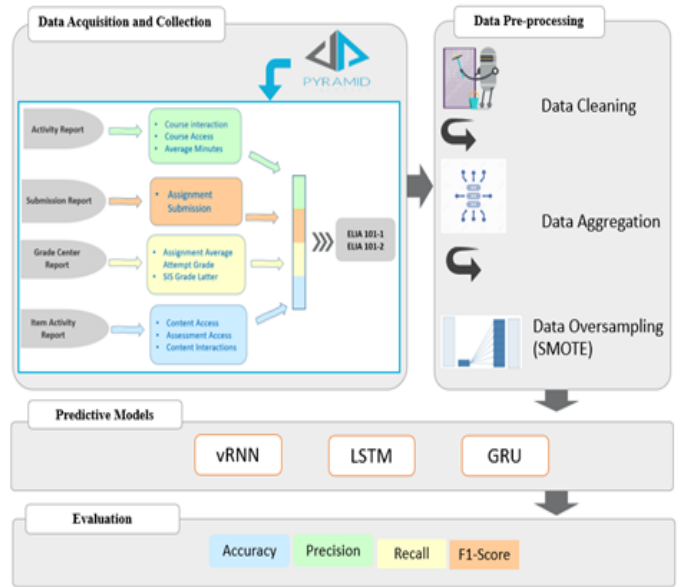


Fig. 2. The proposed models' pipeline.

#### A. Data Collection

The datasets used in this study are retrieved via a collaboration with the Deanship of E-Learning and Distance Education at KAU using the official Learning Analytics system, A4L which supports the Blackboard LMS. This service facilitates the extraction of big educational data; specifically, in our case, detailed reports on students' course activity (overall interactions), submissions, grade centre assessments, and activity on item level alongside their final grade in the course.

The A4L system has two interfaces, one for the institution and the other is user-centric, accessible via the LMS.

1) *The Institution Interface:* A4L records and displays students' LMS behaviour and interactions sliced by multiple data dimensions. Data measures in the form of frequencies, averages, and percentages can be extracted. Examples of dimensions include: Course, Advisor, SIS Major, SIS Student College, SIS Student Level, Student Risk Profile, Term, Time Series, etc. Examples of measures are Items Accessed, Assessments Accessed, Course Accessed, Content Accessed, etc.

2) *The User Interface:* Both instructors and students have a view-only permission to the A4L reports, which allow them to compare their performance to other users and follow their progress.

From the A4L solution described above, two datasets have been extracted. Both datasets are comprised of a total of 3529 students' activity data from an English Foundation-Year course (ELIA 101), which is delivered during the first and second semesters of 2021. The first dataset (ELIA 101-1) is from the Spring term run of (ELIA 101) and consists of 75,971 records representing (2386) students. (2322) of those students passed the course, whereas (64) of them failed. The second dataset (ELIA 101-2) is the Fall run of the (ELIA 101) course and included 26,291 records of 1,143 students. 1,137 of those students passed the course, and 6 of them failed.



TABLE I. DATASETS STRUCTURE

User Id	Assessment Access	Content Access	Course Access	Course Interactions	Course Item Interactions	Avg. Minutes	Assignment Submission Count	Assignment Attempt Grade
STD_1	0	3	2	4	3	117.717	1	100
STD_1	6	1	2	87	7	63.3	1	100
STD_1	3	12	3	96	16	74.367	1	100
STD_1	0	1	1	10	1	209.05	1	100
STD_1	0	0	1	1	0	0.217	1	100

TABLE II. FEATURES DESCRIPTION

Reports	Features	Description
Activity	Course_Access	A count of students' access per the course.
	Course_Interactions	A count of students' interactions per the course.
	Avg_Minutes	Average minutes that the students spent per course
Submission	Assignment_Submission	A count of students' submissions per a specific assignment.
Grade Center	Assignment_Avg_Attempt_Grade	Average students' grade per a specific assignment.
	SIS_Grade_Letter	Corresponding final course grade for the students.
Item Activity	Assessment_Access	A count of students' access per a specific assessment.
	Content_Access	A count of students' access per a specific content.
	Course_Item_Interactions	A count of students' interactions per a specific item.

Ideally, this course is delivered, at least, twice a year. The dataset is basically extracted as a report made up of several online activity indicators. Both datasets included 9 students' activity metrics as shown in Table I. The description of these metrics is listed in Table II.

The following inclusion and exclusion criterion for dataset creation have been observed and implemented:

1) Inclusion criterion:

- The extracted reports included features (measures) representative of 1) the basic elements of instructional design, specifically, assessments and engagement indicators like interaction, as well as, 2) potential risk factors, which might have an impact on the instructional context of ELIA 101 as delivered in the English Language Institute in KAU, where, for example, assignments are delivered weekly via Blackboard as per required by the official Course Specification for this course [20]. Other assessment types like a Final Speaking Exam and a Final Writing Exam are used but are summative assessment tools like the Final Exam, and what we are interested in are formative assessments conducted during the semester. According to the instructional strategy of the course, forums and other collaborative tools are not used as assessment methods, henceforward, data related to them are not included [20].
- Comparability is ensured through extracting data about a definable student cohort (Foundation-year students enrolled in the English Course, ELIA 101).
- The data was extracted from both course and students' perspectives for 3529 students.
- The researchers verified that the course included actual activities so that the extracted reports reflect actual user behaviour.
- Extracted reports coverage is of the first and second semesters of 2021, where KAU migrated to the online learning platform to ensure the continuity of its academic offering during the COVID-19 lockdown.

2) Exclusion criterion:

- Measures which relate to logins were excluded, because they display data representative of all the courses a student is enrolled in, not just ELIA 101.
- Measures which perform complex statistical operations on the data (change rate, moving averages) were as well not considered.

B. Data Pre-processing

1) *Data Cleaning*: Data cleaning is a data pre-processing technique that is used to improve the quality of the data. This process ensures that there is no data nosiness or inconsistency, thus eliminating what researchers consider "garbage" [21]. In this step, the researcher cleans up the data by removing students with undefined grade schemas in the "SIS\_Grade\_Letter" column. For example, values like "NF", "No SIS Match", "W", "XX", and "No Recorded Grade" were removed as they have no relevant reference in the KAU grades schema except for (W) which indicates a student who dropped from the course or the program. Moreover, the grade above the actual (100), reported usually as a percentage mean of assessment grade, is removed from the "Assignment\_Avg\_Attempt\_Grade" and "SIS\_Grade\_Letter" columns, which sometimes reflect an addition of an extra grade by the instructor that disrupts the percentage representation. However, only a few cases of these instances have been found (only 169 grade representations in the two datasets). Similarly, the "SIS\_Grade\_Letter" "DN" and "F" grade marks have been encoded as zeros because these symbols represent students who failed the course either due to their non-attendance or getting a grade lower than 60 out of 100.

2) *Data Aggregation*: The original dataset consisted of 75,971 entries for ELIA 101-1, and 26291 for ELIA 101-2), ranging from two to sixteen rows per student ID indicative of their level of interaction with the course. This necessitates that we find a method by which data representation becomes uniform for all students. So, conditional aggregation of data points based on an index (Student ID) has been performed through computing the mean of all the interaction values per student. The 'mean' value was used for aggregation because, unlike the 'count' and 'median' values, it does not affect the student's final grade, which we have noticed during experimentation with various data aggregation methods.

3) *Data Imbalance*: The number of students who have failed both ELIA 101-1 (64) and ELIA 101-2 (6) is small compared to the number of passing students in both datasets: 2322, 1137, respectively. This indicates (as Fig. 3 and 4 show) that there is a data imbalance problem that needs to be addressed so that the minority class, in this case "Fail", is not misrepresented, or affect the performance of the model. Therefore, data balancing strategies are applied to avoid a lower performance by DL methods which usually expect a balanced class distribution [22].

One method to overcomes data imbalance is Oversampling which increases the instances of the class with fewer numbers. As a first step, Random Oversampling (ROS) has been applied to the ELIA 101-1 and ELIA 101-2 datasets, but it only duplicates the data of the minority class which causes the models to overfit [23].

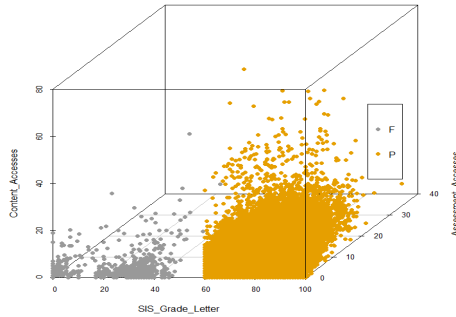


Fig. 3. ELIA 101-1 Pass/Fail imbalance.

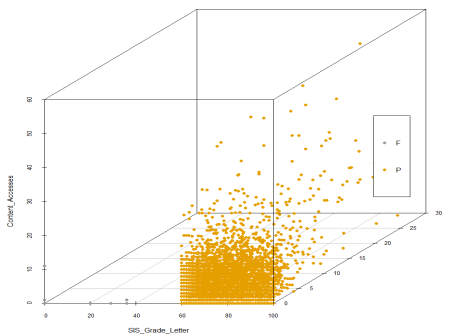


Fig. 4. ELIA 101-2 Pass/Fail imbalance.

To overcome overfitting, the Synthetic Minority Over-sampling Technique (SMOTE) is employed [24]. where it populates the minority class instance (Fail) in the datasets by generating a synthetic sample that selects one of the k nearest neighbours of the feature in the feature space, and in the process, draws a line between the examples in the feature space, while defining a point along that line to generate the sample.

Oversampling the two datasets with SMOTE resulted in balanced datasets. ELIA 101-1, upon oversampling consisted of 4772 samples with equal Pass/Fail count, and ELIA 101-2 included 2286 samples with an equal distribution of the Pass/Fail grading schema.

4) *Data Labelling*: A Target column is added to the oversampled dataset, which translates the “SIS\_Grade\_Letter” grade value into 1 or 0 binary, indicating a Pass/Fail status, respectively. Students who score less than 60 on their final grade are classified as failing students, whereas students scoring 60 or above are recorded as pass.

5) *Training and Testing Split*: The dataset was split into training and testing sets with an 80/20% ratio. The data splits have been stratified by the target column so that neither the training nor testing sets be made completely of either one of the students’ status indicators 0 or 1. Consequently, the proportion of instances of each class (Pass/Fail) in each subset (Train/ Test) is almost equal to that in the original dataset. We assume, as research indicates, that stratification improves the model’s

TABLE III. MODELS’ HYPERPARAMETERS

Models	Layers	Optimizer/ Loss/ Metric	Epochs	Batch Size
<b>vRNN</b>	- Input (128, relu) - Hidden (64, relu) - 2 Hidden (32, relu) - Output (1, sigmoid)	- Adam (learning rate=0.001) - binary_crossentropy - accuracy	100	32
<b>LSTM</b>	- Input (128, relu) - Hidden (64, relu) - 3 Hidden (32, relu) - Output (1, sigmoid)			
<b>GRU</b>	- Input (256, relu) - Hidden (128, relu) - 5 Hidden (64, relu) - Output (1, sigmoid)			

performance as well as contributes to avoiding both bias issues related to variance.

### C. Building the DL Models

The main objective of this research has been to adopt a supervised learning approach to develop DL models that are capable of predicting the presence of at-risk students depending on their LMS interaction with the various course components that made up the final grade (Pass/Fail). More specifically, we performed a binary classification of the two datasets representing the ELIA 101 Course based on students’ final grade. As we are considering a dataset with multiple predictors, we opted for developing and comparing the performance of classification models that are capable of prediction based on multiple indicators. To achieve this objective, we experimented with three deep learning models (vRNN, LSTM, and GRU).

All deep learning models have been trained and tested using Python 3 and TensorFlow 2.6.0. The three models’ hyperparameters are set to the ones illustrated in Table III. In order to avoid the overfitting problem, early stopping is used for all models [25].

1) *Baseline Model*: An initial implementation of a baseline neural network has been attempted, where the results are later used as a reference point of comparison to the proposed models. The objective is to generally investigate the efficacy of our deep learning approach while using baseline structures that can be improved on.

#### a) Multilayer Perceptron (MLP):

An MLP is one of the simplest representations of neural networks. It is a class of Feedforward ANNs which is composed of multiple layers of neurons that are connected through directed connections to the neurons of each subsequent layer [1]. There are three layers of neurons, including the input, hidden, and output layers. In its hidden and output layers, MLP uses sigmoid functions to predict probabilities. As part of the training process, MLP adjusts the weights iteratively by learning through a backpropagation function to produce good results [9]. An MLP with a hidden layer demonstrates a non-convex loss function which results in multiple local minima [26]. Moreover, the decision process in an MLP is made in relation to the immediate input. It does not have memory of past or future input.

#### 2) Proposed Models:

a) *Vanilla Recurrent Neural Networks (vRNN):*

RNNs are a type of artificial neural network which consists of connected nodes in a directed or undirected graph [27]. In RNNs, the information loops through the middle-hidden layer. The input is passed to the input layer, processes it, then passes it to the middle layer. The middle layer usually consists of multiple hidden layers, each with its own activation functions and weights. Unlike MLP, which is a Feedforward network considering only the current input, RNNs implements a feedback loop that ensures information cycles, which means that unlike feedforward connections, RNNs can also have connections that feed information to the previous or same layer [1]. Vanilla RNN is the standard RNN, it passes input as well as a hidden state through a single tanh layer [7]. In this research, the vRNN model is constructed of one input layer with 128 units, one hidden layer with 64 units, 2 hidden layers with 32 units, and the output fully connected layer. All layers use a Rectified Linear Unit (ReLU) activation function, except for the output layer which uses a 'sigmoid' activation. The model training stopped at 37 epochs on the (ELIA 101-1) dataset, and on 35 on the (ELIA 101-2) dataset.

b) *Long Short-Term Memory (LSTM):*

The main issue with vRNNs is the problem of vanishing gradients, which suffers an exponential decrease as the neural network back-propagates, which slows up the learning process in the final layers of the RNN [1]. Therefore, an LSTM model is developed to counteract the limitation of the vRNNs special architecture. The memory cell concept is introduced in LSTM architecture, which enables long-term dependency learning. As a function of its inputs, the memory cell temporarily holds its value, and is composed of three gates that regulate how information flows. Basically, there is an input gate which regulate when new information accesses the memory cell; a forget gate which manages the time limit for storing information in the cell, thus permitting new information to flow in; and the output gate that manipulates when the stored information is to be utilized by the processor [1]. Ultimately, this speeds the learning process as well as retains its information. Our LSTM model is constructed of an input layer with 128 neurons, a hidden layer contains 64 neurons, two hidden layers that include 32 neurons. Finally, the fully connected layer with one neuron was applied. Whereas all layers make use of a ReLU activation function, the output layer applies a 'sigmoid' activation. The model training stopped at 79 epochs with the (ELIA 101-1) dataset, and on 51 with the (ELIA 101-2) dataset.

c) *Gated Recurrent Unit (GRU):*

LSTM relies on using more training parameters, therefore uses more memory and executes slower than other models. So, for addressing this, we developed a GRU model, which is a simplified version of an LSTM [1]. Its hyperparameters are fewer in comparison to the LSTM as it consists of two gates in place of three, a reset and update gates. The GRU's update gate is a merge up of the LSTM's input and forget gates [7].

In this research, GRU is constructed with 7 layers; the input layer has 256 neurons, one hidden layer made of 128 neurons, five hidden layers including 64 neurons, and the output layer which has 1 neuron. All layers use an activation function, a ReLU, except the output layer which uses a 'sigmoid'. The model training stopped at 88 epochs when trained on the (ELIA

101-1) dataset and on 96 when trained on the (ELIA 101-2).

D. *Evaluation*

To evaluate the performance of the baseline and proposed models, we used the following metrics:

- Accuracy: is a metric that helps determine the percentage of correctly categorized instances in relation to the total of those instances based on the following Eq. 1 [9]:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

- Recall: is a metric that is used to evaluate model overall. It computes the percentage of the correctly classified true positives using the following equation 2 [9]:

$$Recall(TPR) = \frac{TP}{TP + FN} \quad (2)$$

- Precision: is a metric that is used to assess the accuracy of the model. It reflects the percentage of true positives to those instances listed as positive by the classifier employing the following Eq. 3 [9]:

$$Precision = \frac{TP}{TP + FP} \quad (3)$$

- F1-score: is a metric that computes the average of precision and recall, and it is useful in cases where the performance of different classifiers is to be compared. The following Eq. 4 represents the F1-core computation process [9]:

$$F - Measure = \frac{2 * Precision * Recall}{Precision + Recall} \quad (4)$$

#### IV. RESULTS AND DISCUSSION

The aim of this research is set initially to predict at-risk students based on their behaviour inside the ELIA 101 course in two datasets (ELIA 101-1) and (ELIA 101-2), which has been delivered via KAU's official LMS, Blackboard. Therefore, the proposed models' performance (vRNN, LSTM, GRU) are evaluated and compared to each other as well as the baseline model (MLP). Table IV shows the results of the various models' predictions on the datasets.

The MLP, as baseline, achieved an accuracy of 84% on the (ELIA 101-1) and 91.65% when tested on the (ELIA 101-2) dataset, which sets it as the model with the lowest performance in classifying students' Pass/Fail status. The GRU model, on the other hand, achieved an accuracy of 94.40% on the (ELIA 101-1) dataset and 98.02% on the (ELIA 101-2) which is considered the highest set of values among baseline and proposed models. The GRU, as well, achieved the best f1-scores (= 94.25% and 97.99%, respectively).

According to the results outlined above, a comparison of all predicted models is provided in Fig. 5 and 6.

Moreover, Fig. 7, 8, 9, 10, 11, and 12 illustrate the loss and accuracy of training and validation data per each model

TABLE IV. PERFORMANCE RESULTS FOR THE MODELS ON THE TWO DATASETS

Models	Dataset	Accuracy	Precession	Recall	F1_Score
MLP	ELIA 101 -1	83.85	82.98	85.13	84.04
	ELIA 101 -2	91.65	98.96	84.14	90.95
vRNN	ELIA 101 -1	84.50	86.53	81.68	84.04
	ELIA 101 -2	96.92	100	93.83	96.82
LSTM	ELIA 101 -1	93.22	97.62	88.58	92.88
	ELIA 101 -2	89.24	92.72	85.13	88.76
GRU	ELIA 101 -1	93.65	97.87	89.22	93.35
	ELIA 101 -2	98.90	100	97.79	98.89

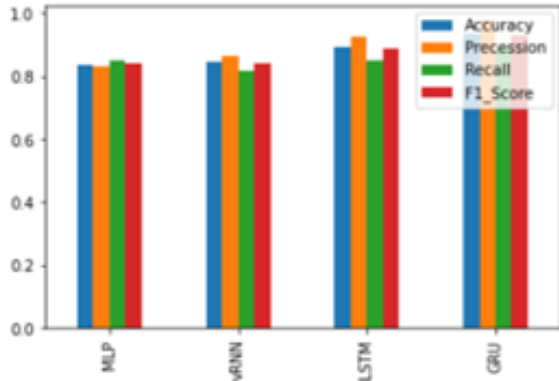


Fig. 5. Comparison of performance results for the models on ELIA 101-1.

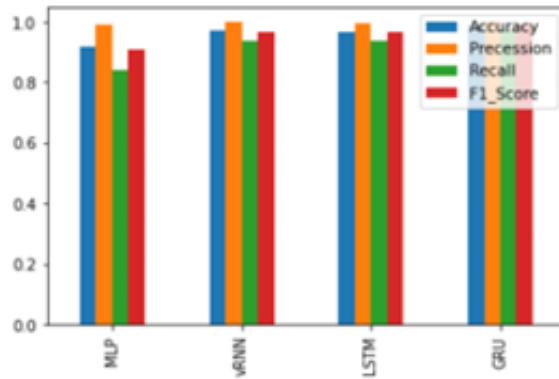


Fig. 6. Comparison of performance results for the models on ELIA 101-2.

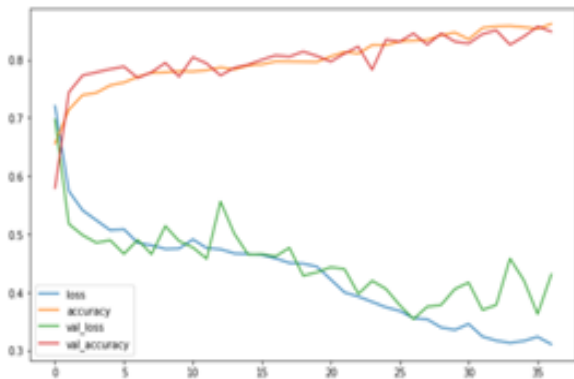


Fig. 7. vRNN loss and accuracy for ELIA 101-1.

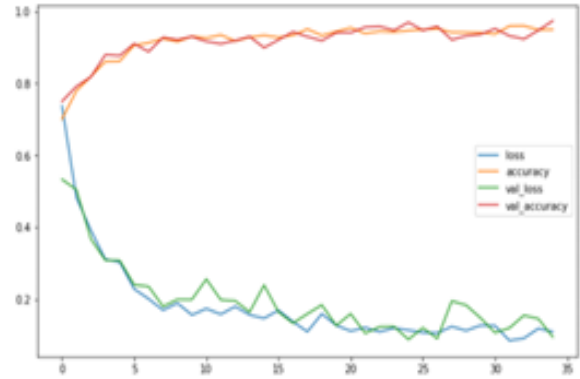


Fig. 8. vRNN loss and accuracy for ELIA 101-2.

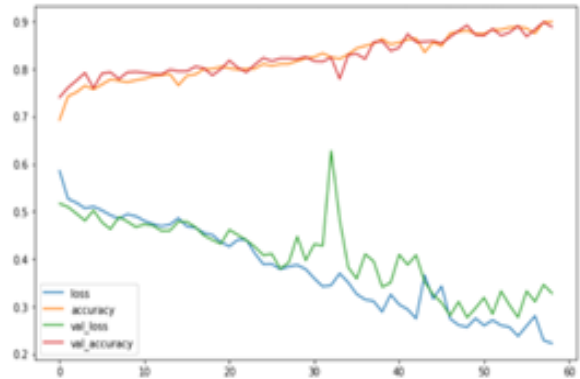


Fig. 9. LSTM loss and accuracy for ELIA 101-1.

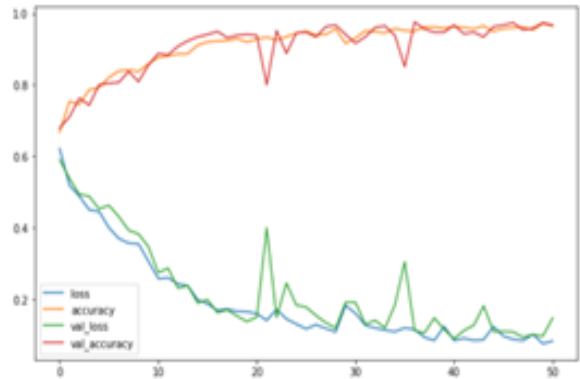


Fig. 10. LSTM loss and accuracy for ELIA 101-2.

with the number of epochs. There is no overfitting since the early stopping was used.

vRNN learned faster than the other models by only 37, and 35 epochs for ELIA 101-1, and ELIA 101-2 datasets, in contrast to the LSTM, which learned by 79, and 51 epochs and GRU, which learned by 88, and 96 epochs, respectively. The slow learning of the LSTM and GRU in comparison with vRNN is due to the models' complexity and the extra wights. This begs the question of the feasibility of using the GRU model on huge students' real-time datasets and the expected time-consuming performance on such data, while considering

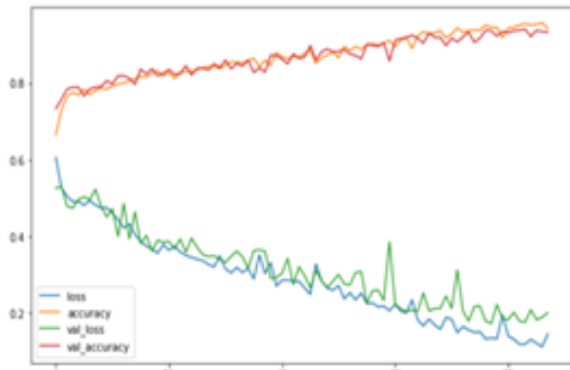


Fig. 11. GRU loss and accuracy for ELIA 101-1.

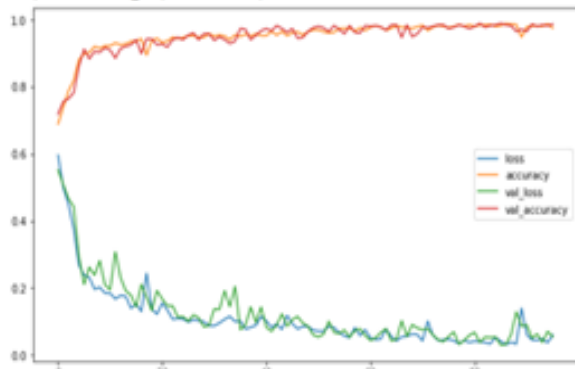


Fig. 12. GRU loss and accuracy for ELIA 101-2.

the sensitivity of at-risk students' activity.

The main objective of this research has been the utilization of DL techniques and models to predict at-risk students, who are, in this learning scenario, the failing students. Therefore, it is of importance that we reflect on the results of the prediction accuracy when it comes to identifying at-risk students. The confusion matrices in Fig. 13, 14, 15, 16, 17, 18, 19, 20 and the Precision and Recall values in Table IV, have demonstrated that the GRU's Recall (representing in our case the failing students) on the (ELIA 101-2) dataset (=97.7%) is the highest value indicative of the model's performance in regard to detecting the at-risk factor, which is critical for our study. The vRNN Recall on the (ELIA 101-2) is also high with a value of 93.8%, which is again representative of the model's capability at classifying the students' fail instances. The GRU's accuracy in identifying failing students on the (ELIA 101-1) comes next with a value of 89.22%, then the LSTM's Recall value (=88.5%) on the same dataset.

The previously cited results point out the predictive power of the GRU, vRNN, and LSTM, almost in that order, especially with reference to detecting at-risk students, on both datasets with Recall values ranging from 81.68% to 97.79%. Though the results in this regard are relatively close, yet the slight distinctions are probably suggestive of two main things. Firstly, there is a differentiation of learning patterns among at-risk students, who are subject to various life situations that impact their learning interactions online which could explain the

distinction in the models' performance regarding the detection of their Fail status. Secondly, there is also no uniformity among at-risk students enrolled in different, time-displaced cohorts with regards to their level of expected learning interactions and the impact of those interactions on their academic performance.

It is also significant to reflect on the models' performance with reference to its ability to differentiate passing from failing students. As the confusion matrices in Fig. 13, 14, 15, 16, 19, 20, 17, and 18 show, except of course for the MLP implementation on the (ELIA 101-1) dataset, there is a greater reported accuracy when it comes to predicting passing students in contrast to failing ones. For the GRU, for example, the model has been able to predict 97.8% of passing students and 89.2% of the failing ones on the (ELIA 101-1) dataset in comparison to 100% accuracy of predicting passing students and 97.7% of failing students on the (ELIA 101-2) dataset. As far as the LSTM and vRNN models are concerned, we notice the same trend of the model's ability to predict successful students with a pass indicator. Whereas, the vRNN application to the first dataset, for instance, has resulted in an accurate prediction of 86.5% passing students and 81.6% of the ones with a failing status, its implementation on the second dataset has yielded a 100% accuracy value for predicting passing students and a 93.8% for students with a failure grade. Almost the same results are reported for the LSTM, with accuracy values for predicting successful learners (97.6%, 92.7%) that are higher than the values of classifying unsuccessful ones (88.5%, 85.1%) on both datasets.

This could be attributed to the almost inherent homogenous nature of intermediate to high-performing students' learning activity and behavior which is often intrinsically motivated to the point that their commitment to the learning process manifests in the form of almost uniform patterns across most learning cohorts. DL models, including the ones developed for this study, discover the hidden patterns in learners' data that contribute to an understanding of their learning behaviour, and this reflects positively on the performance of the models.

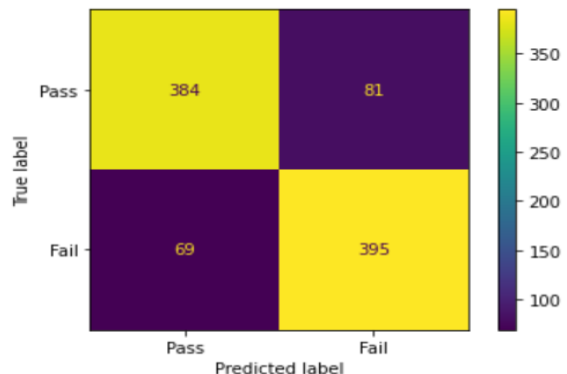


Fig. 13. MLP confusion matrix for ELIA 101-1.

One has to note that the improved performance of the models on the ELIA 101-2 dataset could be attributed to the relatively small number of records originally found in it (1143) including both pass (1137) and fail (6) students, which upon augmentation reached (2274). This, if compared to the

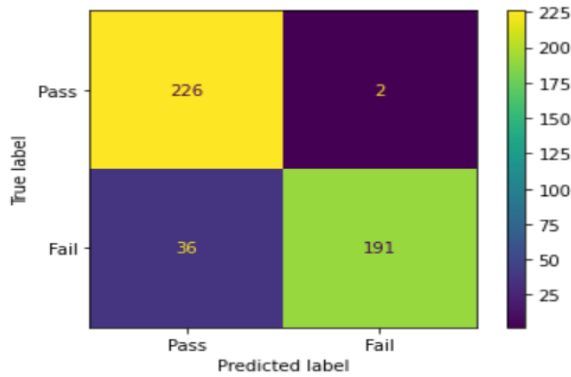


Fig. 14. MLP confusion matrix for ELIA 101-2.

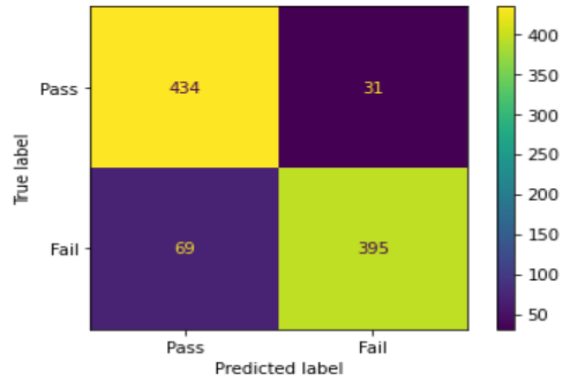


Fig. 17. LSTM confusion matrix for ELIA 101-1.

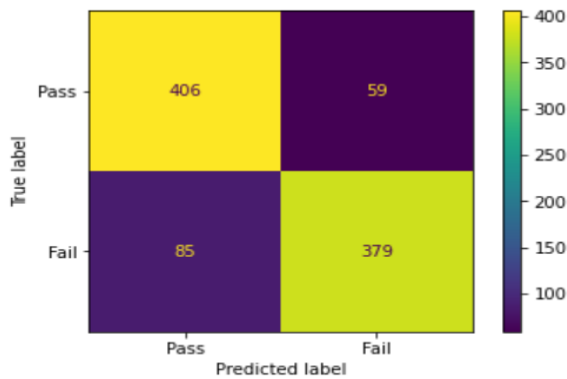


Fig. 15. vRNN confusion matrix for ELIA 101-1.

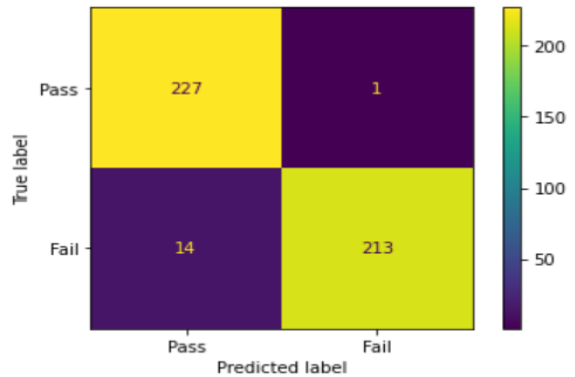


Fig. 18. LSTM confusion matrix for ELIA 101-2.

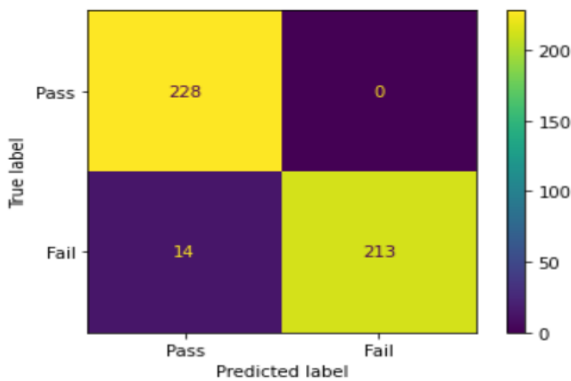


Fig. 16. vRNN confusion matrix for ELIA 101-2.

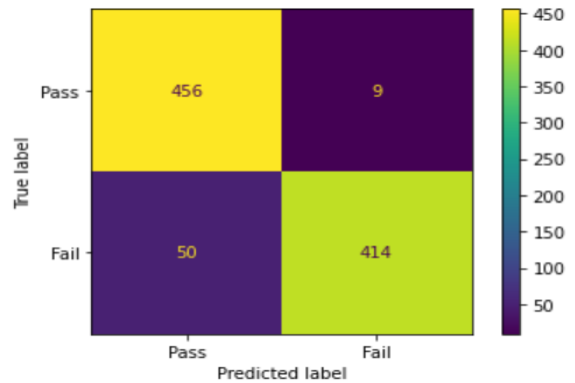


Fig. 19. GRU confusion matrix for ELIA 101-1.

4644 augmented records in the ELIA 101-1 dataset can be considered one of the limitations decision-makers encounter in real-life educational scenarios. Unlike the MOOC, for example, learning experience, students in compulsory university education are usually grouped in smaller cohorts and required to complete courses within a specific timeframe. Rarely, if ever, especially in Foundation courses, we encounter high rates of failure or even dropout.

Another limitation we believe is related to the dataset size and representation of one course and student cohort. More testing on differentiated datasets representing students' LMS

behaviour in KAU can lead to a better understanding of what constitutes risk factors for students.

## V. CONCLUSION AND FUTURE WORK

LMS platforms provide useful information about students' interactions, which can be used to identify at-risk students. In this study, we proposed three neural network models (vRNN, LSTM, and GRU) for predicting both students' final grade performance and at-risk standing based on two datasets extracted from the A4L: KAU Blackboard.

The results show that the GRU performs better than



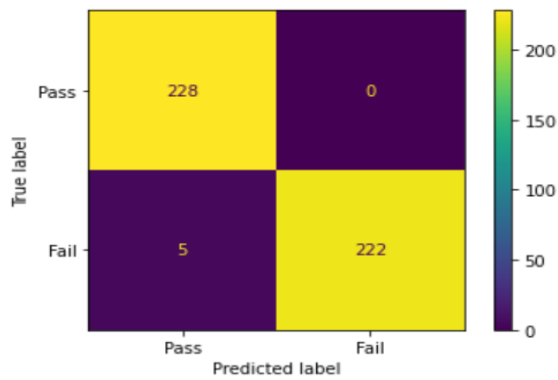


Fig. 20. GRU confusion matrix for ELIA 101-2.

other models in detecting learners' Pass/Fail status because it achieved the highest accuracy 93.65 (on the ELIA 101-1) and 98.90 (on the ELIA 101-2).

As far as predicting the at-risk students (likely to Fail), the previously mentioned results highlight the predictive power of the GRU, vRNN, and LSTM, respectively, on both datasets, with Recall values ranging from 81.68% to 97.79%.

The researchers think the dataset's size and its representation of only one course and student cohort are a drawback. A deeper knowledge of what comprises risk variables for students may result from more testing on differentiated datasets representing students' LMS behaviour in KAU.

For further research, we will use methods to overcome the impact of small size datasets on the realistic performance of DL models by, for example, through implementing advanced data augmentation techniques, considering time-series factors to predict at-risk students half-away through the semester; and, adding other predicators of students' user behaviour inside the LMS and exploring their relation to students' final achievement. More importantly, and while observing the variation among the proposed models in the accuracy of predicting at-risk students on different datasets, we will experiment with ensemble techniques, where the best results of each model might be enhanced by its combination with the others.

#### ACKNOWLEDGMENT

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# Parameter Identification of a Multilayer Perceptron Neural Network using an Optimized Salp Swarm Algorithm

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**Abstract**—Effort estimation in software development (SEE) is a crucial concern within the software engineering domain, as it directly impacts cost estimation, scheduling, staffing, planning, and resource allocation accuracy. In this scientific article, the authors aim to tackle this issue by integrating machine learning (ML) techniques with metaheuristic algorithms in order to raise prediction accuracy. For this purpose, they employ a multilayer perceptron neural network (MLP) to perform the estimation for SEE. Unfortunately, the MLP network has numerous drawbacks as well, including weight dependency, rapid convergence, and accuracy limits. To address these issues, the SSA Algorithm is employed to optimize the MLP weights and biases. Simultaneously, the SSA algorithm has shortcomings in some aspects of the search mechanisms as well, such as rapid convergence and being susceptible to the local optimal trap. As a result, the genetic algorithm (GA) is utilized to address these shortcomings through fine-tuning its parameters. The main objective is to develop a robust and reliable prediction model that can handle a wide range of SEE problems. The developed techniques are tested on twelve benchmark SEE datasets to evaluate their performance. Furthermore, a comparative analysis with state-of-the-art methods is conducted to further validate the effectiveness of the developed techniques. The findings demonstrate that the developed techniques surpass all other methods in all benchmark problems, affirming their superiority.

**Keywords**—Software development effort estimation; machine learning; multilayer perceptron neural network; salp swarm algorithm; genetic algorithm

## I. INTRODUCTION

Software engineering encompasses a systematic, methodical, and quantitative approach to the creation, operation, and maintenance of software systems. In order to ensure the effective and timely production of software products, software engineering management adopts specific actions such as planning, monitoring, measuring, and reporting [1], [2]. Conversely, software development effort estimation (SEE) represents a formidable challenge that holds significant importance in the software development process. SEE can be defined as the process of constructing a model that aids software engineers

in determining the cost of a software project prior to or at the commencement of the software development process [3], [4].

The scholarly literature proposes various methodologies to tackle the SEE problem. Some of these methodologies fall under the non-soft computing category, while others utilize machine learning (ML) techniques. ML techniques have demonstrated their effectiveness and capability to address similar problems encountered in diverse engineering fields. Among these ML techniques, artificial neural networks (ANN) have gained popularity and been extensively adopted in numerous research studies. One common type of ANN is the Multilayer Perceptron Neural Network (MLP), which is widely employed in addressing classification and prediction problems. Additionally, MLP exhibits excellent capability for handling non-linear and complex engineering problems [2], [3].

Motivated by the shortage of accuracy in the available models for estimating software development efforts in the literature, this research study aims to develop a robust and reliable ML model that has the ability to address the problem with high accuracy. However, to overcome limitations in prediction accuracy in the MLP network, the study integrates a metaheuristic algorithm known as the Salp Swarm Algorithm (SSA) into the MLP network. This integration aims to optimize the weights and biases of the MLP network, thereby enhancing its prediction accuracy. Furthermore, considering the SSA algorithm's search restrictions, the research suggests a strategy for using the Genetic Algorithm (GA) to fine-tune the SSA parameters.

Because the optimization procedure is stochastic, the effectiveness of metaheuristic algorithms essentially rests on finding a reasonable balance throughout the exploration and exploitation phases and refining the solutions over generations. The algorithm investigates the search space broadly during the exploration phase in an effort to avoid becoming stuck in local optima. Where, in the exploitation phase, the promising solutions found during the exploration phase are refined to attain the global optimum [5].

The Salp swarm algorithm (SSA) was put out in 2017 by Mirjalili [6] as an effective way for solving optimization issues in the context of metaheuristic methodologies. The swarming behavior of salps in deep waters, which commonly generates a chain of salps, served as the basis for this method. In order to have more control and make coordinated adjustments for quick foraging, this chain advances by pushing water inside its barrel-shaped shells.

The key drawbacks of the SSA algorithm, like those of other metaheuristic algorithms, are delayed convergence and premature convergence toward local optima. The No Free Lunch theorem in optimization states that it must be altered in order to address certain particular problems. This theorem argues that when addressing all optimization issues, all methods function on average equally well. As a result, a particular approach may work effectively for one group of problems but fail miserably for another. In order to enhance algorithms that are acceptable for the majority of issue types, researchers [7], [8], [9] determined that the proper balance between exploration and exploitation needed to be improved.

There are potential benefits to fine-tuning the SSA algorithm parameter settings using the GA algorithm, thus optimizing the MLP network weights. By integrating the SSA's exploration skills with the GA's global search, the SSA optimization capabilities are improved. Therefore, by overcoming local optimum conditions and responding to various scenarios, the developed model becomes adaptable and flexible. The MLP network's estimation error can be reduced, which in turn improves the accuracy of resource planning and project scheduling. The SSA-GA approach makes it easier to facilitate generalization and produce accurate estimates for varied software projects. Overall, this method effectively addresses the issue of estimating the effort required for software development, allowing for good resource management and project planning. The key contributions of this work are as follows:

- 1) Use the MLP network to address the issue of estimating software development effort.
- 2) Use the SSA algorithm to optimize the MLP parameters (Weights and biases).
- 3) Apply the GA algorithm to boost the SSA algorithm's optimization capabilities by fine-tuning its parameters.
- 4) Use several common benchmark SEE datasets to generalize the findings.
- 5) Develop three methods (e.g., MLP, SSA-MLP, and SSA-GA) and conduct statistical comparisons among the methods to determine the most effective one.

The rest of the paper contains the following: Section II provides a brief overview of the SEE problem, the MLP network, and the SSA algorithm. Section III introduces the developed methods. Section IV introduces the research results. Section V introduces a discussion for study finding. Section VI introduces the study conclusion.

## II. BACKGROUND

The research at hand encompasses a variety of tools and topics, including "Software Development Effort Estimation Problem", "Multilayer Perceptron Neural Network", and "Salp Swarm Algorithm." These components form the foundation of

the study and contribute to its overall context and objectives. Below is a brief overview of each of them.

### A. Software Development Effort Estimation Problem

Software development effort estimation (SEE) is a critical procedure that involves utilizing uncertain, noisy, inconsistent, and incomplete data inputs to forecast the optimal and realistic amount of effort required for software development and maintenance. Typically, the level of work accomplished is expressed in units such as man-months, man-hours, or the number of individuals involved in the software development process. Accurate estimations play a pivotal role in effectively planning for software project development. However, underestimation and overestimation are two complex issues that software project managers often face, and these challenges can potentially result in project failure [10], [11].

Robert N. Charette [12] extensively discussed the primary causes of failure in software projects, identifying a range of issues that contribute to project failures. These issues encompass unending system requirements, inadequate communication between developers and customers, the utilization of outdated technologies, ineffective project management practices, commercial pressures, difficulties in handling project complexity, inaccurate project status reports, unrealistic project objectives, uncontrolled risks, and stakeholder conflicts influenced by political factors. However, the ultimate success of a software project heavily relies on the accuracy of work estimation. While precise estimation is essential for both project managers and clients, there is a pressing need to enhance software development effort estimation (SEE). SEE plays a crucial role in supporting efficient software development and maintenance for software developers, while also empowering clients to negotiate contracts, plan project completion timelines, and establish release dates for prototypes, among other aspects. Despite the existence of numerous approaches to software effort estimation, the development of accurate and consistent estimation techniques remains challenging for researchers [13], [1].

### B. Multilayer Perceptron Neural Network

The multilayer perceptron (MLP) neural network, a specific component of the feedforward neural network (FFNN), stands as a unique form of Artificial Neural Network (ANN) capable of effectively approximating and comprehending the characteristics exhibited by computational models [14].

The MLP neural network necessitates a unidirectional arrangement of neurons, where data is transmitted through stacked layers organized into three types: input, hidden, and output layers. The connections between these layers can be established using different weights. Neurons within the MLP perform calculations using summation and activation functions. Summation function responsible for calculating the weighted sum of inputs and their corresponding connection weights. This function aggregates the inputs and weights to generate a weighted sum. The activation function, on the other hand, introduces non-linearity to the output of the summation function. It determines the output of a neuron or an entire layer based on the weighted sum calculated by the summation function. The activation function introduces non-linear transformations,

allowing the network to learn and model complex relationships between inputs and outputs.

The hidden layer neurons in the neural network employ the sigmoid activation function, while the output layer neurons utilize the linear activation function. The linear and sigmoid functions can be mathematically represented by Eq. 1 and 2, respectively.

$$f(x) = x \quad (1)$$

$$f(x) = \frac{1}{1 + e^{-x}} \quad (2)$$

Consequently, by adjusting the biases and weights, the network iteratively minimizes the error in the output and improves the accuracy of predictions. Graphical representations of the linear and sigmoid functions can be observed in Fig. 1 and 2, respectively.

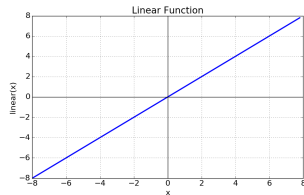


Fig. 1. Linear Activation Function

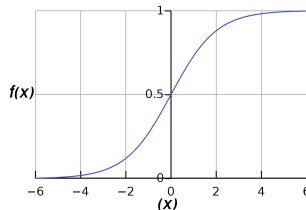


Fig. 2. Sigmoid Activation Function

### C. Salp Swarm Algorithm

The Salp Swarm Algorithm (SSA) is a recently introduced metaheuristic optimization algorithm developed by Mirjalili et al. in 2017 [6]. This algorithm is inspired by the collective behavior of sea salps found in nature. Sea salps, which are transparent, barrel-shaped invertebrates resembling jellyfish, propel themselves forward by pumping water into the back of their shells [15], [16]. They live and swim together in groups, with one salp acting as the leader while the others are considered “followers” [6]. Fig. 3 illustrates the body shape of a salp in (a) and depicts a group of salp swarms in (b).

The collective swimming behavior of salps in a group or swarm can be mathematically formulated and modeled as an optimization algorithm. The positions of the salps are determined within a search space of dimensions  $n \times N$ , where  $n$  represents the number of variables in a specific problem and  $N$  corresponds to the number of solutions in the population. This search space encompasses a food source ( $F$ ) that represents

the desired target or optimal solution for the salps. The leader of the swarm updates its position using Eq. 3.

$$x_j^1 = \begin{cases} F_j + r_1 * ((ub_j - lb_j) * r_2 + lb_j) & r_3 \geq 0.5 \\ F_j - r_1 * ((ub_j - lb_j) * r_2 + lb_j) & r_3 < 0.5 \end{cases} \quad (3)$$

In the provided equations,  $x_j^1$  represents the position of the swarm leader in the  $j^{th}$  dimension,  $F_j$  represents the position of the food source in the same dimension. The variables  $r_1$ ,  $r_2$ , and  $r_3$  correspond to three random numbers, while  $lb_j$  and  $ub_j$  represent the lower and upper boundaries of the search space in the  $j^{th}$  dimension, respectively.

The movement of the swarm leader is determined by the position of the food source  $F$  in the search space, as indicated in Eq. 3. The value of  $r_1$  is used to achieve a balance between exploration and exploitation during the search process, and its formulation is given in Eq. 4.

$$r_1 = 2 * e^{-\left(\frac{4+l}{L}\right)^2} \quad (4)$$

where  $L$  represents the maximum number of iterations and  $l$  represents the current one.

The values of  $r_2$  and  $r_3$  are randomly generated within the range of 0 to 1. These values play a significant role in determining the magnitude of the movement step taken by the salps and influencing the direction of the search, whether it is positive or negative. Consequently, the position of the salps can be updated using the following expression:

$$x_j^{i+1} = \frac{1}{2} (x_j^i + x_j^{i-1}), \quad i \geq 2 \quad (5)$$

where  $x_j^i$  is the position of the  $i^{th}$  follower.

The SSA’s optimization process starts with the population’s random creation of solutions. The followers then start to update their locations, led by the leader’s location, in an effort to find better locations with greater fitness values. Up until the termination condition is satisfied, which signifies the conclusion of the optimization process, these phases are repeated repeatedly.

### III. DEVELOPED TECHNIQUE

The method that has been developed combines an MLP network with SSA and is called “SSA-MLP.” This integration’s main goal is to use SSA to identify the MLP network’s optimal weights and biases, thereby improving the accuracy of MLP predictions. The Genetic Algorithm (GA) is used to upgrade the SSA algorithm to achieve this modification. The goal of this upgrade is to fine-tune SSA’s settings to increase its capacity for optimization. The GA algorithm is used in each iteration of the SSA algorithm to search for the most appropriate values for the SSA parameters, ensuring their optimal setting, which leads to the creation of a new technology called “SSA-GA”. By applying GA iteratively, it fine-tunes the parameters of SSA, leading to enhanced optimization performance. The working steps of the proposed SSA-GA algorithm may be summed up as follows:

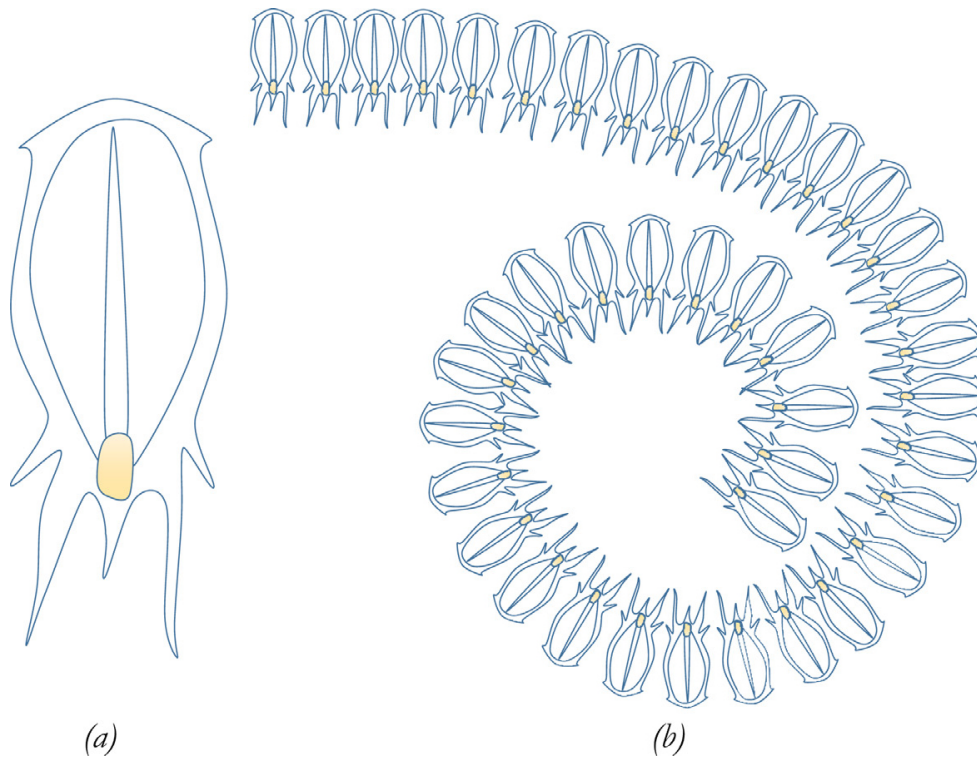


Fig. 3. Salp and Salp Swarm

- **MLP Initialization:** The Multilayer Perceptron (MLP) network's initial state is determined during initialization, and this procedure also provides the groundwork for further training and optimization. The weights and biases of the network are chosen at random during MLP startup. The biases serve as adjustable factors that regulate the activation thresholds of individual neurons, while the weights demonstrate the strength of connections between the neurons in the MLP's various layers. The MLP starts with a diverse collection of values thanks to the random initialization of these parameters, allowing for the exploration of many solutions during the training process. In MLP networks, random initialization is desirable because it lessens biases toward particular patterns or structures that may be present in the training data. The MLP is encouraged to learn a variety of characteristics and patterns by adding randomness, which helps it generalize well to data that has not yet been seen. In addition, initializing the MLP network with random weights and biases stimulates variation among its neurons and allows them to contribute to learning on their own. This variant prevents the network from becoming stale in local optima and enables it to explore diverse regions of the solution space.
- **SSA-Population Initialization:** The approach starts with the SSA-Population Initialization step by running the Multilayer Perceptron (MLP) training phase using the given training data. The number of times this training phase is repeated equals the SSA-population size, or the number of solutions in the population, exactly.

The MLP's updated weights and biases are retrieved and arranged as a vector after each training phase iteration. This vector form includes the precise set of adjusted weights and biases from the training procedure. The SSA-population is then updated with these vectors, which reflect the altered weights and biases. The SSA method treats each vector as an independent solution.

The next step is to evaluate the fitness of each solution inside the population once all the upgraded weights and biases vectors have been introduced to the SSA-population. Based on their individual training-fitness values, which represent how well each solution does in terms of minimizing errors throughout the training phase, an evaluation is made. The training-fitness values provide each solution with a numerical evaluation of its fitness or quality.

The optimal solution within the SSA-population is identified in this assessment by finding the one with the best fitness value. The weights and biases used in this study's best solution are those that produce the most accurate estimates while minimizing the mean squared error (MSE), which acts as the study's objective function. The mean squared difference between the anticipated values and the actual values is quantified by the MSE, an extensively used statistic in machine learning.

The SSA-Population Initialization stage makes it easier to identify the best solution within the population by using the MSE as the objective function. This allows for later optimization and enhancement of the MLP's performance in the estimation assignment.



- **GA-Population Initialization:** The GA-population is generated at random during the population initialization stage. The relevant parameters, indicated as  $p_1$  and  $p_2$ , have discrete values between 1 and 15. The GA-population is formulated as a two-dimensional matrix, where each row represents one GA solution. The number of SSA parameters that need to be tweaked is indicated by the size of each row, which is  $d = 2$ . Two parameters,  $p_1$  and  $p_2$ , make up each GA-solution and contribute to the set of accessible parameters shown in Eq. 6.

$$r_1 = p_1 \cdot e^{-\left(\frac{p_2 l}{L}\right)^2} \quad (6)$$

- **GA-Population Evaluation:** Each GA-solution's fitness value is evaluated in order to ascertain it. This evaluation entails running an SSA algorithm optimization process and introducing each GA solution into the SSA-population. The application of each SSA-solution to the MLP, along with the validation data, aims to determine the optimal SSA-solution. The resulting validation-fitness is then calculated. The SSA algorithm is combined with each GA solution to assess it through run its optimization process. The goal of the optimization is to find the SSA-solution that, when combined with the MLP, produces the best results on the validation data. The validation-fitness is calculated using the MLP and the chosen SSA-solution. Based on the results achieved during the MLP validation phase utilizing the validation data, this validation-fitness measures the caliber or efficacy of the GA solution. By evaluating each GA-solution's performance when it is incorporated into the SSA algorithm and then assessing the validation-fitness attained by the corresponding SSA-solution when combined with the MLP and the validation data, the fitness of each GA-solution is thus determined through this GA-population evaluation step.
- **Parameter Tuning:** The GA-solutions go through mutation and recombination after being encoded into chromosomes. Superior individuals within the population develop as a result of these genetic activities, which alter the encoded parameter values. The favorable parameter values that these superior GA-solutions possess boost their chances of surviving, reproducing, and passing on these enhanced parameter values to their progeny.
- **Selection:** The roulette wheel selection strategy is used in this phase to choose the GA-solution from the population. The fitness function for each solution is calculated using the standard SSA technique in this selection scheme. To do this, the solution is used as an input parameter for the SSA algorithm, and the fitness value that results is taken into account as the objective function value for that specific solution. The roulette wheel selection system ensures that the fittest individuals have a greater chance of being picked for continued breeding and development by favoring individuals with higher fitness ratings.

- **Encoding:** All GA-solutions or individuals are restructured in this stage using a binary format. The solutions are transformed by utilizing binary notation to express them. Each solution is recast in a standardized representation using the binary format, making it easier for genetic processes like crossover and mutation to take place in later iterations of the algorithm. The binary encoding makes it easy to manipulate and modify the GA-solutions, allowing the evolutionary process to explore various genetic material combinations.

- **Crossover:** The crossover operation is performed on the chosen solution in this stage, where two encoded parents are picked at random, the same as in the Selection-Step. Both the single crossover and double crossover approaches were used for this study. The chance of using the crossover operation is determined by the crossover rate, which is defined as  $gamma_r$ , where  $gamma_r$  is a number produced at random between [0, 1].

The amount of crossover applied throughout the population is influenced by the  $gamma_r$  value. A major fraction of the population will experience crossover when  $gamma_r$  is closer to 1, leading to a significant inheritance of genetic material across people. This suggests that during crossover, several genes will be transferred across individuals.

The value of  $gamma_r$  is set at 70% for the provided technique, suggesting a comparatively high crossover rate. This decision guarantees that the population experiences a sizable quantity of genetic recombination, enabling the evolutionary process to explore various genetic combinations.

To prevent similarity or uniformity among the solutions, alterations are made to the chromosomes in the mutation stage. This is accomplished by altering one or more chromosomal genes; the mutation rate ( $mu_r$ ) determines the degree of mutation. In order to ensure regulated exploration of the search space and prevent excessive and disruptive modifications to the solutions, the  $mu_r$  is often given a minimal value.

The  $mu_r$  is set to 0.1 for the proposed approach, which is a quite low mutation rate. In order to promote a certain degree of diversity and exploration among the population, this choice permits modest alterations to the genetic code.

- **Decoding:** The chromosomes' binary representation is converted into a decimal format during the decoding process. The binary-encoded chromosomes are translated into their corresponding decimal values throughout this procedure. The genetic data contained inside the chromosomes is converted during this decoding procedure into a format that is better suited for additional analysis and interpretation during the following phases of the algorithm.

- **Evaluation:** In this stage, each new GA-solution goes through an evaluation using the SSA algorithm. The new values for the SSA parameters  $p_1$  and  $p_2$  are produced from the gene values found in each GA-solution. These gene values serve as the adjusted values for the SSA algorithm's associated parameters.

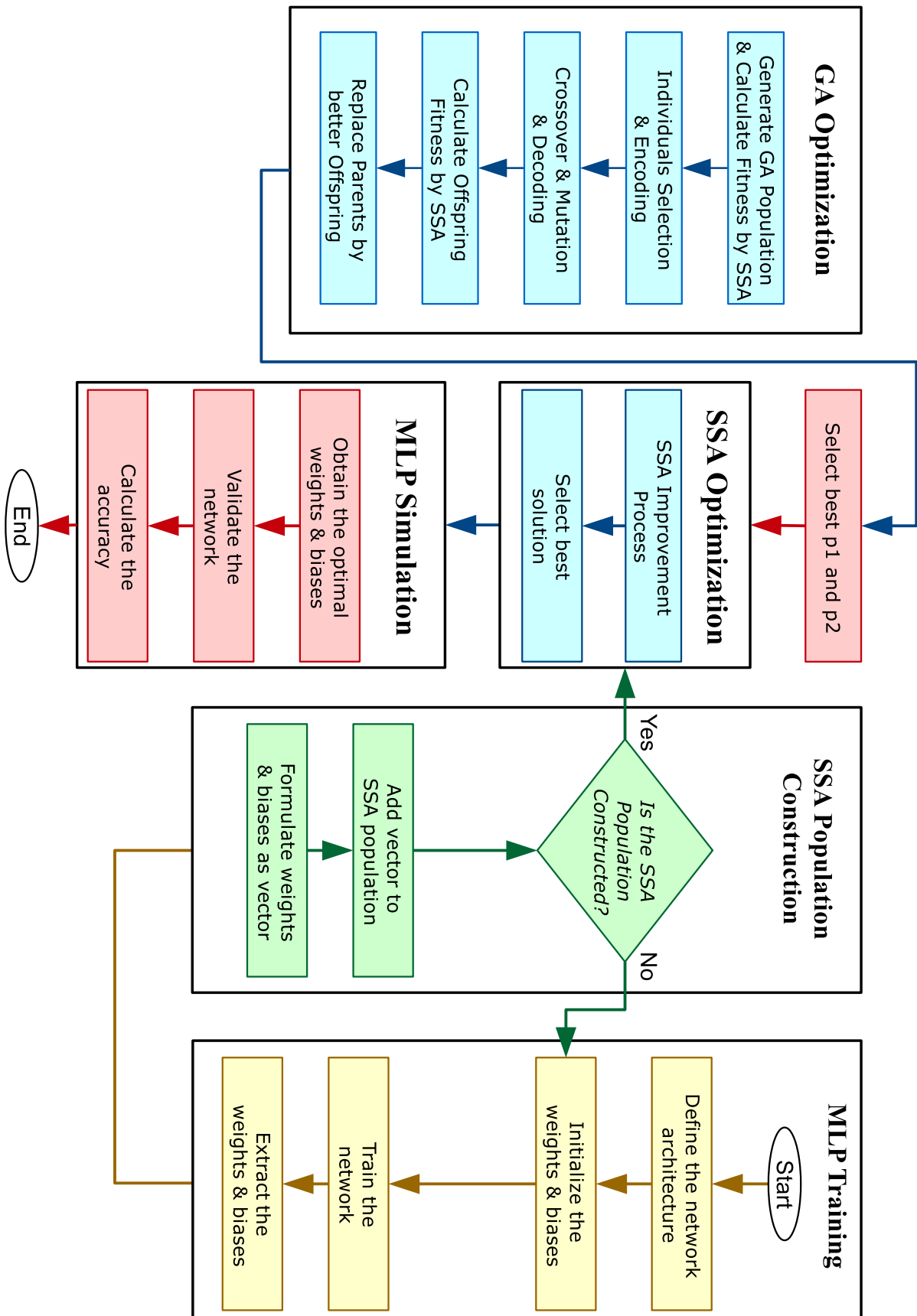


Fig. 4. Developed Technique

The optimal value obtained by using SSA determines the fitness function value for each subsequent GA-solution. The performance or efficacy of any particular solution with regard to the issue at hand is represented by this optimal value. Each solution may be tested for quality or appropriateness within the framework of the optimization process by using SSA to determine its fitness function values.

- **GA Termination Criteria:** To attain the maximum number of generations, repeat the previous procedures (apart from initiation) as many times as necessary. Each generation goes through several procedures like selection, crossover, mutation, and evaluation as the process continues repeatedly. The optimal GA-individual is chosen once the maximum number of generations has been reached. The SSA technique is then used to choose this individual as the candidate for its optimization process. This individual displays the best fitness or performance among all the individuals in the GA-population. The goal of choosing this most optimal GA-solution is to enhance the SSA algorithm's optimization capabilities by enhancing and refining the parameter values linked with it.
- **Select best parameters:** These optimal GA-individuals are chosen when the optimization procedure by the GA is finished and the best individuals have been identified. The SSA algorithm then uses the top candidates that were discovered by the GA optimization as new parameter values. By using these optimal parameters, the SSA algorithm is given the most precise and potent set of parameter values, improving both its performance and its capacity for optimization.
- **Optimization:** Using the optimal parameters discovered in the preceding rounds, the SSA-GA approach is used during optimization. This strategy tries to further optimize the SSA-GA-population and identify the optimal SSA-GA-solution. The MLP's weights and biases are then updated using the best SSA-GA-solution that was chosen. The MLP is provided with better parameters, boosting its prediction accuracy and overall performance by including this new set of perfect weights and biases.
- **Run the MLP simulation phase:** Using recently improved weights and biases, the MLP is run during the simulation phase. The validation data set is used to run this simulation. MLP uses updated weights and biases to produce predictions and estimates based on input data during simulation.
- **Accuracy calculation:** After the simulation, the MLP's estimation accuracy is calculated. Based on the supplied validation data, this accuracy measurement assesses the degree of accuracy and correctness of the MLP's forecasts and estimates. They may be quantitatively assessed by assessing the precision, the efficiency of the optimization procedure, and the influence of the new and optimized weights and biases on the MLP's estimate performance.

The SSA algorithm's parameters are dynamically adjusted

by the GA algorithm by following these formal procedures. As a result, the SSA-GA technique's optimization capabilities are enhanced, increasing the accuracy of MLP predictions. By combining the modeling prowess of MLP and the optimization skills of SSA, this integrated strategy provides an efficient remedy for resolving the SEE problem.

Fig. 4, which shows a flow chart outlining the methodology's several phases, graphically illustrates the suggested and developed process. The proposed methodology is illustrated graphically in the flow chart, which shows the sequence and connections between the numerous parts and steps that make up the method.

#### IV. EXPERIMENT AND RESULTS

This part focuses on the thorough design and construction of an experiment that aims to solve the effort estimation problem, a crucial component of software development. The experiment makes use of MLP embedding together with SSA and GA, two potent metaheuristic techniques. The main goal of this experiment is to build a solid model that can calculate the effort needed for software development projects with accuracy.

The experiment's outcomes will be crucial in determining whether or not the created model is effective. We'll conduct a detailed analysis and comparison of the accuracy and performance of the proposed model with those of currently used effort estimation methods. The outcomes will also give important insights into the model's potential and capabilities for actual software development scenarios.

##### A. Datasets Used

The datasets used in this study are from credible sites like PROMISE and GitHub and are highly recognized benchmark datasets frequently used in research. These datasets illustrate a wide variety of features, traits, and scales, demonstrating their effectiveness. Each dataset is described in full in Table I, including the number of features, dimensions, effort unit, and source repository. Albrecht, Kitchenham, and Kemerer datasets each have seven, seven, and six features, making them the datasets with the lowest feature sizes. On the other hand, Maxwell and COCOMONASA-II have the most characteristics, with twenty-seven and twenty-one, respectively. While the China and Desharnais datasets are gathered from the GitHub and PROMISE repositories and measured in "person-hours," the Maxwell dataset uses "function points" as the measurement unit, in contrast to the other datasets, which all use "man-months" as the measurement unit. The additional datasets, like Albrecht and USPO5, are measured in "man-months" and were downloaded from the PROMISE and GitHub sources, respectively.

##### B. Parameter Setting

A number of careful tests were done to make sure the SSA algorithm worked as intended. Finding the ideal set of parameters—specifically, the population size and maximum iterations—was the main goal. A fair value was found for each parameter: a population size of 30 and a maximum iteration limit of 300, after careful deliberation and thorough investigation. Based on the outcomes of the experiments and how they affected the performance of the algorithm, these

TABLE I. DATASETS

Dataset	Features	Dimension	Unit	Source
Miyazaki-94	048	08	man-months	PROMISE
Kitchenham	145	07	man-months	PROMISE
Desharnais	081	12	man-hours	GitHub
COCOMONASA-I	060	17	man-months	PROMISE
Cosmic	042	11	man-months	PROMISE
Albrecht	024	08	man-months	PROMISE
USP05	203	08	man-months	GitHub
Maxwell	062	27	function points	PROMISE
Kemerer	015	07	man-months	PROMISE
COCOMONASA-II	093	24	man-months	PROMISE
COCOMO-81	063	17	man-months	PROMISE
China	499	16	man-hours	PROMISE

values were determined to be the best ones. Which supports what was used in the original research [6] that developed the SSA algorithm. This study's experiments were all carried out in the environment that was specifically mentioned before.

For the MLP network, this research uses a network with three layers: an input, an output, and a single hidden layer. It is the basic structure of any simple artificial neural network [17], [18]. The trial-and-error method [19], [20] was employed to select the best number of neurons in the hidden layer. Where the number with the best fitness value was considered. Therefore, each dataset has a specific number of neurons in the hidden layer. For instance, the following setting for the number of neurons in the hidden layer for each dataset was found: Miyazaki-94: 12 neurons; Kitchenham: 5 neurons; Desharnais: 15 neurons; COCOMONASA-I: 5 neurons; Cosmic: 10 neurons; Albrecht: 15 neurons; USP05: 12 neurons; Maxwell: 5 neurons; Kemerer: 15 neurons; COCOMONASA-II: 10 neurons; COCOMO-81: 12 neurons; China: 12 neurons. Finally, the activation functions used are as presented in Section II-B, and the learning rate value is 0.05.

Additionally, each experiment was performed 21 times in a row to guarantee accurate findings. As a result of this repetition, a sizable quantity of data was gathered, allowing for the computation of the average performance based on the best results attained over the several runs. In order to conduct the studies, MATLAB 2016a was used. The computing operations were carried out using a device that had 16 GB of RAM and an Intel Core i7 CPU running at a speed of 2.0 GHz. Utilizing this hardware setup gave us plenty of processing power and memory space to support the experimental methods successfully.

### C. Performance Measures

Using six important statistical variables, a thorough assessment of the performance of the developed methodologies was carried out in this study. These metrics were intentionally chosen to offer a comprehensive evaluation of the techniques and cover many facets of error analysis. It's vital to remember that no one measurement can accurately represent all of the performance traits of the developed techniques. As a result, the use of these six metrics enables a flexible and thorough assessment of many elements of the approaches' effectiveness. Researchers can gain a more detailed picture of the benefits and drawbacks of the proposed methodologies by taking into account a variety of measures. The following are the six statistical tests used in this study:

Mean Square Error (MSE): The average of the squared discrepancies between the projected values and the actual values is calculated by the commonly used metric known as MSE. In addition to being very responsive to outliers, it quantifies the overall size of the errors.

$$MSE = \frac{1}{n} \sum_{i=1}^n (A_i - P_i)^2 \quad (7)$$

Root Mean Square Error (RMSE): RMSE is derived from MSE and, by calculating the square root of the MSE value, offers a more understandable measurement. It serves as a representation of the errors' standard deviation and may be used to compare models across various datasets.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (A_i - P_i)^2} \quad (8)$$

Relative Absolute Error (RAE): RAE quantifies the ratio of an absolute prediction error to an absolute error of a straightforward baseline model. By dividing the error by the total absolute errors in the base model, it normalizes the error.

$$RAE = \frac{\sum_{i=1}^n |A_i - P_i|}{\sum_{i=1}^n |A_i - \hat{A}_i|} \quad (9)$$

Root Relative Squared Error (RRSE): A RAE variant known as RRSE takes the square root of the relative squared error into account. Similar to RAE but including the squared components, it offers a relative estimate of the errors compared to a baseline model.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (A_i - P_i)^2}{\sum_{i=1}^n (A_i - \hat{A}_i)^2}} \quad (10)$$

Mean Absolute Error (MAE): The average of the absolute discrepancies between the expected and actual values is determined by MAE. Regardless of their orientation, it offers a clear indication of the average error magnitude.

$$MAE = \frac{1}{n} \sum_{i=1}^n |A_i - P_i| \quad (11)$$

Mean Magnitude Relative Error (MMRE): The average relative error between the anticipated and actual values is assessed using MMRE. It is the result of dividing the actual values by the average of the absolute differences between the expected and actual values.

$$MMRE = \frac{1}{n} \sum_{i=1}^n \frac{|A_i - P_i|}{A_i} \quad (12)$$

where  $A_i$  is the actual values,  $P_i$  is the predicted values, and  $\hat{A}_i$  is the average of actual values.

These mathematical formulas make it possible to calculate the corresponding statistical measures, providing quantitative numbers for assessing how well the research's methodologies performed.

#### D. The Optimal SSA Parameter Values Found

The authors meticulously looked into many issue scenarios during the considerable testing done for this work in order to determine the best parameter values for the SSA method in each situation. The outcomes of this thorough investigation are shown in Table II, which highlights the precise SSA parameter values that are most successful in resolving the issues under consideration.

The proper values for the SSA parameters, namely  $p_1$  and  $p_2$ , for each problem examined in this research project are clearly outlined in Table II. The fact that each problem requires a different set of parameter values in order to function at its best reveals the individuality of each one.

It is essential to understand that the values shown in Table II are neither constant nor unchangeable. Instead, they are prone to variation since the algorithms used are, by their very nature, probabilistic. There is a chance that the calculated parameter values might vary if the experiments were repeated. This difference might be traced to the algorithms' random features, which provide an element of ambiguity and variety to the optimization procedure.

As a result, the researchers stress how crucial it is to take the algorithms' stochastic character into account when interpreting the findings. The parameter values indicated in Table II are the best options based on the experimentation that was performed; however, they should be viewed as recommendations rather than strict guidelines. Recognizing the potential variations in these variables enables a thorough comprehension of the behavior of the algorithm and promotes a strong optimization procedure.

TABLE II. BEST OBTAINED SSA PARAMETERS AFTER TUNED BY GA ALGORITHM

Dataset	$p_1$	$p_2$
Albrecht	03	09
China	04	12
Cosmic	11	14
COCOMO-81	08	08
COCOMONASA-I	15	11
COCOMONASA-II	01	06
Desharnais	03	14
Kemerer	14	11
Kitchenham	14	14
Maxwell	03	14
Miyazaki-94	15	09
USP05	15	12

#### E. Comparison of SSA-GA vs. SSA-MLP and Standard MLP

There were 21 iterations of the experiment. The best findings were therefore averaged, and this was taken into consideration. Table III is a list of the outcomes. The findings of the study for several datasets utilizing MLP (Multi-Layer Perceptron) and two variants of SSA (Salp Swarm Algorithm):

SSA-MLP and SSA-GA, are presented in the supplied data table. For each combination, the average MSE, standard deviation of MSE, worst MSE, and best MSE, as well as MMRE, RMSE, RRSE, MAE, and RAE, were calculated statistically.

The study presented here highlights the results of the recommended approaches and sheds light on two key findings of enormous relevance. First off, it is clear that the efficient optimization of weights and biases made possible by the seamless integration of the Salp Swarm Algorithm (SSA) with the Multi-Layer Perceptron (MLP) network has a significant impact on the predictive capacities of the MLP network. The performance and precision of the MLP predictions are significantly improved as a result of this integration.

The MLP network's training process is improved and made more efficient by using the SSA technique. The SSA algorithm presents a novel method of searching the solution space that is motivated by the organic movement patterns of salp swarms. This technique uses a series of dynamic equations to direct the salps in the direction of the best outcome. The network's predictive capacity is greatly increased as a result of the interaction between the MLP and the SSA algorithm, producing better outcomes and more accurate predictions.

The recommended improvements to the SSA algorithm, which were performed by fine-tuning its parameters with the help of the Genetic Algorithm (GA) have also been shown to significantly improve its optimization performance. The best set of parameters for the SSA may be found using the GA algorithm, which takes its cues from the mechanisms of natural selection and genetics.

The SSA algorithm's efficacy and efficiency in improving the weights and biases are significantly increased by exposing it to the GA's optimization capabilities. Superior optimization results are obtained as a result of the SSA method being able to adapt more precisely to the unique traits and needs of the current issue thanks to this parameter tweaking procedure. The amalgamation the GA algorithm with the SSA algorithm enables the latter to more thoroughly explore the solution space and to converge to optimal solutions in a more effective and efficient way.

In summary, the results obtained using the developed approaches highlight two important facts. First off, by enabling the efficient optimization of weights and biases, the SSA algorithm's integration with the MLP network has a significant positive impact on the performance of MLP predictions. Second, by applying the GA algorithm, the SSA algorithm has been greatly improved in terms of its optimization efficiency, which eventually results in higher-quality results and more precise forecasts. These discoveries open up new opportunities for additional study and application in a variety of fields, enhancing the area of predictive modeling and optimization approaches.

#### F. Comparing the SSA-MLP with State-of-the-Art Methods

A detailed and thorough comparison is made in this phase of the study, contrasting the performance of the recommended approach with leading-edge techniques that have been described in the body of existing literature. The comparison's objective is to show the created technique's effectiveness

TABLE III. RESULTS OBTAINED BY SSA-GA, SSA-MLP, AND STANDARD MLP

Dataset	Method	MSE				MMRE	RMSE	RRSE	MAE	RAE
		avg	std	worst	best					
Miyazaki-94	MLP	0.0035	1.39E-05	0.0042	0.0035	0.3260	0.0218	0.2440	0.0473	0.2130
	SSA-MLP	0.0010	5.44E-04	0.0020	0.0004	0.0634	0.0434	0.2760	0.0274	0.1420
	SSA-GA	0.0008	1.85E-05	0.0008	0.0008	0.0507	0.0022	0.1200	0.0075	0.1270
Kitchenham	MLP	0.0232	9.18E-04	0.0221	0.0220	1.7800	0.1350	0.5890	0.2380	0.6640
	SSA-MLP	0.0132	4.54E-03	0.0149	0.0084	1.1400	0.1220	0.3910	0.0626	0.5290
	SSA-GA	0.0092	5.46E-03	0.0147	0.0037	1.0200	0.1130	0.2140	0.0359	0.3520
Desharnais	MLP	0.0145	8.32E-04	0.0166	0.0148	0.5640	0.2230	0.5240	0.0848	0.5100
	SSA-MLP	0.0091	1.24E-03	0.0128	0.0053	0.2230	0.0192	0.2760	0.0486	0.3050
	SSA-GA	0.0028	1.14E-04	0.0046	0.0042	0.0637	0.0116	0.1080	0.0011	0.1320
COCOMONASA-I	MLP	0.0074	6.89E-05	0.0065	0.0064	1.6400	0.0329	0.2840	0.0773	0.4430
	SSA-MLP	0.0032	9.25E-05	0.0041	0.0041	0.7190	0.0142	0.0554	0.0048	0.0576
	SSA-GA	0.0026	1.19E-04	0.0015	0.0025	0.1340	0.0121	0.0344	0.0033	0.0356
Cosmic	MLP	0.0000	8.98E-10	0.0000	0.0000	0.0004	0.0004	0.0083	0.0182	0.0919
	SSA-MLP	0.0000	2.29E-08	0.0000	0.0000	0.0002	0.0000	0.0014	0.0000	0.0073
	SSA-GA	0.0000	3.14E-11	0.0000	0.0000	0.0001	0.0000	0.0004	0.0000	0.0007
Albrecht	MLP	0.0261	2.65E-05	0.0214	0.0219	0.3490	0.1750	0.3980	0.0895	0.4460
	SSA-MLP	0.0095	8.25E-03	0.0169	0.0028	0.1980	0.0194	0.0438	0.0304	0.0358
	SSA-GA	0.0075	6.97E-03	0.0183	0.0010	0.0854	0.0126	0.0306	0.0132	0.0134
USP05	MLP	0.0144	3.93E-04	0.0294	0.0152	8.7500	0.1390	0.7830	0.0663	1.8700
	SSA-MLP	0.0102	7.24E-03	0.0231	0.0031	4.9600	0.0170	0.3820	0.0174	0.6460
	SSA-GA	0.0072	6.56E-03	0.0122	0.0011	1.5800	0.0115	0.0596	0.0076	0.2340
Maxwell	MLP	0.0056	7.86E-04	0.0076	0.0060	1.0500	0.0717	0.4500	0.0704	0.4880
	SSA-MLP	0.0038	2.16E-03	0.0052	0.0009	0.1720	0.0034	0.0262	0.0033	0.0329
	SSA-GA	0.0007	2.46E-05	0.0007	0.0007	0.1210	0.0020	0.0172	0.0019	0.0112
Kemerer	MLP	0.0002	9.87E-07	0.0002	0.0002	0.2680	0.0132	0.0486	0.0201	0.0242
	SSA-MLP	0.0000	1.24E-06	0.0000	0.0000	0.0072	0.0042	0.0174	0.0036	0.0134
	SSA-GA	0.0000	6.42E-07	0.0000	0.0000	0.0047	0.0035	0.0109	0.0014	0.0063
COCOMONASA-II	MLP	0.0103	8.77E-05	0.0338	0.0113	1.7200	0.1230	0.4170	0.0578	0.4450
	SSA-MLP	0.0050	1.34E-04	0.0063	0.0061	4.3800	0.0462	0.3790	0.0276	0.1980
	SSA-GA	0.0041	1.03E-03	0.0067	0.0039	1.7600	0.0315	0.1120	0.0213	0.0551
COCOMO-81	MLP	0.0160	9.77E-05	0.0161	0.0248	0.1100	0.1470	0.5720	0.2560	0.4460
	SSA-MLP	0.0073	1.42E-04	0.0086	0.0076	3.3400	0.0438	0.3930	0.0401	0.2780
	SSA-GA	0.0040	1.05E-04	0.0031	0.0011	0.0955	0.0126	0.1110	0.0196	0.0642
China	MLP	0.0032	8.79E-05	0.0031	0.0019	0.7450	0.0687	0.3170	0.0288	0.3830
	SSA-MLP	0.0027	2.04E-03	0.0029	0.0004	1.3800	0.0321	0.2620	0.0260	0.3860
	SSA-GA	0.0013	1.14E-03	0.0014	0.0002	0.6300	0.0273	0.2070	0.0221	0.2540

and superiority in addressing the Software Effort Estimation (SEE) problem. The comparison study takes into account two different scenarios and thoroughly compares the created strategy to comparable techniques that have been specifically designed to tackle the SEE problem. The state-of-the-art in the field is represented by these chosen approaches, which also act as benchmark models for evaluating the improvements and contributions of the recommended approach.

The first comparison compares the developed technique to the strategy put forward by Kassaymeh et al. (2021), [21], while the second comparison compares the developed methodology to the strategies put forth by Khan et al. (2021), [22]. The benchmark datasets used in each of these comparative assessments are the same ones used in this study, and they use the same two evaluation metrics to assess performance: mean squared error (MSE) and mean magnitude of relative error (MMRE). Tables IV and V include the specific findings of these comparisons, respectively.

The SSA-GA technique clearly outperforms the SSA-BPNN method in terms of Mean Squared Error (MSE) performance metrics across all datasets in the first comparison, as shown by the results of the comparisons that were conducted. This shows that, when compared to the SSA-BPNN approach, the SSA-GA algorithm offers greater accuracy and precision in calculating software effort. This is due to the ability of the developed model that elicits the benefit of GA algorithm in adjusting its parameter according to problem in the hand.

Furthermore, in the second comparison, it is shown that the

TABLE IV. COMPARISON BETWEEN SSA-GA AGAINST STATE-OF-THE-ART METHODS [21]

Method	SSA-GA	SSA-BPNN
Miyazaki-94	<b>8.41E-04</b>	3.50E-03
Kitchenham	<b>9.20E-03</b>	2.29E-02
Desharnais	<b>2.76E-03</b>	1.57E-02
COCOMONASA-I	<b>2.60E-03</b>	7.40E-03
Cosmic	<b>7.57E-11</b>	1.34E-07
Albrecht	<b>7.52E-03</b>	1.61E-02
USP05	<b>7.23E-03</b>	1.44E-02
Maxwell	<b>6.53E-04</b>	6.80E-03
Kemerer	<b>2.47E-06</b>	1.62E-04
COCOMONASA-II	<b>4.07E-03</b>	1.03E-02
COCOMO-81	<b>4.01E-03</b>	1.60E-02
China	<b>1.30E-03</b>	3.00E-03

- comparison in term of MSE

- best results in bold

SSA-GA technique outperforms a number of other cutting-edge algorithms. The SSA-GA algorithm stands out as the best performer in terms of predictive abilities when compared to the Straw Berry (SB), Ant Colony Optimization (ACO), Cuckoo Optimization (CO), Genetic Algorithm (GA), Grey Wolf Optimizer (GWO), Particle Swarm Optimization (PSO), and Bat Algorithm (BA) algorithms.

In particular, the SSA-GA method exhibits outstanding results on the COCOMO-81 and Maxwell datasets while taking into account the assessment metrics of mean magnitude of



relative error (MMRE). The SSA-GA method outperformed the other state-of-the-art algorithms analyzed in the study in terms of performance on these datasets, demonstrating the algorithm's greater capacity to estimate software effort precisely and with less relative error.

These superiority results are due to the fact that the SSA algorithm in the SSA-BPNN methods did not obtain parameter tuning, as is the case in the method developed in this paper (SSA-GA). This gives conclusive evidence of the desired benefit of introducing another algorithm (GA here) to adjust the parameters of the main algorithm (SSA) so that the developed algorithm becomes more flexible and effective in handling various prediction problems. In addition, the superior results of the developed algorithm play a pivotal role in proving the need to replace traditional training methods for artificial neural networks with metaheuristic algorithms to enhance prediction accuracy and raise the quality of the results.

TABLE V. COMPARISON BETWEEN SSA-GA AGAINST STATE-OF-THE-ART METHODS [22]

Method	COCOMO-81	Maxwell
SB	3.6100	2.7200
ACO	5.6100	4.5400
CO	4.0700	2.8600
GA	4.7800	3.2200
GWO	2.2100	1.4500
PSO	5.0600	3.7200
BA	4.7100	3.6400
SSA-GA	<b>0.0955</b>	<b>0.1210</b>

- comparison in term of MMRE  
- best results in bold

Finally, these results highlight the SSA-GA algorithm's efficiency and competitiveness in the software effort estimation field. The algorithm's use of the Salp Swarm Algorithm and Genetic Algorithm allows it to effectively train the MLP network, improving accuracy and precision in software effort estimation. The SSA-GA method performs better than other advanced techniques, which makes it a promising and reliable alternative for resolving problems related to software work estimates.

## V. DISCUSSION

The SSA-GA framework has the unique capacity to adjust its parameters dependent on the specific problem it is addressing by applying the GA algorithm. This flexibility is critical in improving the overall performance of the algorithm.

The GA method carefully chooses parameter values that are most appropriate for the SSA algorithm. The SSA-GA model assures that the SSA optimizer has optimal parameter values via such a selection procedure. As a consequence, the SSA optimizer becomes extremely trustworthy at avoiding the dangers of local optima, which can stymie exploration of the whole search space. Furthermore, by including the GA method, the SSA-GA model gets the ability to find and explore the most promising parts of the search space.

The ability to avoid local traps and explore the area of search effectively is critical for striking a balance between exploration and exploitation. Exploration entails investigating

different parts of the search space to find possibly optimal solutions, whereas exploitation involves refining and improving the identified solutions. Using the SSA-GA model increases the likelihood of achieving this delicate balance.

On the other hand, the combination of the MLP with the tuned-SSA technique has several advantages, such as enhanced prediction accuracy and higher reusability. The MLP network that results from using the tuned-SSA technique to improve the MLP weights is more reconfigurable. This indicates that the improved MLP may be used with different SEE prediction tasks without requiring substantial adjustments or retraining, saving time and effort.

Additionally, the tuned-SSA technique's improvement of MLP weights results in a decrease in prediction error. The optimized process is successfully guided by the tuned-SSA technique, which enables the MLP to converge towards more precise predictions. This decrease in prediction error results in an improvement in prediction quality, which raises the MLP's dependability and utility.

The addition of the tuned-SSA algorithm also aids in adjusting the MLP network's rate of convergence. The process through which the MLP modifies its weights to reduce estimation error is known as convergence. The MLP weights are optimized using the tuned-SSA method in a way that promotes reasonable convergence. In situations or applications that need critical decisions, this improvement in convergence speed is essential.

A tuned SSA technique further minimizes the MLP's reliance on initial parameter values. Whereas the behavior and performance of MLP convergence can be greatly affected by the values of the initial weights. The MLP becomes less dependent on starting weight values when the Tuned SSA technique is used, which improves the MLP's stability and robustness.

In conclusion, By choosing the best parameter values, the combination of the SSA and GA algorithms improves the performance of the SSA method. With this combination, the algorithm is better able to explore interesting regions of the search space and break out of local optima. An enhanced balance between exploration and exploitation produces more trustworthy optimization results. In addition, using the tuned-SSA method to optimize the weights and biases of MLPs has a number of benefits. When used for various prediction tasks, the improved MLP network becomes more adaptable and requires less alterations. Additionally, it lowers prediction error, raising the accuracy of predictions. A more reliable and stable model is produced thanks to the MLP's faster convergence and decreased reliance on starting weight values.

## VI. CONCLUSION AND FUTURE WORKS

This research explores the integration of the salp swarm algorithm (SSA) and the multilayer perceptron neural network (MLP) in order to tackle the software development effort estimation (SEE) problem. By adjusting the weights and biases of the MLP, the goal is to increase prediction accuracy. Furthermore, a suggested improvement is included by modifying the SSA's parameters using a genetic algorithm (GA). Twelve different SEE datasets with different feature sets are used to comprehensively assess the efficiency of the suggested method.

To evaluate the results of the developed SSA-GA methodology, there are two phases in the assessment process. The outcomes are first contrasted with those attained by traditional MLP and traditional MLP in combination with the original SSA. This comparison research enables a thorough comprehension of the effect of SSA on MLP prediction accuracy. Additionally, the impacts of parameter adjustments on the SSA's optimization performance and the MLP's prediction performance are examined.

In the second evaluation, the results of the developed SSA-GA methodology are contrasted with cutting-edge methods that have been used on datasets related to the SEE problem. The purpose of this comparison is to demonstrate how much better the recommended strategy is than the alternatives. This assessment offers a fair and direct comparison between the proposed methodology and other cutting-edge technologies by using identical datasets.

The main goal of these assessments is to show how SSA affects the precision of MLP predictions as well as how parameter adjustment affects SSA's and MLP's optimization and prediction performance, respectively. The findings of the two assessments consistently show that the proposed methodology is better than the competing techniques. This demonstrates how the SEE problem may be solved by combining SSA and MLP and optimizing the parameters with the GA algorithm, which increases prediction accuracy.

Possible future directions for this work might include expansion to additional software engineering domains and/or exploration of integration with other metaheuristic methods. The suggested approach may be integrated with other metaheuristic optimization methods such as particle swarm optimization (PSO), ant colony optimization (ACO), or differential evolution (DE) in the first potential direction. Investigating hybrid strategies that take advantage of several methods may result in even greater optimization performance and improved software effort estimation accuracy. While In the second scenario, the suggested approach may be investigated further and used in software engineering domains other than effort estimation.

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# A Novel Method for Diagnosing Alzheimer's Disease from MRI Scans using the ResNet50 Feature Extractor and the SVM Classifier

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**Abstract**—Alzheimer's disease (AD), a chronic neurodegenerative brain disorder, caused by the accumulation of abnormal proteins called amyloid, is one of the prominent causes of mortality worldwide. Since there is a scarcity of experienced neurologists, manual diagnosis of AD is very time-consuming and error-prone. Hence, automatic diagnosis of AD draws significant attention nowadays. Machine learning (ML) algorithms such as deep learning are widely used to support early diagnosis of AD from magnetic resonance imaging (MRI). However, they provide better accuracy in binary classification, which is not the case with multi-class classification. On the other hand, AD consists of a number of early stages, and accurate detection of them is necessary. Hence, this research focuses on how to support the multi-stage classification of AD particularly in its early stage. After the MRI scans have been preprocessed (through median filtering and watershed segmentation), benchmark pre-trained convolutional neural network (CNN) models (AlexNet, VGG16, VGG19, ResNet18, ResNet50) carry out automatic feature extraction. Then, principal component analysis is used to optimize features. Conventional machine learning classifiers (Decision Tree, K-Nearest Neighbors, Support Vector Machine, Linear Programming Boost, and Total Boost) are deployed using the optimized features for staging AD. We have exploited the Alzheimer's disease Neuroimaging Initiative (ADNI) data set consisting of AD, MCIs (MCI), and cognitive normal (CN) classes of images. In our experiment, the SVM classifier performed better with the extracted ResNet50 features, achieving multi-class classification accuracy of 99.78% during training, 99.52% during validation, and 98.71% during testing. Our approach is distinctive because it combines the advantages of deep feature extractors, conventional classifiers, and feature optimization.

**Keywords**—Alzheimer's disease; brain images; machine learning; deep learning; brain disorder; ADNI dataset

## I. INTRODUCTION

The neurological illness known as Alzheimer's disease (AD) affects the central nervous system and gradually worsens memory and cognitive function over time [1], [2]. Eventually causing the affected person to lose the ability to learn new information and to retain previously learned information [3] which severely impedes people's daily lives such as failing to recognize the family members and performing essential daily activities leaving the patients with anxiety, aggressiveness, or childish behavior [4]–[6]. Studies [7]–[11] shown that the neurological deterioration of this

disease includes the accumulation of abnormal beta-amyloid proteins and phosphorylated tau resulting in depreciation of the hippocampus and cerebral cortex while expanding the ventricles that leads affecting brain regions involved in remembering, thinking, planning, and decision-making.

Usually, AD symptoms appear after the age of 60 with rare exceptions that emerge relatively early at the age of 30 to 50 years in individuals with gene mutation [12]. However, the transition from a healthy state to AD takes several years [13] while going through three different stages, namely, normal controlled (NC), mild cognitive impairment (MCI), and AD. Among the three stages of Alzheimer's, MCI is the symptomatic stage, progressing to its most severe form over time. Since it leads a patient to experience a set of symptoms [14] it incurs huge costs for their proper care and treatment [15]. Therefore, early detection of the disease is essential for initiating treatments, minimizing brain cell damage, and enhancing the quality of life of affected individuals and their families

In the conventional diagnostic system, Alzheimer's patients can be diagnosed the late stages of the disease's progression. In the early stages, the symptoms are similar to those of normal aging. Also, in the conventional system, it is difficult to determine the stages of the disease which may prevent the patient from starting treatment earlier. Besides this, the conventional diagnostic system is limited by the availability of expert physicians and medical tools.

There are studies for automating the diagnosis of this disease. Conventional machine learning and deep learning-based approaches are proposed [16] to classify AD and their stages from different modalities of data. These Machine learning techniques specifically, deep learning techniques are gaining success in the early diagnosis of AD from magnetic resonance imaging (MRI) modality having better accuracy in binary classification while suffering in multiclass classification [2], [17]–[22]. Conventional machine learning leverages handcrafted features while deep learning methods automatically extract features in regression and classification tasks. Studies have shown that the use of conventional machine learning and deep learning techniques combines the strengths of each to create a more accurate and reliable diagnostic tool [3].

Deep Learning models combined with MRI data can give

a high degree of diagnostic accuracy of age-related cognitive decline (ARCD) in dementia patients [4], [21]. It has been argued that deep learning approaches produce the sufficient information necessary to correlate AD sample data [13]. Deep learning enables the characterization of AD in MRI images by generating computational models with multiple processing layers. It automatically retrieves its necessary information from input images, without the intervention of the expert who labels the information, as in a standard Machine Learning model [23]. Besides the conventional machine learning models demonstrated state-of-the-art performance in classification and regression tasks if the feature is provided. Considering the classification performance of conventional machine learning models and the automatic feature extraction capacity of deep learning models, specifically CNN, we utilized the strength of both approaches in our study to get better performance in multi-class classification. In this work, we have selected structured MRI (sMRI) data rather than multimodal or other single modal data considering the benefits mentioned in [21]. The data were collected from Alzheimer's Diseases Neuroimaging Initiatives (ADNI) database (adni.loni.usc.edu). Here, a robust and efficient machine learning model has been proposed for analyzing brain MRI images. There are five main phases in this work: (a) MRI Preprocessing (b) Region clustering (c) feature extraction (d) feature optimization and (e) classification of AD into one of its three stages. At first, preprocessing was performed. Preprocessing was necessary to alleviate the problem of low contrast and enhance image quality. The preprocessing tasks include skull removal, intensity normalization so that the mean is zero and variance is one, and image enhancement with histogram equalizations, and mean and median filtering techniques. For region clustering, we have experimented with otsu, edge-based clustering, k-means, region growing, morphology-based clustering, and fuzzy C-means algorithms and found the watershed algorithm suitable. From the clustered images we have selected 64 three-view patches of size 128 by 128 for further analysis.

To alleviate the problem of low contrast and enhance image quality watershed algorithm has been applied to the MRI image. For clustering, a region-based clustering technique that performs better than other state of art techniques has been chosen. The clustered image is further processed to extract features through the use of multiple deep-learning techniques. The principal component analysis was performed to find fine-tuned optimized features. Finally, these features are then input into a machine learning algorithm to classify the disease into its three major AD phases. The main contribution of our work are: 1) Combining the strength of both conventional and deep machine learning techniques for achieving better accuracy in multi-class classification of AD stages. 2) Improved performance with single modality structural MRI (sMRI) analysis without computing the whole brain. 3) Addressing dataset inconsistency and enhancing contrast quality and visibility through the use of contrast amplification techniques. 4) Selection of region clustering technique to find uniform samples for feature extraction that exhibits improved performance compared to conventional techniques.

The paper is organized as follows: Section II introduces the materials and methods including chosen dataset. Section III includes result analysis. Section IV incorporates the related works and discussion. Finally, the conclusion is drawn in

Section V.

## II. MATERIALS AND METHODS

The workflow for the proposed framework of Alzheimer's detection mechanism has been divided into several steps such as data collection, data preprocessing, region clustering, feature extraction, feature optimization, classification, and evaluation presented in Fig. 1.

First, the brain MR images have been collected from ADNI. The collected images are then preprocessed through several preprocessing techniques such as intensity normalization, image resizing, contrast enhancement techniques, etc. After completing the pre-processing step, the region clustering algorithms such as C-means, threshold-based otsu clustering, K-means, morphology-based, edge-based, watershed, region-growing, and k-means cluster-based methods have been applied to find out the distinct region for analysis.

Several deep learning techniques such as VGG16, VGG19, Alexnet, Resnet18, and Resnet50 have been applied to extract features from the three view samples selected from clustered images. Then features are optimized by using principal component analysis. Finally, the extracted images are then fed into five different ML techniques such as ensemble-based LP-Boost and TotalBoost, tree-based decision tree (DT), distance-based k-nearest neighbor (KNN), and Support Vector Machine (SVM) methods for the classification into three different stages of Alzheimer's.

### A. Dataset

In this study, a subset of the ADNI database has been considered for the experiment. The database was established in 2004 as a result of a public-private partnership with the collaboration of Dr. Michael W. Weiner. The objective of the ADNI dataset was to find the MRI, PET, clinical and neuropsychological assessments, and another biological marker behind the development of MCI and AD. The dataset comprises of 2042 brain MR images representing three different stages of AD such as AD, CN, and MCI. The details of the data are provided in the Table I.

TABLE I. DEMOGRAPHIC INFORMATION OF THE ADNI1:COMPLETE 2YR 1.5T DATASET

Class Label	Number of Scan	Male Subject	Female Subject	Age (Avg. +-std.)
CN	567	271	296	75.12+-8.10
MCI	1206	797	409	76.81+-5.51
AD	269	137	132	75.73+-7.17

The data imbalance problems were avoided by duplicating the MRIs. As we have sampled three view patches from segmented regions to ensure the representation of each significant region the repeated MRIs do not bias the model performance. We have considered total of 1546 MRIs for the experiment (CN-470, MCI-477, AD-599).

### B. Data Preprocessing

In our work, at first, we removed the skull from the MRI images. Then we performed intensity normalization so that the mean intensity is zero while keeping the intensity

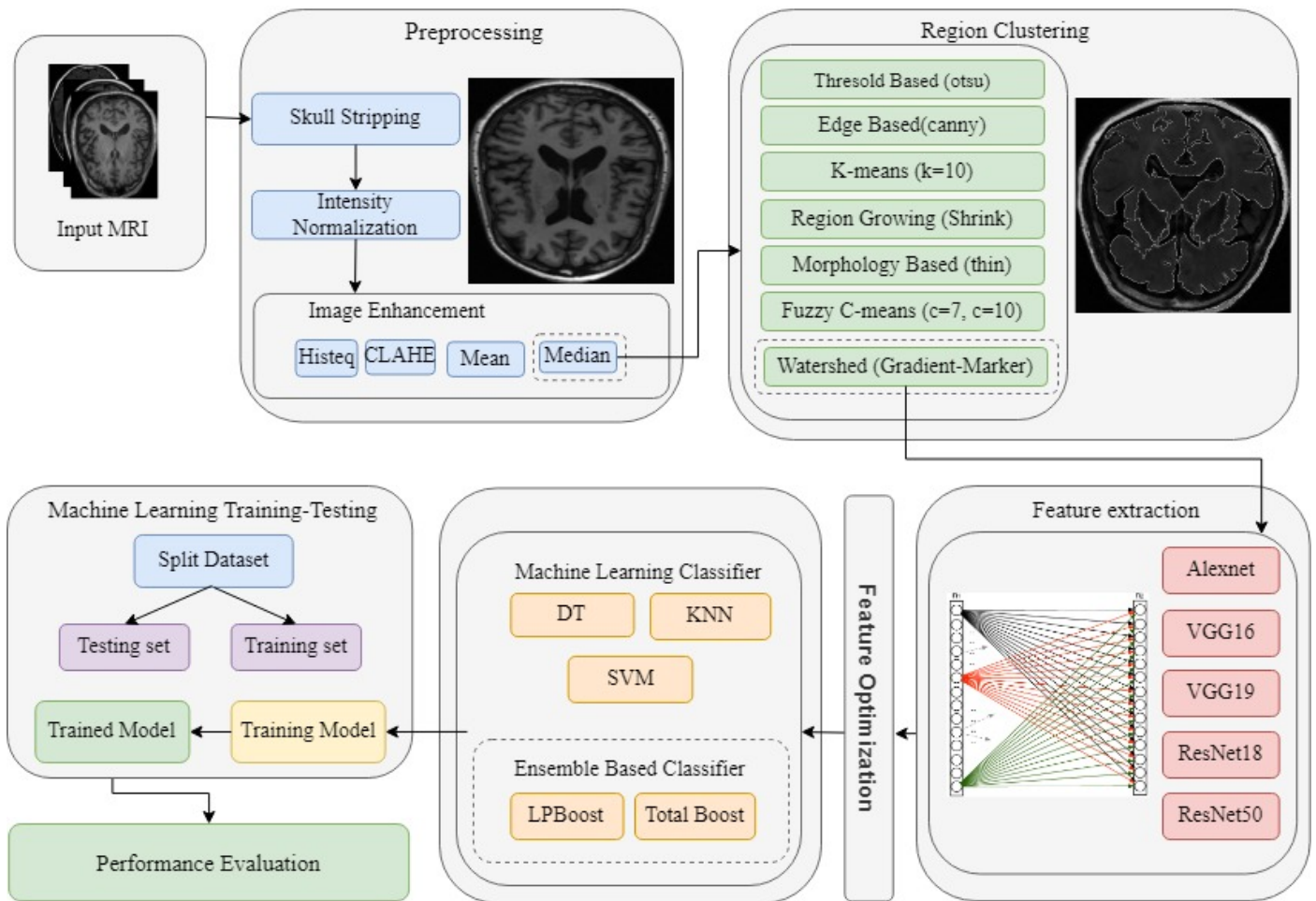


Fig. 1. Conceptual flow of the proposed model.

variance one. We used several pre-processing techniques for contrast enhancement like histogram equalization, contrast limiting adaptive histogram equalization (CLAHE), mean, and median filtering techniques. These techniques are widely used preprocessing methods for medical imaging [24], [25]. The effects of these techniques have been depicted in Fig. 2. Table II represents the comparison of the performance of the preprocessing techniques in terms of mean structural similarity (MSSIM), peak signal-to-noise Ratio (PSNR), and root mean square error (RMSE). It is found that the Median filter outperforms other techniques.

TABLE II. COMPARISON OF VARIOUS PREPROCESSING TECHNIQUES

Preprocessing Technique	MSSIM	PSNR	RMSE
Intensity Transformation	0.9940	12.6433	0.2333
Histogram Equalization	0.9386	3.1293	0.6975
Contrast Limited Adaptive Histogram Equalization (CLAHE)	0.9856	9.1310	0.3495
Mean Filter (3 by 3)	1	32.7397	0.0231
Median Filter (3 by 3)	1	37.5815	0.0132

### C. Region Clustering

In this work, we have applied several region clustering algorithms such as Threshold Based OTSU methods, Edge

Based CANNY filter, region-based region-grow method, Morphological Based THIN filter, K-means Clustering (k=4), Fuzzy Based C-means Clustering (c=4), Watershed with sobel filter considering their wide acceptance in medical imaging [26], [27]. To choose the appropriate method for our system we have calculated the evaluation metrics PSNR, SSIM, and RMSE of these clustering algorithms. In Fig. 3 different output images after using various clustering techniques have been represented. It has been proclaimed here that the Watershed-based clustering technique provides a better image than other techniques. The performance of image enhancement techniques is measured based on evaluation metrics PSNR, MSSIM, and RMSE scores. Table III represents the comparison of different pre-processing techniques. Based on the experimental result it has been found that the watershed algorithm outperforms other algorithms. Here the highest value of MSSIM and PSNR as well as the lowest value of RMSE has been considered to select the method for the system.

### D. Sample three View Patch and Feature Extraction

From the segmented images, we have sampled three view patches as inspired from [2], [21], [22] for further analysis. From each segment of an MRI, we have generated 16 uniformly random three-view patches of size 128 by 128 by 3.

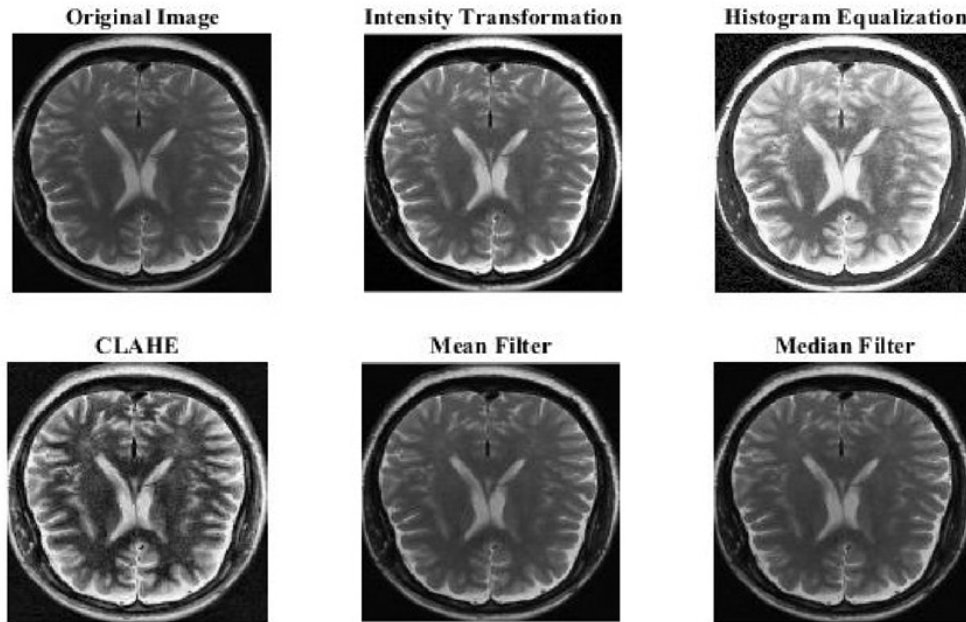


Fig. 2. Effects of various enhancement techniques.

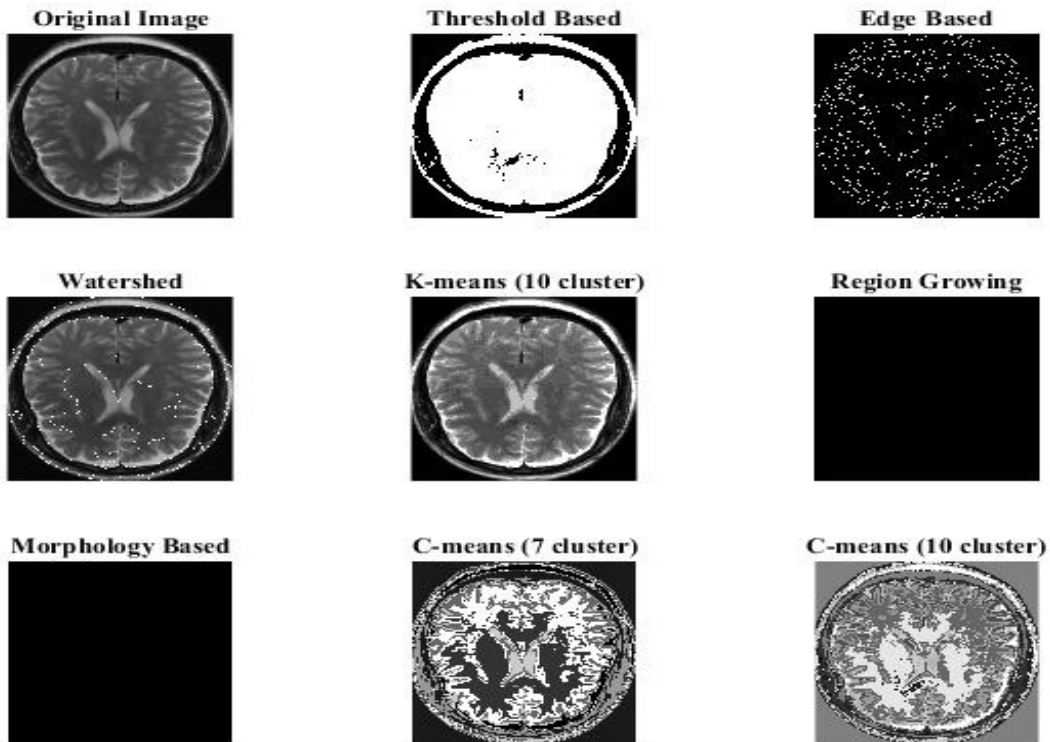


Fig. 3. Images with different clustering techniques.

Then, these are fed to benchmark CNN. In this paper, we have deployed five different benchmark CNN models such as AlexNet, VGG16, VGG19, ResNet18, and ResNet50. We have got the best results using ResNet50. The CNN generated a feature vector of size 262,144. We have applied principal component analysis for selecting optimal 8192 features from 262144 extracted by CNN.

#### E. Classification

In this paper, we have used five different classifiers (considering their classification performance as reputed in [28], [29]) such as DT [30], SVM [31], KNN [32], Linear programming boosting (LPBoost), and TotalBoost [33] after the feature extraction through different techniques.



TABLE III. PERFORMANCE ANALYSIS TABLE FOR IMAGE SEGMENTATION TECHNIQUES

Clustering Technique	MSSIM	PSNR	RMSE
Threshold-based (otsu)	0.9878	9.9152	0.3193
Edge-based (canny)	0.9957	12.1325	0.2474
Watershed (Gradient and Marker)	0.9989	16.3936	0.1515
K-means clustering (4 cluster)	0.9935	12.3958	0.2400
Region growing (shrink)	0.9963	14.5663	0.1869
Morphology based (thin)	0.9959	12.7946	0.2292
Fuzzy C-means clustering (4 clusters)	0.9289	2.5403	0.7464

### III. RESULTS

In this experiment, we have investigated the overall classification accuracy including the individual precision, recall, f1-score, accuracy, and misclassification rate. At first, for each model deep CNN based algorithm such as AlexNet, VGG16, VGG19, ResNet18, ResNet50 were used to extract the enhanced discriminative features. Then ensemble-based TotalBoost, tree-based DT, KNN, and SVM methods were applied for classification. To identify the classification errors of the algorithm, we have calculated the confusion matrix for each method.

#### A. Performance Evaluation

To evaluate the performance of the models we have considered several metrics such as precision, negative predictive value (NPV), sensitivity, efficiency, f1 score, and accuracy. The number of true positives (TP), false positives (FP), true negatives (TN), and false negatives (FN) from the confusion matrix are used to define the performance metrics using the following equations from (1) to (6).

$$Accuracy(x, y) = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

$$PPV(x, y) = \frac{TP}{TP + FP} \quad (2)$$

$$NPV(x, y) = \frac{TN}{TN + FN} \quad (3)$$

$$Recall \text{ or } Sensitivity \text{ or } TPR(x, y) = \frac{TP}{TP + FN} \quad (4)$$

$$Efficiency \text{ or } Specificity \text{ or } TNR(x, y) = \frac{TN}{TN + FP} \quad (5)$$

$$F_1 \text{ Score}(x, y) = 2 \times \frac{Precision \times Recall}{Precision + Recall} \quad (6)$$

#### B. Deep Feature Extraction using AlexNet

Experiments show that the AlexNet+ML classifier can successfully classify the different phases of AD. The overall classification accuracy for DT classifier achieved 81.5%. SVM, LPBoost, and TotalBoost attained 95.1%, 80.3%, and 81.6% accuracy individually. On the other hand, KNN reached the highest accuracy with 95.8% among the others. This result assures that the classification is performed correctly. Table IV illustrates the performance metrics of ML classifier with AlexNet. The detailed measurements of CN, MCI and AD classes are presented sequentially. Among all the classifier, KNN gained the highest average accuracy with 97.20%. Similarly, it reduced the minimum average error rate with 2.80% compared to the DT, SVM, LPBoost, and TotalBoost.

#### C. Deep Feature Extraction using VGG16

With features extracted by VGG16; DT, KNN, SVM, LPBoost and TotalBoost achieved the overall classification accuracy by 81.2%, 90.9%, 93.5%, 79.0% and 75.4% respectively. On the other hand, SVM reached the highest accuracy with 93.5% among the others. Table V illustrates the performance metrics of the ML classifier with VGG16. The detailed Among all the classifiers, SVM gained the highest average accuracy with 95.69%. Similarly, it reduced the minimum average error rate by 4.31% compared to the DT, KNN, LPBoost, and TotalBoost.

#### D. Deep Feature Extraction using VGG19

It has been found that SVM achieved the highest classification accuracy with 96.1%. DT, KNN, LPBoost, and Total Boost gained 79.9%, 92.6%, 84.8%, and 82.2% classification accuracy respectively. Table VI shows the Illustration of the performance metrics of ML classifier with ResNet50. Among all the classifiers, SVM gained the highest average accuracy with 97.41% minimum average error rate of 2.59%.

#### E. Deep Feature Extraction using ResNet18

The ResNet18+ML classifier model shows the classification of 3 different AD phases. SVM achieved the highest classification accuracy with 91.3%. DT, KNN, LPBoost, and Total Boost gained 75.1%, 90.0%, 79.0%, and 74.4% classification accuracy respectively. An illustration of the performance metrics of the ML classifier with ResNet18 is given in Table VII. Among all the classifiers, SVM gained the highest average accuracy with 94.17% minimum average error rate of 5.83%.

#### F. Deep Feature Extraction using ResNet50

It has been observed that SVM achieved the highest classification accuracy with 98.1%. Other classifiers such as DT, KNN, LPBoost, and Total Boost achieved 81.6%, 91.5%, 85.8%, and 81.6% classification accuracy. From the Table VIII we can observe that SVM gained 98.71% average accuracy. So, the average error rate is 1.29.

In Fig. 4 comparison of different CNN models has been shown. This figure has represented the performance of different CNN models based on accuracy and error rate. Here, ResNet50 with SVM has been provided with a high accuracy rate which is 98.71% and an error rate is 1.29% for the dataset. Based

TABLE IV. PERFORMANCE METRICS FOR THREE CLASS ML CLASSIFIER USING ALEXNET

Model	Class	Accuracy	Precision	NPV	Recall	Efficiency	F1 Score
AlexNet+ DT	Alzheimer's	0.9838	0.9833	0.9841	0.9752	0.9894	0.9793
	Cognitive Normal	0.8285	0.6737	0.8972	0.7442	0.861	0.7072
	MCI	0.8188	0.7447	0.8512	0.6863	0.8841	0.7143
	<b>Average</b>	<b>0.877</b>	<b>0.8005</b>	<b>0.9108</b>	<b>0.8019</b>	<b>0.9115</b>	<b>0.8002</b>
AlexNet+ KNN	Alzheimer's	1	1	1	1	1	1
	Cognitive Normal	0.9579	0.8947	0.986	0.9659	0.9548	0.929
	MCI	0.9579	0.9681	0.9535	0.901	0.9856	0.9333
	<b>Average</b>	<b>0.9719</b>	<b>0.9543</b>	<b>0.9798</b>	<b>0.9556</b>	<b>0.9801</b>	<b>0.9541</b>
AlexNet+ SVM	Alzheimer's	1	1	1	1	1	1
	Cognitive Normal	0.9515	0.9263	0.9626	0.9167	0.9671	0.9215
	MCI	0.955	0.9149	0.9674	0.9247	0.963	0.9198
	<b>Average</b>	<b>0.9688</b>	<b>0.947</b>	<b>0.9766</b>	<b>0.9471</b>	<b>0.9767</b>	<b>0.9471</b>
AlexNet+ LPBoost	Alzheimer's	0.9838	0.9667	0.9947	0.9915	0.9792	0.9789
	Cognitive Normal	0.8026	0.7263	0.8364	0.6635	0.8732	0.6935
	MCI	0.8188	0.6702	0.8837	0.7159	0.8597	0.6923
	<b>Average</b>	<b>0.8684</b>	<b>0.7877</b>	<b>0.9049</b>	<b>0.7903</b>	<b>0.904</b>	<b>0.7882</b>
AlexNet+ TotalBoost	Alzheimer's	0.945	0.8667	0.9947	0.9905	0.9216	0.9244
	Cognitive Normal	0.8155	0.8737	0.7897	0.6484	0.9337	0.7444
	MCI	0.8706	0.6915	0.9488	0.8553	0.8755	0.7647
	<b>Average</b>	<b>0.877</b>	<b>0.8106</b>	<b>0.9111</b>	<b>0.8314</b>	<b>0.9103</b>	<b>0.8112</b>

TABLE V. PERFORMANCE METRICS FOR THREE CLASS ML CLASSIFIER USING VGG16

Model	Class	Accuracy	Precision	NPV	Recall	Efficiency	F1 Score
VGG16 + DT	Alzheimer's	0.9450	0.9333	0.9524	0.9256	0.9574	0.9295
	Cognitive Normal	0.8479	0.7474	0.8925	0.7553	0.8884	0.7513
	MCI	0.8317	0.7234	0.8791	0.7234	0.8791	0.7234
	<b>Average</b>	<b>0.8748</b>	<b>0.8013</b>	<b>0.9080</b>	<b>0.8014</b>	<b>0.9083</b>	<b>0.8014</b>
VGG16+ KNN	Alzheimer's	0.9935	1	0.9894	0.9836	1	0.9917
	Cognitive Normal	0.9159	0.7368	0.9953	0.9859	0.895	0.8434
	MCI	0.9094	0.9681	0.8837	0.7845	0.9845	0.8667
	<b>Average</b>	<b>0.9396</b>	<b>0.9016</b>	<b>0.9561</b>	<b>0.9180</b>	<b>0.9598</b>	<b>0.9006</b>
VGG16+ SVM	Alzheimer's	1	1	1	1	1	1
	Cognitive Normal	0.9353	0.8632	0.9673	0.9213	0.9409	0.8913
	MCI	0.9353	0.9255	0.9395	0.87	0.9665	0.8969
	<b>Average</b>	<b>0.9569</b>	<b>0.9296</b>	<b>0.9689</b>	<b>0.9304</b>	<b>0.9691</b>	<b>0.9294</b>
VGG16+ LPBoost	Alzheimer's	0.9709	0.9333	0.9947	0.9912	0.9592	0.9614
	Cognitive Normal	0.8155	0.7263	0.8551	0.6900	0.8756	0.7077
	MCI	0.7929	0.6702	0.8465	0.6563	0.8545	0.6632
	<b>Average</b>	<b>0.8598</b>	<b>0.7766</b>	<b>0.8988</b>	<b>0.7792</b>	<b>0.8964</b>	<b>0.7774</b>
VGG16+ TotalBoost	Alzheimer's	0.9256	0.8167	0.9947	0.9899	0.8952	0.895
	Cognitive Normal	0.7767	0.8421	0.7477	0.597	0.9143	0.6987
	MCI	0.8058	0.5851	0.9023	0.7237	0.8326	0.6471
	<b>Average</b>	<b>0.8360</b>	<b>0.7480</b>	<b>0.8816</b>	<b>0.7702</b>	<b>0.8807</b>	<b>0.7470</b>

on this result it can be notified that SVM and KNN perform better than other classifiers. The performance of the ensemble classifier is not that much efficient for AD classification.

#### IV. DISCUSSION

The main objective of this work is to diagnose of AD in the early stages accurately. The comparative study of some of the recent state-of-the-art works in this field with our proposed

TABLE VI. PERFORMANCE METRICS FOR THREE CLASS ML CLASSIFIER USING VGG19

Model	Class	Accuracy	Precision	NPV	Recall	Efficiency	F1 Score
VGG19 + DT	Alzheimer's	0.9515	0.9500	0.9524	0.9268	0.9677	0.9383
	Cognitive Normal	0.8123	0.7263	0.8505	0.6832	0.8750	0.7041
	MCI	0.8350	0.6809	0.9023	0.7529	0.8661	0.7151
	<b>Average</b>	<b>0.8662</b>	<b>0.7857</b>	<b>0.9017</b>	<b>0.7876</b>	<b>0.9029</b>	<b>0.7858</b>
VGG19+ KNN	Alzheimer's	0.9871	1	0.9788	0.9677	1	0.9836
	Cognitive Normal	0.9320	0.8211	0.9813	0.9512	0.9251	0.8814
	MCI	0.9320	0.9362	0.9302	0.8544	0.9709	0.8934
	<b>Average</b>	<b>0.9503</b>	<b>0.9191</b>	<b>0.9634</b>	<b>0.9244</b>	<b>0.9653</b>	<b>0.9194</b>
VGG19+ SVM	Alzheimer's	1	1	1	1	1	1
	Cognitive Normal	0.9612	0.9368	0.972	0.9368	0.9720	0.9368
	MCI	0.9612	0.9362	0.9721	0.9362	0.9721	0.9362
	<b>Average</b>	<b>0.9741</b>	<b>0.9577</b>	<b>0.9813</b>	<b>0.9577</b>	<b>0.9814</b>	<b>0.9577</b>
VGG19+ LPBoost	Alzheimer's	0.9644	0.9167	0.9947	0.9910	0.9495	0.9524
	Cognitive Normal	0.8544	0.8421	0.8598	0.7273	0.9246	0.7805
	MCI	0.8770	0.766	0.9256	0.8182	0.9005	0.7912
	<b>Average</b>	<b>0.8986</b>	<b>0.8416</b>	<b>0.9267</b>	<b>0.8455</b>	<b>0.9248</b>	<b>0.8413</b>
VGG19+ TotalBoost	Alzheimer's	0.9450	0.8583	1	1	0.9175	0.9238
	Cognitive Normal	0.8479	0.7368	0.8972	0.7609	0.8848	0.7487
	MCI	0.8511	0.8617	0.8465	0.7105	0.9333	0.7788
	<b>Average</b>	<b>0.8813</b>	<b>0.8189</b>	<b>0.91457</b>	<b>0.8238</b>	<b>0.9119</b>	<b>0.8171</b>

TABLE VII. PERFORMANCE METRICS FOR THREE CLASS ML CLASSIFIER USING RESNET18

Model	Class	Accuracy	Precision	NPV	Recall	Efficiency	F1 Score
ResNet18 + DT	Alzheimer's	0.9159	0.8833	0.9365	0.8983	0.9267	0.8908
	Cognitive Normal	0.7767	0.6737	0.8224	0.6275	0.8502	0.6497
	MCI	0.8091	0.6596	0.8744	0.6966	0.8545	0.6776
	<b>Average</b>	<b>0.8339</b>	<b>0.7389</b>	<b>0.8778</b>	<b>0.7408</b>	<b>0.8771</b>	<b>0.7393</b>
ResNet18+ KNN	Alzheimer's	0.9968	0.9917	1	1	0.9947	0.9958
	Cognitive Normal	0.8997	0.8000	0.9439	0.8636	0.914	0.8306
	MCI	0.9029	0.883	0.9116	0.8137	0.9469	0.8469
	<b>Average</b>	<b>0.9331</b>	<b>0.8916</b>	<b>0.9518</b>	<b>0.8924</b>	<b>0.9519</b>	<b>0.8911</b>
ResNet18+ SVM	Alzheimer's	0.9871	0.9833	0.9894	0.9833	0.9894	0.9833
	Cognitive Normal	0.9126	0.8632	0.9346	0.8542	0.939	0.8586
	MCI	0.9256	0.8723	0.9488	0.8817	0.9444	0.877
	<b>Average</b>	<b>0.9418</b>	<b>0.9062</b>	<b>0.9576</b>	<b>0.9064</b>	<b>0.9576</b>	<b>0.9063</b>
ResNet18 + LPBoost	Alzheimer's	0.9547	0.9000	0.9894	0.9818	0.9397	0.9391
	Cognitive Normal	0.7929	0.8632	0.7617	0.6165	0.9261	0.7193
	MCI	0.8317	0.5745	0.9442	0.8182	0.8354	0.6750
	<b>Average</b>	<b>0.8598</b>	<b>0.7792</b>	<b>0.8984</b>	<b>0.8055</b>	<b>0.9004</b>	<b>0.7778</b>
ResNet18 + TotalBoost	Alzheimer's	0.9320	0.8333	0.9947	0.9901	0.9038	0.9050
	Cognitive Normal	0.7476	0.8316	0.7103	0.5603	0.9048	0.6695
	MCI	0.8091	0.5426	0.9256	0.7612	0.8223	0.6335
	<b>Average</b>	<b>0.8296</b>	<b>0.7358</b>	<b>0.8769</b>	<b>0.7705</b>	<b>0.8770</b>	<b>0.7360</b>

model has been shown in Table IX.

Jain et al. [34] utilized VGG19 features for classification using DT and demonstrated 86.62% overall accuracy with a sensitivity of 78.76% and a specificity of 90.29. The

authors computed the whole brain in their work. Our method demonstrated higher performance with the VGG16+PCA+DT pipeline in reduced sampled brain region (accuracy 87.48%, sensitivity 80.13%, and specificity 90.83%). Pueto-Castro et

TABLE VIII. PERFORMANCE METRICS FOR THREE CLASS ML CLASSIFIER USING RESNET50

Model	Class	Accuracy	Precision	NPV	Recall	Efficiency	F1 Score
ResNet50 + DT	Alzheimer's	0.9482	0.9250	0.9630	0.9407	0.9529	0.9328
	Cognitive Normal	0.8317	0.6842	0.8972	0.7471	0.8649	0.7143
	MCI	0.8511	0.8085	0.8698	0.7308	0.9122	0.7677
	<b>Average</b>	<b>0.8770</b>	<b>0.8059</b>	<b>0.9100</b>	<b>0.8062</b>	<b>0.9100</b>	<b>0.8049</b>
ResNet 50+ KNN	Alzheimer's	0.9968	0.9917	1	1	0.9947	0.9958
	Cognitive Normal	0.9450	0.9053	0.9626	0.9149	0.9581	0.9101
	MCI	0.9482	0.9255	0.9581	0.9063	0.9671	0.9158
	<b>Average</b>	<b>0.9633</b>	<b>0.9408</b>	<b>0.9736</b>	<b>0.9404</b>	<b>0.9733</b>	<b>0.9406</b>
ResNet50+ SVM	Alzheimer's	0.9968	0.9917	1	1	0.9947	0.9958
	Cognitive Normal	0.9806	0.9684	0.9860	0.9684	0.9860	0.9684
	MCI	0.9838	0.9787	0.9860	0.9684	0.9907	0.9735
	<b>Average</b>	<b>0.9871</b>	<b>0.9796</b>	<b>0.9907</b>	<b>0.9789</b>	<b>0.9904</b>	<b>0.9792</b>
ResNet50 + LPBoost	Alzheimer's	0.9741	0.9333	1	1	0.9594	0.9655
	Cognitive Normal	0.8576	0.9158	0.8318	0.7073	0.9570	0.7982
	MCI	0.8835	0.7021	0.9628	0.8919	0.8809	0.7857
	<b>Average</b>	<b>0.9050</b>	<b>0.8504</b>	<b>0.9315</b>	<b>0.8664</b>	<b>0.9324</b>	<b>0.8498</b>
ResNet50 + TotalBoost	Alzheimer's	0.9547	0.8833	1	1	0.9310	0.9381
	Cognitive Normal	0.8155	0.8842	0.7850	0.6462	0.9385	0.7467
	MCI	0.8608	0.6596	0.9488	0.8493	0.8644	0.7425
	<b>Average</b>	<b>0.8770</b>	<b>0.8090</b>	<b>0.911267</b>	<b>0.831833</b>	<b>0.9113</b>	<b>0.8091</b>

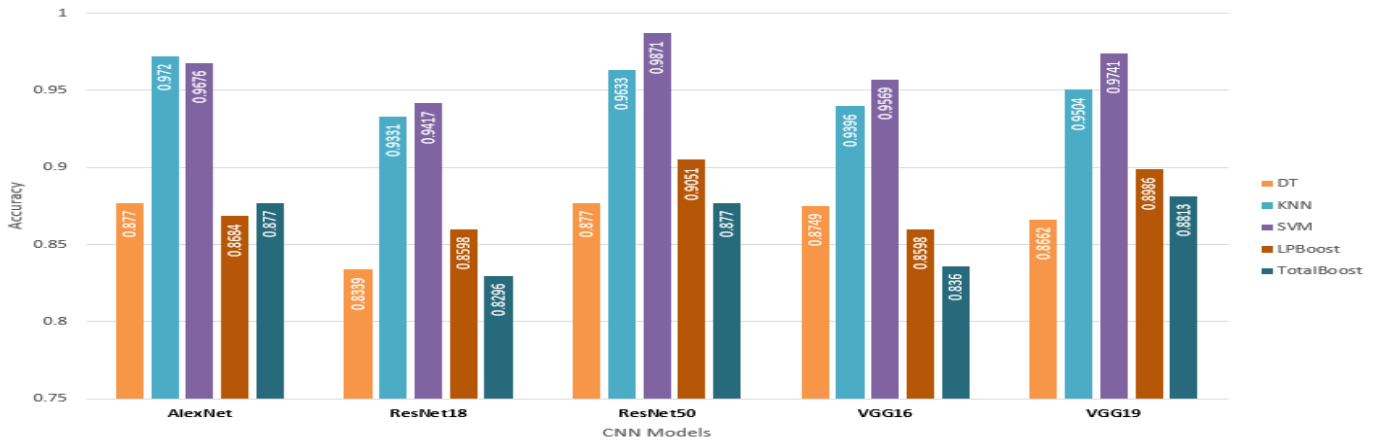


Fig. 4. Comparison of the performance of applied techniques consists of CNN feature extractor with ML classifier.

al. [35] exploited OASIS dataset and deployed RESNET18 with SVM classifiers on the whole brain. The method demonstrated a sensitivity of 58.66% and specificity of 80.21% while combining the RESNET 18 features with DenseNet121 features Odusami et al. [36] showed more than 98% in all performance measures. Feng et al. [6] utilized 3DCNN with SVM and showed 92% accuracy with standard deviation of 2. Raju et al. [37] have shown higher performance with the same method and same dataset(97% above in terms of accuracy, precision and recall). Abdulazeem et al. [38] designed a CNN classifier and demonstrated 97.50% accuracy while Hazarika et al. [39] demonstrated 88.66% accuracy with CNN based hybrid model. They have computed the whole brain. In our work, the CNN model ResNet50 along

with SVM classifier has achieved comparable performance with 98.71% accuracy, 97.96% precision, 99.07% NPV, 97.89% recall, 99.04% specificity, and 97.92% f1 score. It is evident from the Table IX that our proposed model outperforms other works such as [6], [34]–[39]. Moreover, in comparison to the whole brain computation of the studies we have computed features from 128 by 128 by 3 slices of MRIs.

## V. CONCLUSIONS

In this paper, we have presented a pipeline for classifying an MRI into one of its three stages(AD, MCI, CN). We have leveraged the benefits of the capacity of deep learning

TABLE IX. COMPARISON WITH STATE-OF-THE ART WORKS

Study	Dataset with stages	Modality	Feature Extraction with Classifier	Performance metrics
Jain et al. [34]	ADNI-150 subjects (AD-50,CN-50, MCI-50)	sMRI	VGG16	Accuracy: 95.73% Precision:96.33% Recall: 96% F1 score: 95.66%
Pueto-Castro et al. [35]	OASIS-416 (AD-2, CN-316, MCI-98); ADNI-1743 (AD-287, CN-525, MCI-921)	MRI	Resnet 18 and SVM	Accuracy: 78.72% Precision: 68.96 % Recall: 58.66% Specificity: 80.21% F1 score: 60.79%
Odusami et al. [36]	ADNI (AD,CN, MCI)	MRI	Resnet18 and DenseNet121 with Randomized weight	Accuracy: 98.21% Precision: 98.14 % Recall: 98.14%
Feng et al. [6]	ADNI-469 subjects (AD-153, MCI-157, CN-159)	MRI	3D-CNN with SVM	Accuracy: 92.11%± 2.31
Raju et al. [37]	ADNI-465 subjects (AD-132, MCI-181, CN-152)	MRI	3D-CNN with SVM	Accuracy: 97.77% Precision: 97.93% Recall: 97.76% F1 score: 97.80
Abdulazeem et al. [38]	ADNI-211,655 (After augmentation)	MRI	CNN	Accuracy: 97.50%
Hazarika et al. [39]	ADNI- 150 subjects (CN:50, MCI: 50, AD: 50)	MRI	Custom CNN based Hybrid Model	Accuracy: 84.66% Precision: 88.33% Recall: 87.66% F1 score: 88.33%
<b>Proposed</b>	<b>ADNI-1546 (CN-470, MCI-477, AD-599)</b>	<b>MRI</b>	<b>Resnet50 +SVM</b>	<b>Accuracy: 98.71%</b> <b>Precision: 97.96 %</b> <b>NPV: 99.07%</b> <b>Sensitivity/Recall: 97.89%</b> <b>Specificity: 99.04%</b> <b>F1 Score: 97.92%</b>

methods in feature extraction and the classification strength of conventional ML methods. In our method, we have optimized benchmark CNN-extracted features from three view patches by PCA that are generated from segmented regions of MRI enabling us to avoid whole-brain computation. We have demonstrated state-of-the-art performance exploited on the ADNI dataset. Our work showed that the RESNET50-PCA-SVM pipeline suits well for this multi-class classification task.

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# Uncertainty-Aware Traffic Prediction using Attention-based Deep Hybrid Network with Bayesian Inference

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**Abstract**—Traffic congestion has an adverse impact on the economy and quality of life and thus accurate traffic flow forecasting is critical for reducing congestion and enhancing transportation management. Recently, hybrid deep-learning approaches show promising contributions in prediction by handling various dynamic traffic features. Existing methods, however, frequently neglect the uncertainty associated with traffic estimates, resulting in inefficient decision-making and planning. To overcome these issues, this research presents an attention-based deep hybrid network with Bayesian inference. The suggested approach assesses the uncertainty associated with traffic projections and gives probabilistic estimates by applying Bayesian inference. The attention mechanism improves the ability of the model to detect unexpected situations that disrupt traffic flow. The proposed method is tested using real-world traffic data from Dhaka city, and the findings show that it outperforms than other cutting-edge approaches when used with real-world traffic statistics.

**Keywords**—Traffic flow prediction; uncertainty; deep learning; Bayesian inference; Dhaka city

## I. INTRODUCTION

Traffic congestion has a significant negative impact on the global economy as it decreases productivity, and increases waiting time, fuel consumption, air pollution, etc. According to INRIX, a major transportation analytics provider, estimates that the typical commuter in the top 1000 cities in the world will spend 99 hours stuck in traffic congestion in the year 2020 [1]. As a consequence of this, an estimated economic cost of \$1,036 per commuter was incurred as a result of wasted time as well as fuel [2]. More specifically, Dhaka city, the capital of Bangladesh lost Tk56,000 crore (6.5 billion US Dollar) in 2020 due to traffic congestion [3]. Thus for improving the country's economy and for better people's daily life, it is needed to improve the traffic condition. For example, reducing congestion in only Dhaka city gets to benefit from the massive economic growth of 35 percent of the country's GDP [3]. One promising way to mitigate traffic congestion is to accurately predict traffic flow since it helps users to make better route planning and city planners to effectively manage traffic throughout the city.

Extensive research has been conducted on traffic flow prediction, and several strategies have been developed over the years. Among them, deep hybrid approaches have recently gained attention and popularity because of their capacity to capture the complex dynamic nature of traffic data [4]. Traffic flow has complex dynamics as it depends on both space and time dimensions since it has spatiotemporal features. Recent

approaches make use of the power of deep learning algorithms to identify complex spatiotemporal patterns and dependencies in the traffic flow. Besides these, traffic flow is also affected by the many sudden incidents such as accidents, rain, VIP movement, social event, and many more. The attention mechanism is incorporated with a deep hybrid approach to tackle this dynamic and sudden traffic nature. Although the deep hybrid methods can capture the spatiotemporal traffic pattern, it only generates a point prediction and neglects the inherently uncertain nature of the traffic data [5]. Uncertainty is associated with every outcome of any prediction algorithm and most of the existing prediction methods do not consider uncertainty of their predicted outcome. However, uncertainty is accompanied by predicted outcomes due to the overfitting nature of learning, lack of model knowledge, and also the dynamic nature of the traffic flow [6].

Prediction models can generate overly optimistic or gloomy projections when uncertainty is not appropriately addressed in traffic flow prediction. This can lead to poor decision-making and planning since they are providing deterministic predictions. If a forecast model, for instance, does not take into account the uncertainty associated with unexpected traffic events, then it is possible that it would underestimate or overestimate the levels of congestion.

To solve this issue, this paper proposes a prediction approach where Bayesian inference is incorporated with the attention-based deep hybrid network. The proposed method considers the network-traffic flow rather than a single road and considers the connectivity among the links to make better predictions. This method captures the spatiotemporal features of the traffic flow by using a deep hybrid network and handles the sudden incident using an attention mechanism. To handle uncertainty, we mainly incorporate Bayesian inference with attention-based deep hybrid network for prediction. Bayesian inference reduces uncertainty in predicted outcomes made by deep hybrid networks by providing probability. Probabilistic prediction can provide a better outcome to measure the uncertainty and risks of the predicted outcome since it provides an interval consisting of the lower and upper bound in which the future estimation should lie [7]. Thus we have incorporated Bayesian inference in our prediction model. The main contribution of this paper is three folds:

- Proposed model takes into account linked road information, which enables a more comprehensive and precise forecast of traffic flow. The utilization of

this technique allows for the model to effectively apprehend the spatiotemporal interconnections and interdependencies among distinct road segments.

- To handle uncertainty, Bayesian inference is incorporated in the proposed method to measure the probability of the traffic flow propagating to a certain direction. Then, prediction is made by combining the traffic features and reducing uncertainty.
- The proposed approach is validated on the real-life traffic data of Dhaka city collected from Google Maps. To the best of our understanding, this is the first study that uses deep learning with Bayesian estimation to estimate traffic flow in Dhaka. The outcomes indicate that the proposed methodology outperforms all of the standard techniques in terms of prediction accuracy.

The remaining sections of the paper are structured as follows: Section II provides a comprehensive literature review, discussing existing works in the field. In Section III, we present essential background knowledge that underpins our proposed method. Section IV elaborates on our proposed methodology. The results and interpretations of our studies are presented in Section V. In Section VI, we delve into a related discussion surrounding our proposed method. Finally, Section VII offers a concise conclusion summarizing our findings.

## II. LITERATURE REVIEW

Accurate prediction of traffic patterns plays a vital role in mitigating congestion and improving traffic flow. Many existing research has focused on traffic flow prediction, however, only a few of them have taken the uncertainty associated with these projections into account. Traffic flow is naturally unpredictable and it is critical to take this into account when making predictions. In this section, some research works that concentrate on uncertainty within prediction are addressed here.

Researchers aim to improve the precision and dependability of traffic forecast models by including uncertainty quantification. Ying Wu et al. [8], for example, develop a Bayesian deep learning model for traffic speed prediction with uncertainty quantification. This model uses ChebNet to capture the spatial feature and uses gated linear units (GLU) for temporal prediction. The model is designed to be a universal traffic forecasting framework and perform better in traffic flow and speed forecasting tasks both in prediction accuracy and handling uncertainty. However, this model can not be able to capture all the factors that affect traffic speed, such as weather conditions and sudden incidents.

Another recent work proposed by Genwang Liu et. al. [9] focuses on the problem of incident detection on freeways and addresses the challenge of uncertainty quantification. The proposed method utilizes a variant of convolutional neural networks (CNN) within a Bayesian framework. The weight of the model is updated using mechanisms such as Bayes by backpropagation and local reparameterization techniques. By integrating the aleatoric uncertainty (uncertainty in the data) and epistemic uncertainty (uncertainty in the model), the method models the predictive uncertainty comprehensively.

The results of the experiments indicate that the aleatoric uncertainty of the model remains relatively stable under different noise levels.

Mundher Seger et al. [10] presents a Monte Carlo simulation-based method for quantifying uncertainty in traffic assignments, as well as insights into the unpredictability and bias of expected traffic flows. The authors created an approach that utilizes Monte Carlo simulation to evaluate uncertainty in traffic flows. The values of the origin-destination (OD) matrix were handled as stochastic variables with a specified probability distribution. The methodology calculated values for every link by simulating traffic patterns on the transportation network. This work focuses on four scenarios that can occur when uncertainty exists: Case 1: low prediction uncertainty, Case 2: medium prediction uncertainty, Case 3: large prediction uncertainty with ensemble agreement, and Case 4: severe prediction uncertainty with divergence estimates. They also discovered that traffic flow uncertainty occurs on all transportation network links, but to varying degrees, depending on the scenario's specifications and actual traffic flow.

To deal with the issue of low fitting between projected and real values in existing research methodologies, Lingmin Yang [11] proposes a traffic flow uncertainty prediction approach based on the K-nearest neighbor (KNN) algorithm. To generate the necessary database for the prediction process, the suggested method uses numerous databases, comprising the original database, classification center database, k-nearest neighbor database, and intermediate search database. The method employs multivariate linear regression to assign weights to state variables, taking into account the uncertainties of traffic flow. The K-nearest neighbor algorithm and Kalman filter are then utilized to update the weights iteratively, adapting them to the evolving uncertainties of traffic flow. Through this iterative process, the predicted values of traffic flow uncertainties are obtained. In their paper, they mainly handle the uncertainty by considering linked road information. When predicting a road segment they consider the other connected road traffic condition. Their experimental result shows that the model achieves good accuracy but it still suffers from uncertainty and the sudden incident can not be handled by the method.

For traffic prediction, Jun Fu et al. [12] suggests a Bayesian Spatio-Temporal Graph Convolutional Network (BSTGCN). This method learns the graph structure using both the physical road network topology and the traffic data. Graph convolutional networks (GCN) are utilized for expressing traffic data as well as the physical structure of road networks as graphs. This enables a more accurate depiction of the intricate interactions between traffic flows to be captured. Furthermore, they provide a probabilistic generative model for expressing the graph structure, which improves the generalization capability of GCNs and handles uncertainty.

## III. BACKGROUND

In this paper, we use ConvLSTM to handle spatiotemporal data, attention mechanism to handle sudden incidents and Bayesian Inference to handle uncertainty. In the following section, the background of this models is discussed.

### A. Convolutional Long Short-Term Memory

ConvLSTM (Convolutional Long Short-Term Memory) is a type of recurrent neural network (RNN) that is intended to handle spatiotemporal data. It uses the strengths of both convolutional neural networks (CNNs) and long short-term memory (LSTMs) to make a better model. This makes ConvLSTM very good at jobs that involve sequential data with a spatial structure, like analyzing videos, predicting the weather, and predicting traffic.

In ConvLSTM, the input data is in a matrix format, where the measurements are width, height, and time steps.

$$X_t^s = \begin{bmatrix} V_{t-m}^s \\ \vdots \\ V_{t-1}^s \\ V_t^s \end{bmatrix} = \begin{bmatrix} V_{t-m}^1 & V_{t-m}^2 & \cdots & V_{t-m}^n \\ \vdots & \vdots & \ddots & \vdots \\ V_{t-1}^1 & V_{t-1}^2 & \cdots & V_{t-1}^n \\ V_t^1 & V_t^2 & \cdots & V_t^n \end{bmatrix} \quad (1)$$

where  $X_t^s$  represents the road networks state, including  $m+1$  time periods and  $n$  road segments.  $V_t^s = [V_t^1, V_t^2, \dots, V_t^n]$  denotes traffic intensity of all road segments in the road networks at time  $t$ . The convolutional layer and pooling layer of the first CNN takes the input data and convert multi-dimensional data  $V_t^s$  into one-dimensional data for LSTM. The main idea behind ConvLSTM is to record spatial dependencies by using convolutional operations instead of fully connected layers in the LSTM cell. This lets the model take advantage of the local connectedness and parameter-sharing features of CNNs, which are good for dealing with spatial data. The equations for ConvLSTM can be expressed as follows:

Input Gate:

$$i_t = \sigma(W_{xi} * X_t + W_{hi} * H_{t-1} + W_{ci} \circ C_{t-1} + b_i) \quad (2)$$

Forget Gate:

$$f_t = \sigma(W_{gf} * O_t^s + W_{hf} * H_{t-1}^s + W_{cf} \circ C_{t-1} + b_f) \quad (3)$$

Cell Update:

$$C_t = f_t \circ C_{t-1} + i_t \circ \tanh(W_{gc} * O_t^s + W_{hc} * H_{t-1}^s + W_{cc} * H_{t-1}^s + b_c) \quad (4)$$

Output Gate:

$$O_t = \sigma(W_{go} * O_t^s + W_{ho} * H_{t-1}^s + W_{co} \circ C_t + b_o) \quad (5)$$

In these equations,  $X_t$  represents the input tensor at time step  $t$ ,  $H_{t-1}$  represents the hidden state tensor from the previous time step, and  $C_{t-1}$  represents the cell state tensor from the previous time step. The  $*$  operator denotes the convolution operation,  $\circ$  represents the Hadamard product (element-wise multiplication), and  $\sigma$  denotes the sigmoid activation function. The ConvLSTM cell consists of input gates ( $i_t$ ), forget gates ( $f_t$ ), and output gates ( $o_t$ ) that control the flow of information within the cell. The cell state ( $C_t$ ) is updated based on the input, previous cell state, and the gates. The hidden state ( $H_t$ ) is computed by applying the output gate to the cell state passed through the hyperbolic tangent activation function. By using convolutional operations within the LSTM cell, ConvLSTM can describe complex spatiotemporal patterns in the data. It does this by capturing spatial dependencies across different time steps. This makes ConvLSTM a powerful tool for analyzing and predicting spatiotemporal data.

### B. Attention Mechanism

The attention mechanism is crucial for enhancing the performance and effectiveness of traffic flow prediction systems. It enables the model to focus on important spatial and temporal information, focusing on specific regions or time steps that are more useful for the prediction aim [13]. Incorporating attention processes can help collect complicated trends, dependence, and changes in traffic data, leading to more precise and interpretable forecasts. To gain the benefits of the attention mechanism in traffic flow prediction, a combination of two ConvLSTM layers can be used. ConvLSTM layers are RNN layers that combine convolutional layers with LSTM (Long Short-Term Memory) units. These layers are quite helpful in mimicking spatiotemporal dependencies in traffic data. By combining spatial information from the first ConvLSTM layer with temporal information from the second ConvLSTM layer, the model can successfully capture both local spatial patterns and long-term temporal correlations in traffic data. This combination enables the attention mechanism to prioritize important spatial and temporal regions, resulting in more accurate predictions from the model.

### C. Bayesian Inference

Bayesian inference is an approach to statistics that uses Bayes' theorem to revise our assumptions or probabilities depending on observed data. Bayesian inference represents the uncertainty related to predictions in a probabilistic manner [14]. Bayesian inference, rather than offering a single-point projection, provides a posterior probability range that defines the range of alternative outcomes and associated likelihoods. This distribution represents the prediction's uncertainty, providing decision-makers with a full picture of the probable outcomes. The Bayes theorem can be represented mathematically as:

$$P(H|D) = \frac{P(D|H).P(H)}{P(D)} \quad (6)$$

where,  $P(H|D)$  is the posterior probability of hypothesis  $H$  given the observed data  $D$ .

$P(D|H)$  is the likelihood of observing data given hypothesis  $H$ .

$P(H)$  is the prior probability of hypothesis  $H$  before observing the data.

$P(D)$  is the probability of observing the data  $D$ .

The Bayesian inference posterior distribution provides a quantifiable measure of uncertainty. It can be used to compute statistics such as confidence intervals or reasonable intervals, which specify the range of values that the real value of a parameter or variable is expected to fall. These intervals indicate the prediction's uncertainty and serve as a measure of the confidence or dependability associated with the estimations.

## IV. PROPOSED METHOD

In this section we have presented our proposed prediction approach with Bayesian Inference which incorporated linked road traffic information using graph. We start with a linked road network graph  $G(V, E)$ , where  $V$  is the set of  $N$  roads and  $E$  is the set of edges. We also collect historical information about the road segments.  $X_{1:t} = \{X_1, X_2, X_3, \dots, X_t\}$ , where  $X_t$  is a member of  $\mathbb{R}^{N \times n}$  and  $n$  is the size of the traffic data. Our

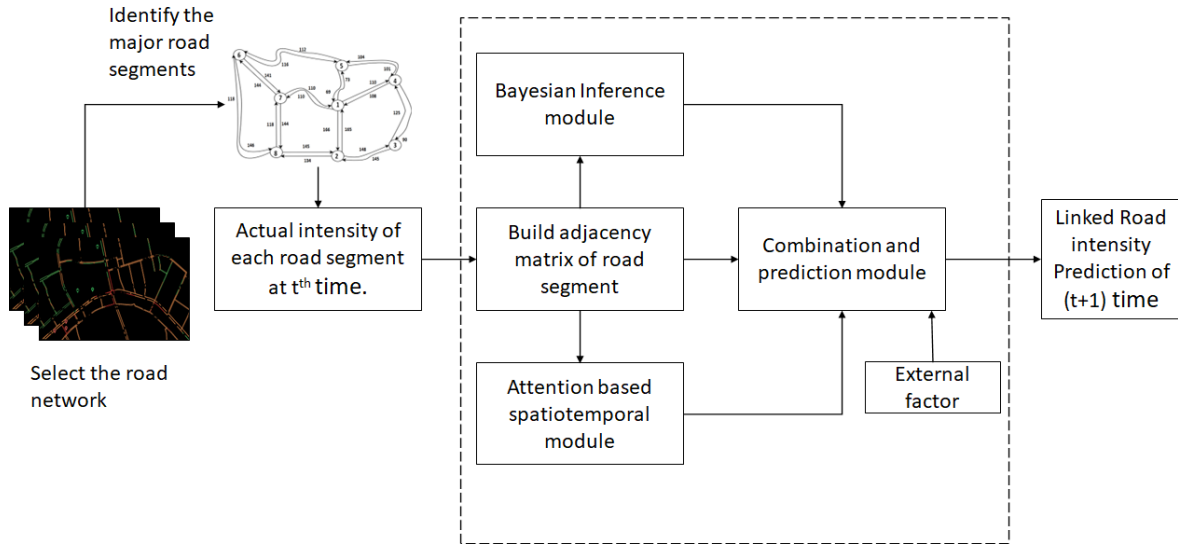


Fig. 1. Overall process of our proposed attention-based deep hybrid network with bayesian inference.

main goal is to predict the traffic flow for the next  $T$  timesteps, from  $X_{t+1}$  to  $X_{t+T}$ , based on collected historical data. For accurate traffic flow prediction, we proposed a technique that incorporates three modules, an attention-based spatiotemporal module, a Bayesian inference module, and a prediction module. An attention-based spatiotemporal module ( $H$ ) can handle the spatiotemporal nature of traffic data and also handle sudden incidents. The Bayesian inference module ( $B$ ) handles the uncertainty of traffic prediction. Lastly, the prediction module ( $P$ ) combines the other modules and produces the next timesteps traffic flow prediction  $X_{t+T}$ . So our objective function is used to minimize the prediction error by reducing uncertainty which can be written as

$$\min(\|Y_i - P(X_{t+1:t+T} : X_{1:t}, G(V, E), H, B, P)\|) \quad (7)$$

Our proposed model's main objective is to produce a more accurate prediction and the difference should be minimized from the actual value. In equation 7  $Y_i$  is the actual value of traffic flow. Fig. 1 represents the proposed attention-based deep hybrid network with Bayesian inference. In the following subsection, we describe the procedures of the modules.

#### A. Attention-based Spatiotemporal Module

The Attention-based spatiotemporal module is a key component of the proposed model, designed to calculate the spatiotemporal weight ( $STW$ ). This module utilizes two ConvLSTM layers to capture the temporal dependencies in the data. The input to the module consists of the data from each road segment, along with external factors such as temperature, holidays, or any other relevant information. These inputs are processed by the ConvLSTM layers, which enable the model to learn and capture the temporal patterns and dependencies in the data. By incorporating the external factors, the module can account for their influence on the spatiotemporal weight calculation. This allows the model to adapt its predictions based on specific contextual information, such as the impact of temperature or holidays on traffic patterns. The internal structure of the module is shown in Fig. 2.

#### B. Bayesian Inference Module

Most existing works only predict traffic flow using spatiotemporal weights without considering the data's uncertainty. Those predictions neglect the diversity and uncertainty of data and network parameters and provide a deterministic forecast. Indeed, traffic conditions can vary between different days and times, such as the difference between a Sunday at 8:00 AM and a Monday or the following Sunday. This variation can lead to differing levels of congestion. However, if a deep learning model overfits the data, it may struggle to capture this uncertainty accurately, resulting in uncertain predictions. To overcome this problem, the proposed framework incorporated Bayesian inference with an attentive spatiotemporal convolutional network to handle uncertainty within the prediction. Bayesian inference determines the probability associated with certain predictions which defines the probability of a particular prediction.

Incorporating Bayesian inference with the transitional probability ( $TP$ ) calculation can help to handle uncertainty and provide a more accurate estimate of the probability of traffic flow propagation. We used the Bayesian theorem to calculate the posterior probability of a particular road segment given the collected traffic data, which is represented as  $P(i|D(t))$ . Then, using the adjacency matrix of the graph, we calculate the prior probability of being on that road segment at the next time step, represented as  $P(i|t+1, D(t))$ . Using the prior and posterior probabilities, the transitional probability of propagating traffic from road segment  $i$  to road segment  $j$  at time  $t$ , represented as  $P(i \rightarrow j|t)$  is calculated.

$$P(i \rightarrow j|t) = P(j|i, t) \cdot P(i|t+1, D(t)) \quad (8)$$

where  $P(j|i, t)$  is the conditional probability of propagating from road segment  $i$  to road segment  $j$  within a given time period, and  $D(t)$  refers to the traffic data collected at a particular time step  $t$ . By combining the Bayesian inference with the transitional probability calculation, we can obtain the Bayesian transitional probability of propagating traffic from road segment  $i$  to road segment  $j$  at time  $t$ , which is

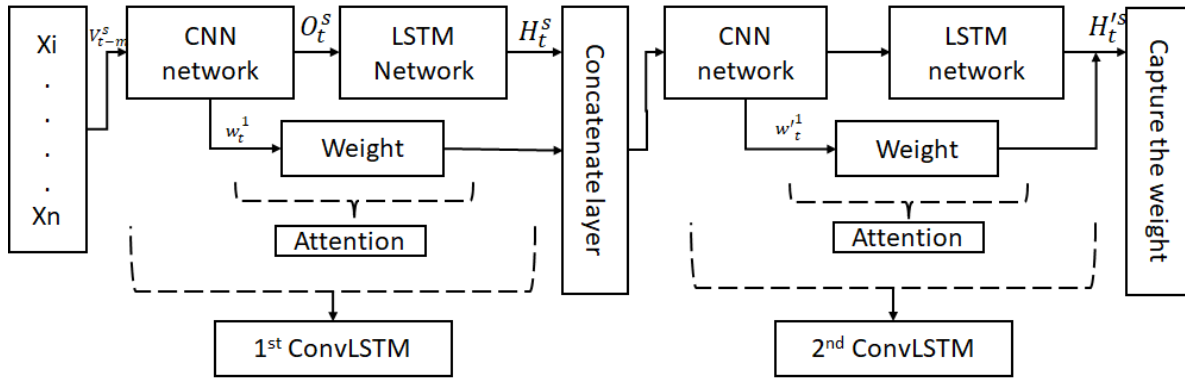


Fig. 2. Internal structure of attention-based spatiotemporal module.

represented as  $P(i \rightarrow j|D(t))$ .

$$P(i \rightarrow j|D(t)) = P(j|i, t) \cdot P(i|D(t)) \quad (9)$$

This probability represents the likelihood of traffic flow transitioning from segment  $i$  to segment  $j$  given the historical traffic data. We calculate the posterior probability of each road segment using the collected traffic data, then calculate the prior probability using the adjacency matrix of the graph. Finally, we use the prior and posterior probabilities to obtain the Bayesian transitional probability of traffic flow transitions between road segments in the network. Bayesian inference with the transitional probability calculation using the last two-time adjacency matrix, we can obtain the Bayesian transitional probability of traffic flow transitions between road segments in the network. This probability takes into account the uncertainty in the data and network parameters, providing a more accurate estimate of the likelihood of traffic flow transitions.

### C. Combination and Prediction Module

After finding the matrices such as the transitional probability matrix represented as  $(TP)$  and the spatiotemporal weight matrix as  $(STW)$ . The process of finding these values is described above. To predict the intensity of the next time step  $(t)$ , we combine spatiotemporal weights  $(STW)$ , transitional probability  $(TP)$ , and actual intensity matrix  $(A)$  of the previous time step  $(t-1)$ . We combine the spatiotemporal and transitional probability of the previous time step  $(t-1)$  using equation 10 and find the combined weight as  $(SPW)$ , which handles spatiotemporal traffic features and uncertainty. Then, the prediction is made by multiplying previous time steps combined weight  $(SPW^{t-1})$  with the actual intensity matrix  $(A^{t-1})$  as shown in equation 11. Where  $(A^t)$  represents the next timesteps prediction outcomes. Algorithm 1 shows the overall process of the proposed prediction architecture where three dynamic characteristics of traffic flow are incorporated.

$$P^{t-1} = STW^{t-1} + TP^{t-1} \quad (10)$$

$$A^t = A^{t-1} \times P^{t-1} \quad (11)$$

## V. SIMULATION AND RESULT ANALYSIS

To evaluate our proposed approach we have compared it with that of the states of the art method and this section provides the details of the simulation setup and result analysis.

**Algorithm 1** Proposed Prediction Method: Attention based deep hybrid prediction network with Bayesian inference

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1: procedure PREDICTNEXTTIMESTEP( $X, D(t), I$ )
2: Attention-based spatiotemporal module
3:    $n \leftarrow$  number of road segments
4:    $m \leftarrow$  number of time steps
5:    $X' \leftarrow$  input data from CSV file, reshaped to  $n \times m$ 
6:    $h_1, c_1 \leftarrow$  initial hidden and cell states for ConvLSTM
7:   1
8:      $h_2, c_2 \leftarrow$  initial hidden and cell states for ConvLSTM
9:   2
10:  for  $t \leftarrow 1$  to  $m$  do
11:     $X_t \leftarrow$  input tensor of shape  $n \times 1 \times 1$ 
12:     $H_1, c_1 \leftarrow$  ConvLSTM 1( $X_t, h_1, c_1$ )
13:     $H_2, c_2 \leftarrow$  ConvLSTM 2( $H_1, h_2, c_2$ )
14:     $I_t \leftarrow$  attention weights from  $H_2$ 
15:     $H_t \leftarrow$  weighted sum of  $H_2$  using  $A_t$ 
16:  end for
17: Bayesian Inference module
18:    $W \leftarrow$  BayesianTransitional( $D(t), A^{t-1}, A^t$ )
19: Combination and prediction module
20:    $A' \leftarrow$  last time step intensity matrix from  $I$ 
21:    $P \leftarrow$  empty matrix of size  $n \times n$ 
22:   for  $i \leftarrow 1$  to  $n$  do
23:     for  $j \leftarrow 1$  to  $n$  do
24:        $P_{i,j} \leftarrow W_{i,j}$ 
25:     end for
26:   end for
27:    $A^t \leftarrow P \times A^{t-1}$ 
28:   return  $A^{t-1}$ 
29: end procedure

```

### A. Data Description

To evaluate our proposed model we have chosen Dhaka city's traffic data as a case study since it is the fifth most congested city in the world. The real-life traffic data of Dhaka city is collected from Google map images using the tool [15, 16] available at [17].

We have worked on road network topology rather than a single road, thus it is needed to collect traffic data from individual road segments. To achieve this, we first select a zone and identify the major road segments. Then collect the

starting and ending latitude and longitude of each road segment and collect traffic data from every road segment. For our simulation, we have selected the Shahbag region of Dhaka city and selected twelve main road segments, each with two lanes thus a total of twenty-four roads. Fig. 3(a) represents the Shahbag region road network with eight-road intersections and Fig. 3 (b) represents the graph that is built considering the selected road network. We need to collect each road segment data separately and then combine it according to the graph network. For simulation, we collect one-month data. One month of data provides a sufficient amount of data for short-term traffic flow modeling and analysis [18]. Our collected data set comprises a total of 3720 data instances for each road segment. Thus we have a total of  $3720 \times 24 = 89280$  instances for twenty-four road segments. Since we considered a total of eight intersections (nodes), thus the size of the adjacency matrix is  $8 \times 8$ . We split the collected data into two sets: 80% for training and 20% for testing our model. Table I represent the learning parameter of the Attention-based Spatiotemporal Module.

TABLE I. ATTENTION-BASED SPATIOTEMPORAL MODULE LEARNING PARAMETER

Parameter	Value
Learning Rate	0.01
Number of Epochs	1000
Batch Size	32
Loss Function	RMSE
Optimizer	Adam
Regularization Techniques	L2 regularization

### B. Performance Metrics

Three performance indices the mean absolute error (MAE), the mean absolute percentage error (MAPE), and the root mean square error (RMSE) are used to evaluate the effectiveness of the proposed model. This is carried out to assess how accurately the model's predictions were made. The suggested model's efficacy is evaluated using three performance indices: MAE, MAPE, and RMSE. RMSE is frequently used to assess the effectiveness of traffic forecast models [19, 20]. The RMSE gives a general notion of the typical discrepancy between the values of the observed and forecasted data. The model and its predictions are better when the RMSE value is lower. We can calculate the value of RMSE by using equation 12, where  $f_i$  is the predicted value and  $\hat{f}_i$  is the observed value.

$$RMSE = \left[ \frac{1}{n} \sum_{i=1}^n (|f_i - \hat{f}_i|)^2 \right]^{\frac{1}{2}} \quad (12)$$

A statistical indicator of a forecast system's accuracy is the MAPE. It is easy to understand since it measures as a percentage. MAPE calculation is represented in equation 13, where  $f_i$  is the predicted value and  $\hat{f}_i$  is the observed value.

$$MAPE = \frac{1}{n} \sum_{i=1}^n \frac{|f_i - \hat{f}_i|}{f_i} \quad (13)$$

A negative number becomes positive through a mathematical operation known as the absolute. As a result, when calculating the MAE, the difference between an expected value and a

predicted value is always positive. We can use equation 14 for calculating MAE, where  $f_i$  is the predicted value and  $\hat{f}_i$  is the observed value.

$$MAE = \frac{1}{n} \sum_{i=1}^n |f_i - \hat{f}_i| \quad (14)$$

MAE is calculate using equation (14) where  $f_i$  is the actual traffic flow and  $\hat{f}_i$  is the predicted traffic flow. In general, a good prediction model should have lower values of MAE, MAPE, and RMSE, indicating that the predicted values are closer to the actual values. On the other hand, a bad prediction model will have higher values of these metrics, indicating that the model's predictions are further from the actual values. It is essential to consider these metrics when evaluating the effectiveness of a prediction model as they provide insights into the accuracy and reliability of the model's predictions.

### C. Compared Methods

We evaluated our proposed model's performance against the following widely used models for traffic flow prediction. Here we choose five widely used methods from deep learning, and conventional time-series prediction techniques which include ARIMA, SVR, LSTM, GRU, and DNN.

*a) ARIMA (Autoregressive Integrated Moving Average):* is a conventional statistical method that models the temporal dependence in the data using autoregression, differencing, and moving average techniques. Several research has made use of modeling that is based on ARIMA for the purpose of predicting traffic flow [24, 26, 27]. For instance, an ARIMA model was proposed to develop a short-term time series traffic flow forecast model[26].

*b) SVR (Support Vector Regression):* makes use of a hyperplane to capture the relationships that exist between the input variables and the output variables. It is efficient in dealing with nonlinear relationships present in the data and has been applied in a number of studies for the purpose of predicting traffic flow [25]. For instance, SVR was applied to the problem of predicting trip times, and it was found to be applicable and to perform well when applied to the study of traffic data [28]. For the purpose of traffic forecasting, LS-SVMs, also known as Least Squares Support Vector Machines, were used. These machines demonstrated benefits such as rapid convergence, high accuracy, and little computational effort [29]. When used in conjunction with other methodologies, SVR can accurately forecast changes in traffic flow as well as accidents. The capability of SVR to handle high-dimensional data, its resistance to noise, and its adaptability to non-linear relationships in the data are just some of its many advantages. SVR, on the other hand, has a number of drawbacks, including the fact that it is very dependent on the kernel function that is used and that it has difficulties managing huge datasets [30].

*c) LSTM (Long Short-Term Memory):* has been successful at identifying long-term dependencies in sequential data. Due to its capacity for handling input and output of varying lengths, it is frequently employed in time series prediction problems. LSTM is frequently used to estimate traffic flow and has been demonstrated to perform better than other machine learning techniques [23, 31, 32]. An example



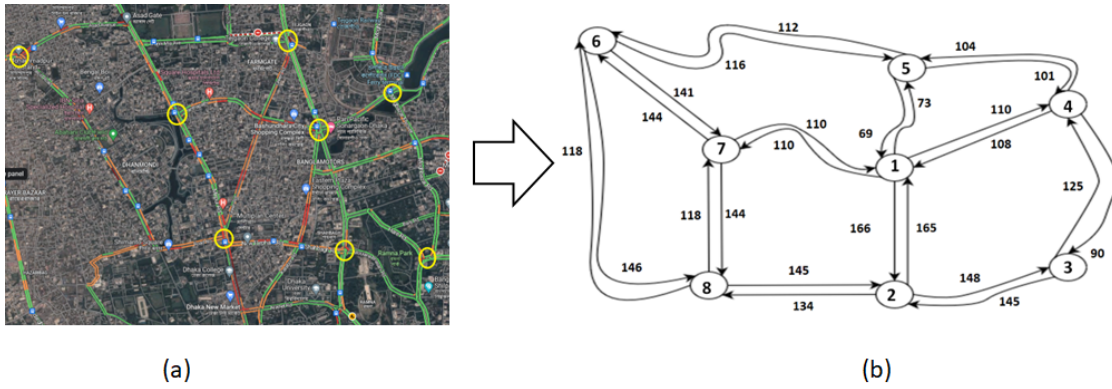


Fig. 3. Road network selection from Google map and graph representation of the selected road network.

TABLE II. PREDICTION COMPARISON FOR OUR PROPOSED ATTENTION-BASED DEEP HYBRID NETWORK WITH BAYESIAN INFERENCE, ARIMA, SVR, LSTM, GRU, AND DNN

	Time	15 min	30 min	45 min	60 min	75 min	90 min	105 min	120 min
<b>Proposed method</b>	RMSE	<b>15.785</b>	<b>16.60</b>	28.35	17.408	19.90	<b>14.79</b>	<b>17.43</b>	16.897
	MAE	<b>7.462</b>	<b>7.68</b>	15.013	<b>7.03</b>	7.90	<b>7.88</b>	<b>6.575</b>	<b>6.303</b>
	MAPE	14.055	<b>13.75</b>	<b>13.75</b>	15.206	17.42	<b>14.453</b>	<b>14.83</b>	12.912
<b>Proposed method without Bayesian Inference (BI)</b>	RMSE	15.94	16.74	16.74	29.209	17.466	19.87	17.69	17.091
	MAE	7.625	7.725	<b>7.88</b>	15.56	7.095	8.055	6.862	6.633
	MAPE	14.329	14.329	14.079	35.90	15.435	17.875	15.467	13.660
<b>DNN [21]</b>	RMSE	20.155	23.066	34.357	17.842	<b>9.690</b>	28.944	21.368	19.209
	MAE	15.386	17.514	27.897	15.348	<b>7.3035</b>	23.753	16.658	13.864
	MAPE	9.577	13.800	21.683	<b>9.882</b>	<b>6.479</b>	18.805	13.180	<b>11.134</b>
<b>GRU [22]</b>	RMSE	17.856	18.602	21.527	24.216	24.784	19.829	18.064	14.543
	MAE	15.890	12.772	16.792	15.054	17.475	12.981	12.350	13.107
	MAPE	15.168	12.906	<b>14.016</b>	15.875	19.340	19.978	18.266	14.427
<b>LSTM [23]</b>	RMSE	16.186	16.828	<b>13.661</b>	<b>16.832</b>	16.093	15.013	15.446	<b>14.518</b>
	MAE	13.041	12.383	11.507	13.776	13.200	12.490	13.341	11.937
	MAPE	15.548	14.277	12.764	10.114	14.697	16.094	13.164	15.249
<b>ARIMA [24]</b>	RMSE	32.295	29.449	29.123	28.751	30.305	27.163	26.830	26.777
	MAE	27.047	24.493	24.204	23.680	25.501	22.335	21.811	22.240
	MAPE	22.800	20.733	20.476	19.962	20.916	18.208	17.824	18.101
<b>SVR [25]</b>	RMSE	17.840	21.008	21.201	22.339	11.991	22.073	18.812	21.183
	MAE	14.708	16.27	17.253	17.861	9.778	17.557	15.147	16.753
	MAPE	<b>9.303</b>	13.843	14.281	10.910	8.700	14.237	14.973	13.533

of a Recurrent Neural Network (RNN) that uses memory cells to preserve significant information over time is the LSTM. Long-term memory storage technology (LSTM) is capable of learning long-term dependencies and non-linear traffic flow data. To increase the accuracy of traffic flow prediction [23], LSTM has also been integrated with other techniques, such as multiple linear regression (MLR) [31].

d) *GRU (Gated Recurrent Unit)*: deep learning model, has been effective at identifying dependencies in sequential data. Its capacity to accommodate variable-length inputs and outputs makes it a popular choice for time series prediction jobs. In contrast to the assertion, GRU is frequently employed in traffic flow prediction and has been proven to be successful in doing so [22]. GRU is a variant of recurrent neural networks that work well for predicting traffic flow and can memorize data from the prior sequence [33]. To increase the accuracy of traffic flow prediction, GRU has also been integrated with other approaches like graph convolution networks [34].

e) *DNN (Deep Neural Network)*: is a class of machine learning models that use multiple layers of artificial neurons to make predictions. DNNs have been widely used in various applications, including regression and classification tasks, due to their capacity to learn complex nonlinear correlations in

data. Keras is a popular Python library for building DNNs and CNNs (Convolutional Neural Networks) [21]. Keras provides a high-level API for building and training DNNs, making it easy to create and experiment with different architectures [35]. Keras also supports various optimization algorithms, activation functions, and loss functions, making it a versatile tool for building and training DNNs.

#### D. Performance Evaluation

The simulation result of our proposed traffic flow prediction models is presented in this section. Table II presents the forecasting performance comparison of the proposed model and other baseline methods for different forecasting horizons ranging from 15 minutes to 120 minutes on our collected data set. The findings demonstrate that over the majority of the forecasting horizons, the proposed model performs better than other models in terms of several evaluation measures. Due to its inability to handle complicated spatiotemporal data, the ARIMA model scores the lowest. Because models based on LSTM have the ability to capture dependence over time and nonlinear interactions in the data, LSTM forecasts are sometimes better. In comparison to previous models, the DNN model performs substantially better when predicting traffic

flow for 75 minutes, but it performs poorly in all other situations.

Further, we try to measure the statistical significance of our result. We perform a one-way ANOVA test to determine the statistical significance of the differences in the RMSE values among the models. F-statistic is 8.055 and the p-value is  $4.496 \times 10^{-6}$ , which is very small. This indicates that there is a significant difference in the RMSE values among the models. The confidence interval for the proposed method, which is the model of interest, is 15.04 to 21.75. This means that with 95% confidence, the true population means of RMSE values for the proposed method is between 15.04 and 21.75. For measurement of uncertainty we calculate the confidence interval, Table III represents the confidence interval range for different models. Comparing the proposed method's confidence interval to the other models' confidence intervals, it can indeed measure the uncertainty associated with a prediction [36]. A wider confidence level suggests greater uncertainty since it contains a wider spectrum of possible values. A narrower confidence interval, on the other hand, indicates less uncertainty because it gives an estimate that is more accurate [37]. We can see that the proposed method's interval does not overlap with some of the other models, such as ARIMA, SVR, LSTM, the proposed method without BI, and the proposed method. This means that the proposed method has significantly different RMSE values compared to these models. Additionally, the proposed method's confidence interval is narrower than some of the other models, such as DNN and GRU, indicating that the proposed method has less uncertainty in its predictions. Results suggest that the proposed method performs better in handling the uncertainty in traffic flow prediction compared to other models. The narrower confidence interval for the proposed method suggests that it provides more accurate predictions with less uncertainty.

TABLE III. CONFIDENCE INTERVAL OF RMSE OF DIFFERENT MODEL

Model	Start	End	Difference
<b>Proposed method</b>	15.0437	21.746	6.702
<b>Proposed method without BI</b>	14.446	30.333	15.887
<b>DNN</b>	16.050	27.607	11.557
<b>SVR</b>	16.874	27.236	10.362
<b>ARIMA</b>	17.339	30.313	12.974
<b>GRU</b>	17.233	26.621	9.388
<b>LSTM</b>	14.690	23.454	8.764

## VI. PERFORMANCE ANALYSIS

Our suggested model takes into account the effect of linked roads on traffic flow forecast. This model captures the influence of neighboring roads on the target road segment by including the road network topology and analyzing the dependencies between road segments. This allows for more precise predictions by accounting for traffic dynamics and flow patterns over the whole road network. It employs Bayesian interference for addressing prediction uncertainty. It can calculate the uncertainty related to its predictions by adding probabilistic modeling. This is especially useful when the prediction outcomes may fall outside of a given range or demonstrate greater variability. This model uses Bayesian inference to assist measure and managing uncertainty, resulting in more trustworthy and robust predictions. It also handles the spatiotemporal patterns and relationships in the traffic flow data

like other deep learning models. By giving more importance to relevant spatial and temporal features, this model can make more precise predictions. This model also used an attention mechanism that allows it to focus on the most informative features and road segments.

## VII. CONCLUSION

We proposed an attention-based deep hybrid network with Bayesian inference for traffic flow forecasting to address the problem of uncertainty. The attention mechanism in our suggested methodology enhanced the model's ability to recognize unexpected scenarios that impede traffic flow. By collecting complicated spatiotemporal trends in traffic data, our deep hybrid network effectively identified patterns and dependencies, improving the accuracy of traffic flow predictions. Most significantly, by applying Bayesian inference, we successfully evaluated and minimized uncertainty in the projected outcomes. In future, the suggested method's transferability and scalability will be evaluated by testing it in various parts of cities or regions with diverse traffic patterns and features. To prove its generalizability, it would be beneficial to assess its performance in other metropolitan areas also.

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# An Enhanced Variational AutoEncoder Approach for the Purpose of Deblurring Bangla License Plate Images

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**Abstract**—Automated License Plate Detection and Recognition (ALPDR) is a well-studied area of computer vision and a crucial activity in a variety of applications, including surveillance, law enforcement, and traffic management. Such a system plays a crucial role in the investigation of vehicle-related offensive activities. When an input image or video frame travels through an ALPDR system for license plate detection, the detected license plate is frequently blurry due to the fast motion of the vehicle or low-resolution input. Images of license plates that are blurred or distorted can reduce the accuracy of ALPDR systems. In this paper, a novel Variational AutoEncoder(VAE) architecture is proposed for deblurring license plates. In addition, a dataset of obscured license plate images and corresponding ground truth images is proposed and used to train the novel VAE model. This dataset comprises 3788 image pairs, in which the train, test, and validation set contains 2841, 568, and 379 pairs of images respectively. Upon completion of the training process, the model undergoes an evaluation procedure utilizing the validation set, where it achieved an SSIM value of 0.934 and a PSNR value of 32.41. In order to assess the efficacy of our proposed VAE model, a comparison with contemporary deblurring techniques is presented in the results section. In terms of both quantitative metrics and the visual quality of the deblurred images, the experimental results indicate that our proposed method outperforms the other state-of-the-art deblurring methods. Therefore, it enhances the precision and dependability of an ALPDR system.

**Keywords**—Image blur; bangla license plate blur; Variational AutoEncoder (VAE); computer vision

## I. INTRODUCTION

With the increase in the number of vehicles on the road, violations of traffic laws such as racing through red lights, leaving the scene of an accident, and kidnapping escalated. As a result, ALPDR systems have been extensively developed and applied to a variety of intelligent traffic systems [1]–[4]. Unfortunately, despite the fact that drive recorders and surveillance cameras perform significantly better than in the past, license plates of vehicles are frequently blurred due to fast-moving vehicles, camera shakes during the exposure period, and other factors. Multiple variables contribute to the blurring and distortion of license plate images. The initial variable is the local environment. For instance, the impacts of intense illumination, precipitation, and weather may increase the likelihood of blurring. The second variable consists of the vehicle's motions. For instance, when vehicles run red lights, they are frequently traveling at a very high rate of speed; consequently, the pictures taken tend to be blurry. The

surveillance system serves as the final variable. Due to the fact that surveillance cameras are frequently positioned at higher elevations, far from the car, the captured image has a reduced resolution, leading to poor image quality. Blurred license plate images can significantly reduce the accuracy of ALPDR systems. Therefore, deblurring of the license plate images is a crucial step towards achieving reliable ALPDR systems.

Starting from deblurring images using methods such as dihedral group [5], image deblurring techniques have significantly advanced [6] in recent years. On the basis of high-frequency residual image learning, the authors of [7] proposed a two-phase deblurring algorithm for restoring blurred images of dynamic scenes. The method proposed in [8] defines a new regularization term that incorporates both intensity and gradient assumptions and provides an efficient and convergent solution for deblurring license plate images. Convolutional Neural Networks (CNNs) have been extensively utilized [9]–[11] alongside Generative Adversarial Networks (GANs) [8], [12] to generate sharp license plate images. However, these approaches demand a large amount of training data, as with a small dataset the model may not converge and can lead to a less generalized model. To our knowledge, there are a handful of works related to Bangla license plate deblurring.

The purpose of this study is to develop and establish a state-of-the-art Bangla license plate deblurring system that can work in real-time. In order to accomplish this we propose a novel VAE architecture with a custom loss function for Bengali license plate image deblurring. The proposed VAE network is a generative model capable of learning the underlying distribution of training data and producing new samples based on the learned distribution. Thus, it can perform well even if it is trained on a small dataset. However, there's a lack of publicly available Bangla license plate dataset for deblurring. Thus, we created a new balanced and generalized dataset consisting of 3788 pairs of images that were used to train, test and validate the model. 75% of the data belong to the train set, whereas 15% and 10% data belong to the test and validation sets, respectively. The proposed VAE model achieved an SSIM score of 0.934 and a PSNR score of 32.41. To assess the efficacy, we recreated state-of-the-art deblurring models [13], [14] and trained them on our dataset. The evaluation demonstrates that our method outperforms state-of-the-art deblurring techniques in terms of both quantitative metrics and image quality. In addition, we demonstrate the

efficacy of our procedure using actual blurred license plate images in this paper.

**The most significant contributions of this study are as follows:**

- Established a novel VAE network for the deblurring of Bangla license plate images.
- Created a new dataset for Bangla license plate deblurring.
- Provided quantitative and visual performance analysis of the proposed model with other available image deblurring models.

The subsequent sections of the paper are structured in the following manner: Section II encompasses the literature review. The following Section III, provides a comprehensive summary of the dataset. Section IV presents a detailed description of the proposed methodology. Section V presents the results and comparisons of this research. The conclusive remarks can be found in Section VI. The residual content comprises references.

## II. LITERATURE REVIEW

The field of deblurring license plate images is a highly intriguing area of research. Despite the limited amount of research on the deblurring of Bangla license plate images, a small number of studies have successfully developed methods that can be applied in real-world scenarios. Nevertheless, this area of research remains largely unexplored. The following segment delineates the progression of scholarly inquiry pertaining to the restoration of clarity in license plate images.

Fang *et al.* [8] introduced a deblurring methodology that integrates gradient priors and intensity through a novel regularization technique. In addition, the authors determined that the binarization threshold of the image is a significant factor in distinguishing between blurred and clear images. CNNs have been employed in the past for the purpose of image denoising [9]–[11], as well as for super-resolution [15], [16]. The study conducted by the author of [9] aimed to address the issue of image blurring in traffic surveillance. To achieve this objective, the author developed a customized CNN model. This model was designed to take a blurry image as input and generate a clear image as output, with the license plate content being easily discernible. While the methods proposed by [8], [9] were deemed partially satisfactory, they were found to be lacking in terms of accuracy measures and evaluations.

Qingbo *et al.* [17] introduced a new approach for estimating blur kernels by integrating linear uniform convolution and the angle of the image. A scheme was proposed utilizing sparse representation to detect the blur kernel resulting from rapid vehicular movement. The authors analyze the coefficients of the sparse representation of the reconstructed image to ascertain the orientation of the kernel. They estimate the length of the motion kernel using the Radon transform in the Fourier domain. However, the dataset that the authors used only had 240 images, which limited its ability to include all aspects of real-world scenarios.

Orest *et al.* [6] proposed an innovative approach for image deblurring that employs a Generative Adversarial Network

(GAN) architecture. The researchers utilized the GoPro and Kohler datasets in order to train their model. Despite the fact that the dataset consists of arbitrary blurred images, the proposed approach demonstrates the ability to deblur, blurry vehicle images. The model proposed by the author attained a Peak signal-to-noise ratio (PSNR) score of 26.10 and a structural similarity index measure (SSIM) score of 0.816. The proposed model's inference time is 0.85 seconds. Subsequently, the author introduced an enhanced approach in [14]. The authors put forth a sophisticated GAN framework, which achieved a PSNR score of 29.55 and an SSIM score of 0.93. They concluded that the novel architecture outperformed their previous model. Furthermore, the inference time of the model under consideration is a mere 0.35 seconds. In any case, the duration required for inference in both of the aforementioned studies can be considered unsuitable for the practical application of ALDPR systems.

The researchers of [18] proposed a GAN architecture to address the task of image deblurring. The authors additionally employed the GoPro and Kohler dataset for the purposes of training and assessing their model. A PSNR score of 29.32 and an SSIM score of 0.93 show that the network the authors propose is significantly effective in the task of deblurring vehicle images. However, it is worth noting that the inference time associated with this network is relatively high, at 0.64s. A sparse regularization model for vehicle image deblurring was proposed by the author of [19], utilizing the statistical distribution characteristics of the image. The author presents a concise analysis of the statistical distributions of vehicle images and concludes that the gradient histogram of the ground truth follows the Hyper-Laplacian distribution. The model exhibited exceptional performance in comparison to contemporary techniques for deblurring vehicle images. The PSNR and SSIM values are 28.2 and 0.99 respectively. However, the impact of the model parameter  $p$  on the deblurring quality is not extensively discussed in the paper. Hence, additional research may be necessary to explore the optimal value of  $p$  for diverse license plate images.

Hiroki *et al.* [12] presented a technique for achieving high-quality image deblurring. The method employs a Discrete Cosine Transform (DCT)-based loss function to maintain texture and mitigate ringing artifacts in the resulting image. The authors' proposed model exhibits reduced computational complexity in comparison to alternative methods that employ multi-scale architecture. The proposed method involves a comparison of the frequency domain of the deblurred image with the ground truth image via DCT. This approach effectively mitigates block noise and ringing artifacts, while simultaneously preserving the deblurring performance. The empirical findings indicate that DeblurDCTGAN exhibits better results compared to conventional techniques. Their proposed model achieved PSNR and SSIM values of 28.84 and 0.93, respectively. Moreover, DeblurDCTGAN exhibits a comparatively quicker runtime of 0.28s per pair in contrast to alternative techniques, rendering it a more efficient alternative for the purpose of image deblurring. The Enhanced Super Resolution Generative Adversarial Network (ESRGAN) was employed by the authors of [20] to enhance the quality of license plate images that were originally of low quality. ESRGAN has undergone training using a dataset comprising license plate images, with the aim of acquiring the ability to perform image deblurring and



upsampling. Subsequently, the generated high-resolution images are employed to achieve precise recognition of license plates. However, The size of the dataset utilized in the training of ESRGAN is comparatively limited, potentially impeding the model's ability to generalize to license plate images beyond those included in the dataset. Additionally, the optical character recognition accuracy for the reconstructed images is lower than that of the ground truth images, indicating that there is still room for improvement for the generator model. Finally, the paper did not provide a detailed description of the results obtained using the ESRGAN.

Despite notable progress made in the domain of image deblurring in recent years, a number of constraints remain prevalent in previous research endeavors, as indicated earlier. A significant constraint lies in the challenge of precisely simulating the blurring mechanism, which can exhibit substantial variability contingent upon factors such as vehicle motion, lens, and scene attributes. Furthermore, the majority of previous studies concerning license plate deblurring or image deblurring have concentrated on restoring clarity to comparatively uncomplicated scenes or images, and may not possess the capability to address more intricate or demanding scenarios. One additional constraint pertains to the computational cost linked with deblurring techniques, which may pose a significant hindrance for real-time implementations. In general, although previous studies on the deblurring of license plates or images have made noteworthy advancements in enhancing the quality of deblurred images, there remain various obstacles that require attention to enhance the robustness, efficiency, and efficacy of these approaches.

### III. DATASET DESCRIPTION

This section discusses the dataset's curation and preprocessing. There is a scarcity of publicly accessible datasets for deblurring purposes, as very little research has been conducted on the deblurring of Bangla license plates. Therefore, a new dataset is proposed for this investigation. Initially, a license plate-related dataset was proposed in [4]. As shown in Fig. 2, their proposed dataset was for license plate detection and recognition. Therefore, we accumulated and expanded this dataset. Afterward, the license plate was extracted from these images, and a dataset containing 3788 image pairs of license plates was created, samples of which are depicted in Fig. 3. Each image of a clear license plate  $I_i$  is passed through a blur function, resulting in a blurred license plate  $B_i$ . The blur function is denoted by the Eq 1.

$$B_i = I_i \otimes F + N + R + S \quad (1)$$

A dataset that is unbalanced and insufficient can cause the VAE network to produce low-quality images, which can hinder its ability to generalize to new data. A balanced dataset is crucial for training VAE since it helps to ensure that the network is trained properly and is capable of generalizing adequately to new data. The distribution of the dataset among the train, test, and validation set is shown in Fig. 1, where the train, test, and validation sets, respectively, include 2841, 568, and 379 pairs of images. The validation set is used to assess the model post-training but is concealed from the model during training.

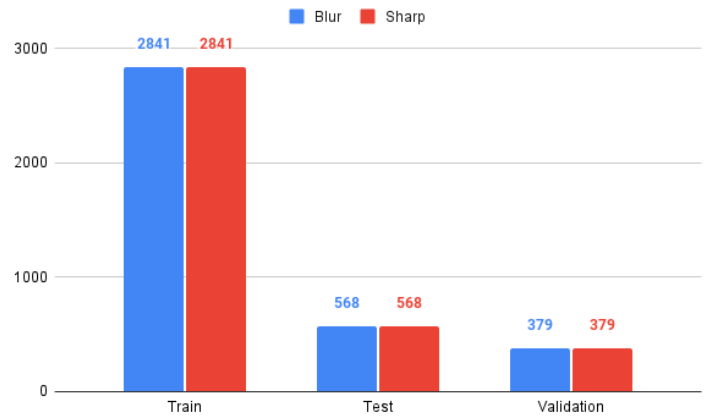


Fig. 1. Data distribution.

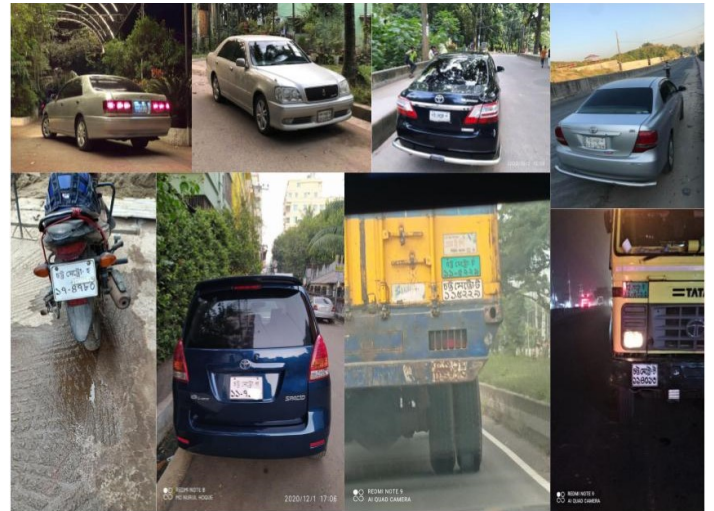


Fig. 2. Sample images from the dataset of [4].

### IV. PROPOSED METHOD

Traditional approaches for deblurring license plate images [8], [12], [20], function well. However, issues with compute power, inference time, loss of details in the generated image, and the likelihood that noise may recur in the resulting image continue to exist. In this paper, a novel approach is proposed to address the issue of license plate image blurring. The proposed method utilizes the capabilities of a Variational AutoEncoder (VAE) to achieve this objective. The proposed approach involves developing a novel VAE network that has the capability to acquire a low-dimensional representation of the underlying image data. This representation can be leveraged to effectively eliminate blur and distortion from license plate images, while simultaneously preserving the texture and details of the input image. The objective of the model is to restore a clear image of a license plate denoted as  $I_i$ , given a blurred image  $B_i$  as the input. It is noteworthy that no information pertaining to the blur kernel is unseen by the model in the training, testing, and validating phases.





Fig. 3. Sample images of the proposed dataset.

#### A. VAE Architecture

The proposed VAE network incorporates a prior distribution on the latent vector  $Z$ , which follows a Multi-Variate Gaussian distribution. In contrast to mapping the image onto a point space, the encoder of VAE maps the image onto a normal distribution. The encoder employs a Convolutional Neural Network (CNN) as a dimensionality reduction model to effectively map intricate training data onto the latent space  $Z$  while maintaining appropriate statistically significant attributes.

Fig. 4 depicts the comprehensive structure of the proposed VAE network. The encoder receives a visually blurred input image denoted as  $X$ , from which it generates two latent vectors,  $ZU$  (mean) and  $ZS$  (variance), that serve as the distribution parameters learned during the training process. The ultimate latent vector  $Z$  is obtained through the utilization of a Multi-Variate Gaussian distribution, which samples from  $ZU$  and  $ZS$ . Subsequently, the vector  $Z$  is transmitted to the decoder module, where it is subjected to the inverse transformation of the encoding process. This results in the generation of the predicted image  $Y$ , which represents a restored and clear version of the original blurry input image. The proposed VAE network encompasses a specific region that is centered on the mean and has a magnitude equivalent to the standard deviation. This provides the decoder with a greater amount of data, enabling it to generate an image that closely resembles the ground truth image.

#### B. Encoder-Decoder

This section outlines the definition of the Encoder and Decoder components of the network. The encoder-decoder model is presented in Fig. 6 for a comprehensive understanding. The input image's dimensions for the encoder are (None, 128, 128, 3). The encoder architecture comprises three convolutional blocks, each of which incorporates Conv2D alongside the ReLu activation function and Batchnormalization. The final layer employs a Flatten operation to transform the feature matrix, which has dimensions of (16, 16, 256), into a vector with a size of 65536. Subsequently, the Flatten layer's outcome is transmitted to two distinct dense layers with the aim of obtaining latent vectors  $ZU$  and  $ZS$ . The encoder network acquires the ability to establish a mapping between the input data and  $ZU$  and  $ZS$ , which are anticipated to conform to a normal distribution. Subsequently, the  $ZU$  and  $ZS$  vectors are transmitted to a sampling block that employs a Lambda layer. The utilization of the lambda layer proves to be advantageous in the implementation of bespoke functions that are not inherently incorporated as standard functions within TensorFlow<sup>1</sup>. Equation 2 presents a bespoke Lambda layer function that accepts  $ZU$  and  $ZS$  as input and generates the  $Z$  vector as output during the training stage. The utilization of a basic sampling technique may result in a bottleneck within the backpropagation process. To address this concern, a reparameterization technique<sup>2</sup> is employed. This technique enables the loss to propagate backward through the mean and variance nodes, which are deterministic while segregating the sampling node by introducing a non-deterministic parameter  $\epsilon$ , which is drawn from a standard normal distribution. This property ensures that  $Z$  is deterministic.

$$Z = ZU + ZS^2 * \epsilon \quad (2)$$

The two computation graphs depicted in Fig. 5 illustrate the original sampling block in (a) and its reparameterized form in (b). The blue nodes in the diagram depict the deterministic nodes, specifically the input, and weights, whereas the red nodes represent the stochastic nodes. Throughout the training process, the input image undergoes a mapping procedure resulting in the derivation of two latent variables, namely  $ZU$  and  $ZS$ . Subsequently, a vector  $Z$  is sampled from the aforementioned variables. The stochastic sampling process employed in this operation renders  $Z$  a random node, thereby creating an obstacle due to the inability of gradients to backpropagate through the sampling layer, owing to its stochastic nature. Consequently, the parameters  $ZU$  and  $ZS$  are unable to acquire knowledge. The process of backpropagation necessitates that the nodes exhibit determinism in order to facilitate the iterative propagation of gradients. The proposed VAE network introduces a reparameterization technique to tackle the aforementioned concern, whereby the stochastic node  $Z$  is transformed into a deterministic node. The utilization of  $\epsilon$  enabled the preservation of the stochasticity of the entire system while allowing the  $ZU$  and  $ZS$  vectors to function as the learnable parameters of the network.

The decoder network receives the output of the encoder (vector  $Z$ ), which has a dimension of (None, 2). The initial

<sup>1</sup>[https://www.tensorflow.org/api\\_docs/python/tf/keras/layers/Lambda](https://www.tensorflow.org/api_docs/python/tf/keras/layers/Lambda)

<sup>2</sup><https://gregorygundersen.com/blog/2018/04/29/reparameterization/>

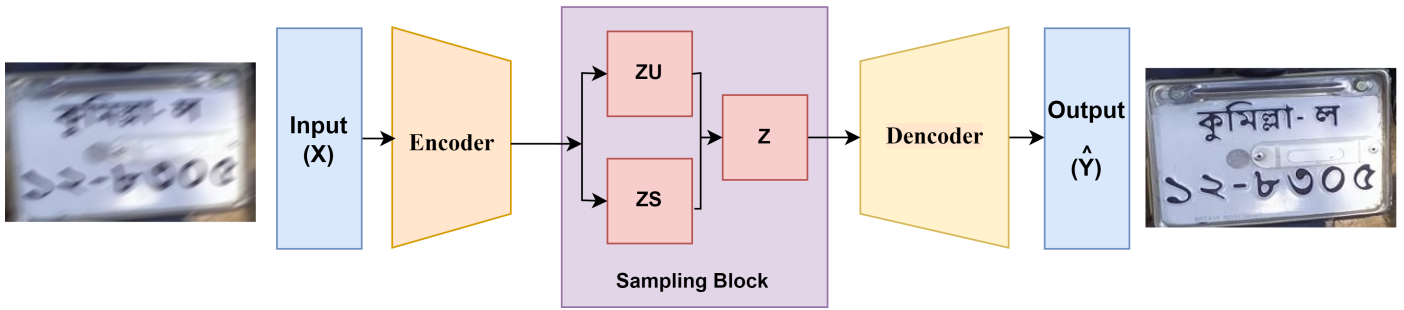


Fig. 4. Overview of the proposed VAE network.

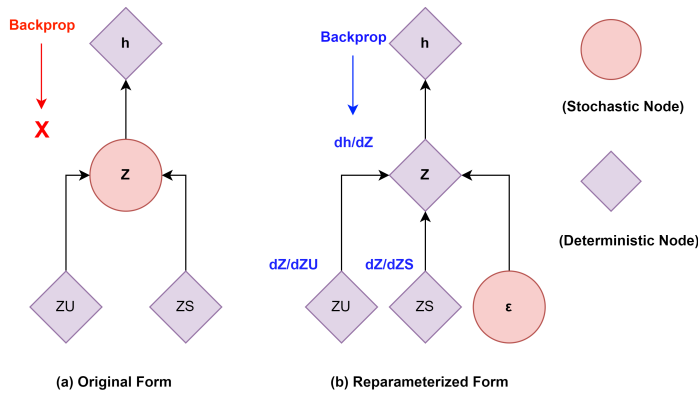


Fig. 5. Reparameterized form of custom sampling block.

dense layer is assigned a filter value of 65536, which corresponds to the product of 16, 16, and 256. Thus to make the vector into a 2D matrix a reshape layer is utilized with the shape value of (16,16,256). This value is derived from the flattened output of the preceding encoder. The architecture consists of four inverse convolutional blocks, each of which incorporates Conv2DTranspose with Relu activation function and Batchnormalization. The final convolutional block within the decoder exhibits a filter value of 3, resulting in an output image shape of (None, 128, 128, 3). Therefore, a clear image of the license plate is obtained.

### C. Loss Function

The latent vector  $Z$  conforms to a Gaussian distribution with unit variance and is accountable for the minimization of the reconstruction loss denoted as  $L_r$ . The final loss function of the VAE that has been suggested is a combination of the reconstruction loss and Kullback–Leibler Divergence (KLD) loss, which is represented as a weighted sum in Equation 3. Both loss functions are optimized in this context. The reconstruction loss serves to guarantee that the resulting image is comparable to the ground truth image, while the KLD loss ensures that the latent variables are in proximity to the standard normal distribution. The KLD metric quantifies the divergence between the latent vector  $Z$  (sampled from  $ZU$ , and  $ZS$ ) and the unit normal distribution  $\gamma$ . The parameters of the encoder and decoder are represented by  $\sigma$  and  $\eta$  in Equation 3.

$$L_{total}(\sigma, \eta, y) = L_r(\sigma, \eta, \hat{y}) + KLD[ZU, ZS, \gamma] \quad (3)$$

Equation 4 refers to the calculation of  $L_r$ , where  $P$  refers to the total number of pictures in a training batch,  $y$  is the ground truth image, and  $f_\sigma(g_\eta(y))$  is the reconstructed image. The reconstruction loss is calculated by determining the difference between each pixel of the ground truth image and the corresponding pixel of the reconstructed output image. This difference is then squared and averaged across the entire batch of the data.

$$L_r(\sigma, \eta, y) = \frac{1}{P} \sum_{j=1}^P (y_j - f_\sigma(g_\eta(y_j)))^2 \quad (4)$$

The Variational Autoencoder (VAE) is trained with the objective of minimizing the Kullback-Leibler Divergence (KLD) between the latent vectors and  $\gamma$ . In the event that the encoder produces a vector  $Z$  that deviates significantly from a standard normal distribution, the KLD loss function will impose a greater penalty. The KLD serves as a regularization technique to ensure adequate diversity within vector  $Z$ . During the computation of the KLD, it is customary to assign the parameter  $ZS$  to the natural logarithm of the variance. The mathematical expression for KLD is represented by Equation 5. Through the application of the logarithmic function to the  $ZS$ , the network is constrained to produce output values within the domain of natural numbers, as opposed to solely positive values. This facilitates more seamless illustrations of the underlying space.

$$KLD[ZU, ZS, \gamma] = -0.5 * \sum_{j=1}^P (1 + \log(ZS_j^2) - ZU_j^2 - e^{\log(ZS_j^2)}) \quad (5)$$

## V. RESULT AND ANALYSIS

The objective of this research is to design a Variational Autoencoder (VAE) architecture that exhibits high performance in the task of restoring clarity to the input image of license plates. The images in the dataset represent a variety of perspectives and environmental conditions. In addition to images of average to excellent quality, the dataset also contains rotated, tilted, pixelated, and occluded images. Therefore, this dataset is highly suitable for extrapolating the deblurring issue. This section provides an analysis of the results obtained from the proposed VAE model. Furthermore, a comparative analysis is presented between the proposed VAE model and prominent deblurring models such as DeblurGan [13] and DeblurGanV2 [14].

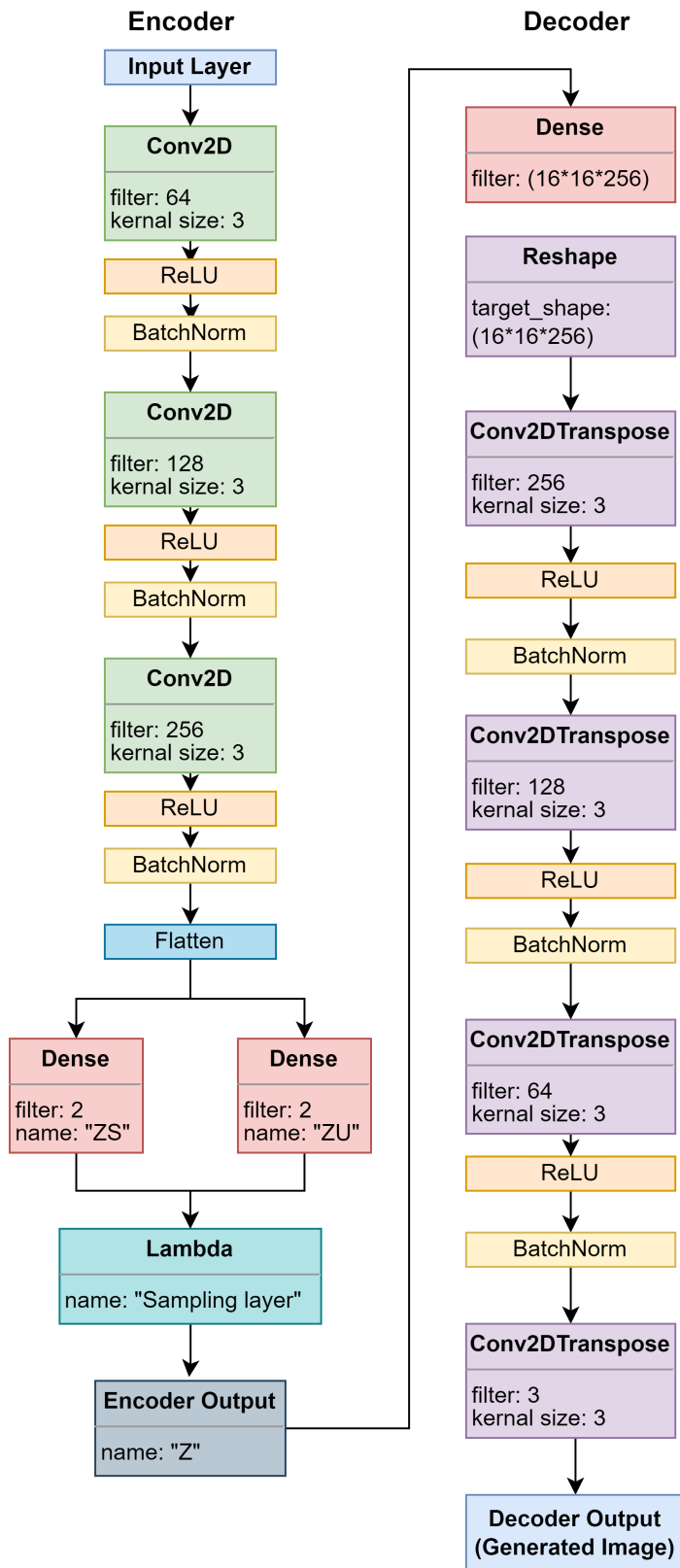


Fig. 6. Proposed encoder and decoder in the VAE network.

### A. Experimental Setup

Throughout the model training and testing process, the hardware setup consisted of an Intel Core i7 10700K Central Processing Unit (CPU), a total of 32 GB of DDR4 RAM, and an Nvidia GTX 1070 GPU with 8 GB of memory. The VAE model was developed utilizing the Tensorflow 2.11 deep learning framework in conjunction with the Python 3.9 programming language.

### B. Evaluation Metrics

1) **PSNR**: The Peak Signal-to-Noise Ratio (PSNR) is a metric employed to assess the fidelity of an image that has been restored. The process involves a comparison between the initial image and the restored image, followed by the computation of the ratio between the highest attainable value of the original signal and the value of the interference that impacts the quality of the restoration. The quality of a restoration of an image is positively correlated with the PSNR value, such that a higher PSNR value indicates superior image quality. Due to the broad dynamic range of signals, the PSNR is often expressed in decibels, a logarithmic scale. The PSNR is calculated using Equation 7. In Equations 6 and 7, the symbols  $p$  and  $q$  respectively denote the matrix values of the ground truth image and the restored image. The indices  $i$  and  $j$  represent the row and column of the matrices, while  $MAX_g$  represents the maximum value present in the original data. The primary constraint of this metric pertains to its exclusive reliance on numerical comparison, without considering any other factors of the human vision system, such as the structural similarity index (SSIM).

$$MSE = \frac{\sum_0^{i-1} \sum_0^{j-1} \|p(i,j) - q(i,j)\|^2}{i * j} \quad (6)$$

$$PSNR = 20 \log_{10} \left( \frac{MAX_g}{\sqrt{MSE}} \right) \quad (7)$$

2) **SSIM**: The Structural Similarity Index Measure (SSIM) is a prominent metric employed to evaluate the degree of similarity between two images. In contrast to conventional metrics such as MSE or PSNR, which concentrate exclusively on discrepancies at the pixel level, SSIM incorporates both the structural characteristics and perceptual attributes of images. The Structural Similarity Index (SSIM) assesses three fundamental elements of image similarity, namely luminance ( $L$ ), contrast ( $C$ ), and structure ( $S$ ).  $L$ ,  $C$ , and  $S$  are calculated using Equation 8, Equation 9, and Equation 10 respectively. The method operates by evaluating the resemblance of matching localized image patches and subsequently calculating a weighted mean over the entire image. The SSIM value obtained falls within the range of 0 to 1, where a value of 1 denotes a high degree of similarity. The SSIM metric shown in Equation 11 is designed to overcome certain drawbacks of conventional metrics, including susceptibility to noise and variations in image resolution. The incorporation of human visual perception and structural information renders it more perceptually significant. The SSIM metric is highly advantageous in applications that involve image quality evaluation, image recovery, and image compression, as it is imperative to maintain perceptual quality in these tasks.





Fig. 7. Sample output of the proposed VAE network; where a) input, b) ground truth, and c) generated image by the proposed model.

$$L(n, m) = \frac{(2\mu_n\mu_m + v1)}{(\mu_n^2 + \mu_m^2 + v1)} \quad (8)$$

$$C(n, m) = \frac{2\sigma_n\sigma_m + v2}{\sigma_n^2 + \sigma_m^2 + v2} \quad (9)$$

$$S(n, m) = \frac{\sigma_{nm} + v3}{\sigma_n\sigma_m + v3} \quad (10)$$

$$SSIM(n, m) = L(n, m)^\delta * C(n, m)^\lambda * S(n, m)^\omega \quad (11)$$

The variables  $n$  and  $m$  represent the deblurred image and its corresponding ground truth image, respectively. The variables  $\mu_n$  and  $\mu_m$  represent the arithmetic means of the values of  $n$  and  $m$ , respectively. The variables  $\sigma_n^2$  and  $\sigma_m^2$  denote the variances of  $n$  and  $m$ , respectively, while  $\sigma_{nm}$  represents the covariance between  $n$  and  $m$ . The variables  $\sigma_n$  and  $\sigma_m$  represent the standard deviation of  $n$  and  $m$  respectively. The stabilization of the division with a weak denominator is achieved through the utilization of three parameters, namely  $v1 = (U1 * L)^2$ ,  $v2 = (U2 * L)^2$ , and  $v3 = v2/2$ . Here,  $L$  denotes the dynamic range of the pixel values, while the values of  $U1$  and  $U2$  are assigned as 0.01 and 0.03, respectively.

### C. Analysis of the VAE's Performance

Here Fig. 7 illustrates a) the input blurred image of the license plate, b) ground truth in other words sharp image, and c) the output image of the proposed VAE model. From Fig. 7, it is evident that the proposed model is better able to retain and restore the texture in the deblurred image. It shows superior results in terms of visual representation. The images depicted in Fig. 7(a) exhibit a significant degree of blurriness, rendering the license plate information indiscernible. However, the model performs well in restoring the image and the informations are clearly visible. Along with restoring private vehicle license plate images (with white license plate background), the model is also capable of restoring public vehicle license plate images (with green license plate background). The 6<sup>th</sup> image of Fig. 7(b) has a noise and ringing effect. However, the generated image is very clear and there is no existence of noise in it. Thus, in accordance with image deblurring the proposed model can also reduce noise in the input image. After training the model for 100 epochs we achieved such results due to a generalized dataset and careful tuning of the hyperparameters and loss function tuning of the proposed model.

To conduct a comparative analysis, we replicated the structural design of DeblurGan [13] and DeblurGanV2 [14], and subsequently subjected them to training using our suggested dataset. The visual comparison between the two models and the proposed VAE network is depicted in Fig. 8. The analysis reveals that the DeblurGan [13] and DeblurGanV2 [14] models exhibit unsatisfactory performance, as evidenced

by their inability to produce output images of comparable quality and texture to the original ground truth image. The VAE network proposed in the majority of cases exhibits superior performance in deblurring and effectively enhances the legibility of license plates, resulting in the identification of information contained within the plate image. The results depicted in Fig. 8 demonstrate that the model proposed in this study exhibits superior performance in generating license plate images that are deblurred, noise-free, and the semantic characteristics of the image are preserved.

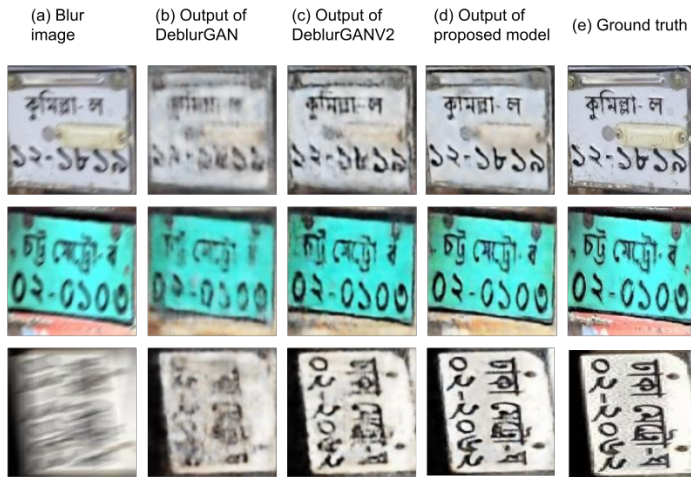


Fig. 8. Comparison with state-of-the-art-models; where a) input blurred image, b) Output of DeblurGan [13], c) Output of DeblurGanV2 [14], d) generated image by the proposed VAE model and (e) is the ground truth image.

The assessment of performance with respect to three primary metrics, namely Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Inference Time, is presented in Table I. The validation set of our proposed datasets is employed for the purpose of validating these models. Table I demonstrates that the PSNR and SSIM metrics of our model are significantly higher than those of the previous state-of-the-art models. The model under consideration attained a PSNR score of 32.41 and an SSIM score of 0.934. The VAE network proposed exhibits superior performance in terms of producing visually, semantically correct, and readable outcomes. Unlike alternative neural models, our model is not dependent on L2 distance within the pixel area, and therefore, it is not inherently optimized for the PSNR metric. The output, as depicted in Fig. 7, demonstrates the capability of the method to effectively mitigate the effects of camera shake and object movement-induced blur. Furthermore, the approach does not exhibit the typical artifacts that are commonly observed in kernel estimation techniques. Simultaneously, it exhibits the shortest inference time.

TABLE I. PERFORMANCE EVALUATION WITH RESPECT TO PSNR, SSIM, AND INFERENCE TIME

Performance Metrics	DeblurGan [13]	DeblurGanV2 [14]	Proposed Network	VAE
PNSR	20.99	24.15	32.41	
SSIM	0.504	0.563	0.934	
Inference Time	0.85s	0.28s	0.16s	

## VI. CONCLUSION

This research introduces a new approach for enhancing the clarity of license plate images through the utilization of a novel Variational AutoEncoder(VAE) network. The experimental findings indicate that the proposed model surpasses the current state-of-the-art deblurring techniques, exhibiting a higher peak signal-to-noise ratio (PSNR) score of 32.41 and a structural similarity index measure (SSIM) score of 0.934. The proposed approach utilizes VAE to acquire a reduced-dimensional depiction of the image data, thereby facilitating the efficient elimination of blurriness and noise from license plate images. In future research, our suggested model may be further refined to minimize the duration of execution and enhance its efficacy, rendering it appropriate for real-time implementations. Despite the absence of a publicly accessible dataset for Bangla license plate deblurring, the model can be effectively trained on license plates from other countries to enhance its applicability. Furthermore, the model has the potential to be deployed on edge devices, such as smartphones or embedded systems, thereby facilitating license plate recognition applications in resource-constrained or remote settings.

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# Facial Image Generation from Bangla Textual Description using DCGAN and Bangla FastText

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**Abstract**—The synthesis of facial images from textual descriptions is a relatively difficult subfield of text-to-image synthesis. It is applicable in various domains like Forensic Science, Game Development, Animation, Digital Marketing, and Metaverse. However, no work was found that generates facial images from textual descriptions in Bangla; the 5th most spoken language in the world. This research introduces the first-ever system to generate facial images from Bangla textual descriptions. The proposed model comprises two fundamental constituents, namely a textual encoder, and a Generative Adversarial Network (GAN). The text encoder is a pre-trained Bangla text encoder named Bangla FastText which is employed to transform Bangla text into a latent vector representation. The utilization of Deep Convolutional GAN (DCGAN) allows for the generation of face images that correspond to text embedding. Furthermore, a Bangla version of the CelebA dataset, CelebA Bangla is created for this study to develop the proposed system. CelebA Bangla contains images of celebrities, their corresponding annotated Bangla facial attributes and Bangla Textual Descriptions generated using a novel description generation algorithm. The proposed system attained a Fréchet Inception Distance (FID) score of 126.708, Inception Score (IS) of 12.361, and Face Semantic Distance (FSD) of 20.23. The novel text embedding strategy used in this study outperforms prior work. A thorough qualitative and quantitative analysis demonstrates the superior performance of the proposed system over other experimental systems.

**Keywords**—Bangla text-to-face synthesis; Natural Language Processing (NLP); Computer Vision (CV); GAN; text encoders

## I. INTRODUCTION

Generative Adversarial Networks (GANs) have been identified as an effective tool for producing lifelike images in diverse domains, encompassing natural landscapes and human countenances. The capacity to produce superior images from textual depictions has garnered considerable interest owing to its potential implications in virtual avatars, content creation, and tailored advertising.

The generation of an image from a given textual input is referred to as text-to-image generation. The Text-To-Face (TTF) technique is a subfield of the Text-To-Image (TTI) generation field, wherein a depiction of a human face is furnished, and a facial image is produced by utilizing the description. Generating images of faces is a more challenging task compared to text-to-image generation, primarily due to the intricate nature of facial attributes. The utilization of text-to-face synthesis holds significant potential in various practical domains, such as Forensic Science, Game Development, Animation, Digital Marketing, and the Metaverse. The generation

of images and faces from text has emerged as a prominent area of research in recent times, resulting in a substantial body of literature on the subject. Notably, a majority of scholars have directed their attention towards image generation in the English language [1]. Although significant advancements have been achieved in the field of English-based text-to-image synthesis, there has been a dearth of research pertaining to non-English languages, specifically the Bangla language. The Bangla language possesses distinct linguistic and cultural subtleties, thereby posing distinctive obstacles to the synthesis of text-to-face. The process of generating facial images from Bangla text necessitates a profound comprehension of the language's phonological, syntactic, and semantic frameworks. The accurate representation of the visual heterogeneity and distinctive facial attributes of Bangla-speaking individuals is imperative in producing genuine and culturally appropriate facial depictions.

To mitigate this gap, in this paper, a novel GAN-based system, specifically for generating face images from Bangla textual input is proposed. The objective of the proposed system is to mitigate the challenges related to Bangla text and cultural diversity in multimodal synthesis research, thereby filling an existing gap in this field. The proposed model consists of two primary components, namely a text encoder and an image generator. The utilization of Bangla FastText [2] by the text encoder serves the purpose of encoding Bangla text into a latent vector representation that adeptly captures the semantic information that is intrinsic to the text. Subsequently, the image generator utilizes a Deep Convolutional Generative Adversarial Network (DCGAN) architecture to produce facial images that align with the encoded textual depiction. Modifications have been made to the CelebA dataset [3] to enhance the efficiency of our model's training and evaluation processes. Labels have been meticulously assigned to 40 distinct facial attributes using semantically accurate Bangla vocabulary. This has led to the creation of a novel dataset named CelebA Bangla. The CelebA Bangla dataset is a compilation of face images showcasing celebrities, accompanied by 40 facial attribute annotations in the Bangla language. Utilizing these attributes, textual depictions of Bangla faces are generated through our novel algorithm for Bangla facial description generation. By conducting thorough experimentation and utilizing both quantitative and qualitative evaluation metrics, the quality, diversity, and fidelity of the produced facial images are evaluated. Then, the performance of our proposed model is compared to that of the current leading models. The proposed system attained a Fréchet Inception Distance (FID) score of 126.708, Inception Score (IS) of 12.361, and Face Semantic Distance (FSD) of 20.23.

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**The major contributions of this paper are:**

- A novel version of the CelebA dataset has been proposed entitled CelebA Bangla.
- A novel system for generating facial images from Bangla text descriptions has been developed, whereby meaningful images are produced in response to input in the Bangla language. The system under consideration attained an FID score of 126.708.

The subsequent segments of the document are structured in the following manner: Section II discusses the related works. The dataset is elaborated upon in Section III, while Section IV provides an overview of the methodology employed. Section V presents a thorough analysis of the qualitative and quantitative outcomes. Section VI establishes the limitations or constraints of the study followed by Section VIII containing the conclusion. The remaining portion comprises references.

## II. RELATED WORK

In this section, significant works of state-of-the-art Generative Adversarial Networks, text encoders, text-to-image, and face synthesis architectures are analyzed.

### A. GANs

Generative Adversarial Network (GAN) [4] is an exceptional framework that can learn to generate new data based on the data of a specified training set. GANs are composed of two parts, the Generator and Discriminator respectively. There is a constant competition between these two parts where the generative network generates new data learning to map from a latent space of data distribution while the discriminative network differentiates the data produced by the generator from the actual data distribution. Deep Convolutional Generative Adversarial Network (DCGAN) [5] is an extension of GAN that incorporates convolutional and convolutional-transpose layers in the generator and discriminator accordingly. Self-Attention Generative Adversarial Network (SAGAN) [6] provides attention-driven modeling of long-range dependencies for image generation activities where its discriminator can verify the consistency of highly detailed features in distant portions of the image and attention mechanism can provide the generator and discriminator with more power to directly model the long-range dependencies in the feature maps and better approximate the original image's distribution.

Attentional Generative Adversarial Network (AttnGAN) enables multi-stage, attention-driven image generation from textual description [7], [8]. AttnGAN begins with a rudimentary low-resolution image which it then refines in multiple phases to produce a final image from the natural language description. StyleGAN [9]–[11] is another extension of the progressive GANs that enables generation of high-quality photorealistic images by means of the incremental development of discriminator and generator models beginning with a low resolution and expanding to a high resolution of 1024x1024 pixels. GigaGAN\* synthesizes high-resolution images, such as ultra-high 4k resolution images in 3.66 seconds, and supports a variety of latent space editing options including latent interpolation, style blending, and vector arithmetic operations.

\*<https://github.com/lucidrains/gigagan-pytorch>

### B. Text to Image Synthesis

In paper [12], they proposed an efficient deep GAN architecture-based text-to-image synthesis of birds and flowers images from human-written descriptions. They utilized the Caltech-UCSD Birds dataset (CUB), Oxford-102, and MS COCO dataset to train and evaluate their model. Their proposed model showed substantial improvements in Text-to-image synthesis. Later on, the paper [7] suggested the first Bangla language-based Text-to-image generation method AttnGAN that analyzed Deep Attentional Multimodal Similarity Model and Attentional GAN to generate improved and realistic high-resolution images from Bangla text description surpassing the state-of-the-art (SOTA) image synthesis GAN models by an ideal inception score of  $3.58 \pm .06$ .

The author of [8], presented AttnGANTRANS which consists of Attentional GAN and transformer models such as Bidirectional Encoder Representations from Transformers (BERT), GPT2, and XLNet that were capable of extracting semantic information from text descriptions more accurately than the conventional AttnGAN. Gao *et al.* [13] proposed LD-CGAN comprised of one generator and two independent discriminators to regularize and generate 64x64 and 128x128 images. The generator includes three major components- Conditional Embedding (CE) which disentangles integrated semantic attributes in the text, Conditional Manipulating Modular (CM-M) used to continuously provide image features with compensation information and Pyramid Attention Refine Block (PAR-B) to enrich multi-scale features. The experiments were evaluated on CUB and Oxford-102 datasets achieving an Inception score of  $3.64 \pm 0.04$  and  $4.18 \pm 0.06$  on 64x64 and 128x128 images.

Zhang *et al.* [14], presented XMC-GAN comprised of several contrastive losses, an attentional self-modulation generator, and a contrastive discriminator to generate images of higher quality and closer correspondence to the input descriptions which was evaluated on three datasets demonstrating SOTA FID score of 9.33 on the MS-COCO dataset and an impressive benchmark FID score of 26.91 on the Open Image Data. Siddharth *et al.* [15] proposed AttnGAN with pre-trained text encoder RoBERTa using the Caltech-UCSD birds dataset for textual descriptions obtaining an FID score of 20.77.

The authors of [1], [16], [17] suggested DF-GAN that can directly synthesize high-resolution images without entanglements between different generators, improve TTI semantic coherence and make complete integration between text and synthesized features that was evaluated on the CUB and COCO datasets where yielded results surpassed SOTA models.

### C. Text to Face Synthesis

It is a very challenging task to convert human-written descriptions into human faces. But many types of research [1], [9], [18]–[22] have been conducted in this field of Text-to-face synthesis.

Deorukhkar *et al.* [1], proposed to use Sentence Bidirectional Encoder Representations from Transformers (SBERT) to convert the textual descriptions (from their own dataset based on CelebA dataset) into embeddings and generated 128x128 sized images using DCGAN, SAGAN and DFGAN models. Recently, StyleGAN-based models [9], [19] have

advanced Text-to-face synthesis in terms of image quality and diversity. The author of [9] introduced a Multi-Modal CelebA-HQ dataset. They also introduced a framework containing the GAN inversion technique based on the multi-modal inputs. Finally, evaluating the model on the Multi-Modal CelebA-HQ dataset, they achieved an FID score of 106.37 and generated 1024x1024 sized images. The authors of [19] presented a two-stream framework combining CLIP visual concepts and StyleGAN using Multi-Modal CelebA-HQ and CelebAText-HQ [23] datasets for high-fidelity Text-to-face synthesis. Later, they evaluated the model on two datasets including the Multimodal CelebA-HQ dataset and the CelebAText-HQ dataset, and finally, achieved an FID score of 50.56 and 56.75, respectively.

Recently, StyleGAN2-based models [18], [20] have been introduced in the field of Text-to-face synthesis. The authors of [18], used a Text-to-face framework with StyleGAN2 and a sentence encoder named BERT and generated 1024x1024-shaped high-quality images. In the paper [20], they proposed a TTF-HD framework with StyleGAN2 using the CelebA dataset in order to generate high-quality facial images with a wide range of variations leading to generating 1024x1024 sized images.

Peng *et al.* [21] introduced a dynamic pixel synthesis network that can transform text features into dynamic knowledge embeddings and generate accurate Text-to-face images that were trained and evaluated on the Multi-Modal CelebA-HQ dataset achieving an excellent FID score of 13.48. The authors of [22], proposed a GAN model which can directly convert the text descriptions into pixel values. They conducted zero-shot experiments on Face2Text [24] then trained and evaluated their proposed model on Multi-Modal CelebA-HQ and managed to achieve an FID score of 14.45.

There are many existing works on English text-to-face synthesis, as discussed in this sub-section. However, there is no research work done on Bangla text-to-face synthesis. There are also some limitations in the prior English text-to-face synthesis works. For instance, when the textual descriptions of faces are long, some of the works failed in handling those long descriptions of faces. As a result, the models could not generate accurate facial images. In some other works the models are not robust enough, so the generated images do not match with the input text descriptions.

### III. DATASET

The present study employs the CelebA dataset, which was introduced by the authors of [3]. The dataset comprises in excess of 200,000 images of celebrities' faces, each with a resolution of 128x128 pixels. Additionally, it contains annotations (in English) of 40 facial attributes for each image.

Nonetheless, the CelebA dataset is inadequate for creating a system that utilizes Bangla facial description as input and produces the corresponding image. Consequently, a novel iteration of the CelebA dataset, titled CelebA Bangla, has been created and presented in this paper. The proposed dataset consists of three distinct segments. The initial segment depicts a collection of images of notable celebrities, followed by a list of 40 attributes that have been manually annotated in the Bengali language. The third segment pertains to the Bangla

TABLE I. FACIAL ATTRIBUTE SAMPLE OF THE PROPOSED CELEBA BANGLA DATASET

image_file_name	হালকা দাড়ি (5_o_Clock Shadow)	কুঁচকানো ঝুঁক (arched eyebrows)	আকর্ষণীয় (attractive)	.....	অল্পবয়স্ক (young)
 000001.jpg	-1	1	1	.....	1
 000002.jpg	-1	-1	-1	.....	1
.....					
 202599.jpg	-1	1	1	.....	1

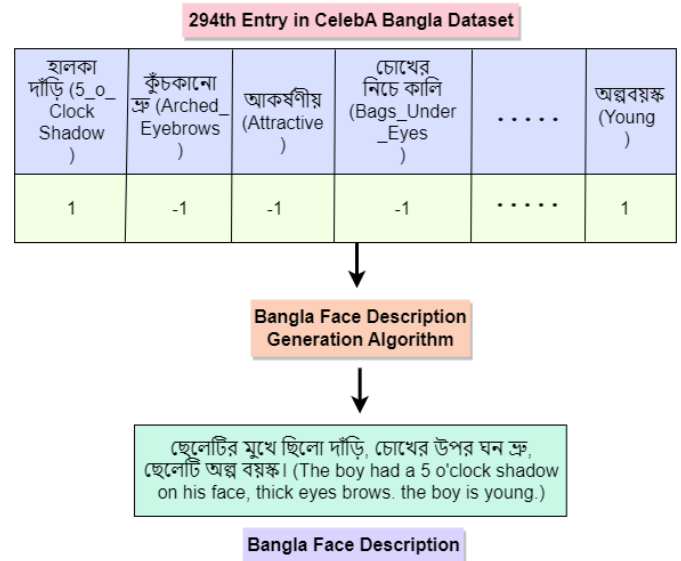





Fig. 1. Proposed Facial Description Generation Process.

descriptions, which are obtained from the second segment. Therefore, it can be observed that every image is associated with 40 distinct Bangla facial attributes and a corresponding Bangla facial description.

Table I represents 40 facial attributes corresponding to a single image. Here, the first column shows the image of celebrities and each of the following columns is facial attributes in Bangla. Considering  $i$  as row and  $j$  as the column

of Table I, if  $TableI[i][j] = 1$ , it implies that attribute  $j$  is present in image  $i$ . Otherwise,  $TableI[i][j] = -1$  means attribute  $j$  is absent in image  $i$ . Face attributes were manually annotated into the most suitable Bangla attributes.

TABLE II. BANGLA TEXT DESCRIPTION SAMPLES OF THE PROPOSED CELEBA BANGLA DATASET

image_file_name	text_description
 000001.jpg	মেয়েটির ক্র কুচকানো ছিল। মেয়েটির সোনালী চুল ছিল। মেয়েটির মুখে ভারী মেকাপ ছিল। মেয়েটির উচু গালের হাড় ছিল। মেয়েটির মুখ কিছুটা খোলা ছিল। মেয়েটির চোখ নাক ছিল। মেয়েটির মুখে ছিল হাসি। মেয়েটির সোজা চুল ছিল। মেয়েটির কানে দুলা পরা ছিল। মেয়েটির লিপস্টিক পরা ছিল। (The lady had arched eyebrows. She had blonde hair. She was wearing heavy makeup. The lady had high cheekbones. Her mouth was slightly open. She had a pointy nose. The lady was smiling. She was wearing earrings and lipstick.)
 000002.jpg	মেয়েটির চোখের নিচে কালি ছিল। মেয়েটির বড় নাক ছিল। মেয়েটির সোনালী চুল ছিল। মেয়েটির উচু গালের হাড় ছিল। মেয়েটির মুখ কিছুটা খোলা ছিল। মেয়েটির মুখে ছিল হাসি। (The woman had bags under eyes. She had a big nose. She had blonde hair. The woman had high cheekbones and her mouth was slightly open. She had a smile on her face.)
	.....
 202599.jpg	মেয়েটির ক্র কুচকানো ছিল। মেয়েটির সোনালী চুল ছিল। মেয়েটির মুখে ভারী মেকাপ ছিল। মেয়েটির চেহারা ফ্যাকাশে। মেয়েটির চোখ নাক ছিল। মেয়েটির ডেউ খেলানো চুল ছিল। মেয়েটির লিপস্টিক পরা ছিল। (The woman has arched eyebrows. She has blonde hair, heavy makeup and pale skin. Her nose is pointy. She has wavy hair. The woman was wearing lipstick.)

Algorithm 1 is utilized to generate a Bangla description for each image based on its facial attributes. Algorithm 1 depicts a partial segment of the comprehensive algorithm for generating Bangla facial descriptions. This particular segment outlines the process for generating textual descriptions pertaining to males and females of varying ages. The gender and age attributes of the dataset are represented by row[22] and row[41], respectively. The Bangla text descriptions in Table II have been generated through the utilization of the suggested description generation algorithm. In order to produce significant textual depictions in Bangla, the algorithm receives annotated Bangla attributes. Subsequently, the Bangla text description generation algorithm generates semantically accurate Bangla text descriptions that correspond to the images of faces. The aforementioned procedure is depicted in Fig. 1.

#### IV. METHODOLOGY

The proposed system utilized DCGAN+Bangla Fasttext to generate face images from the corresponding Bangla descriptions. Firstly the Bangla text description is fed to Bangla Fasttext [2] which returns a  $[300 \times 1]$  shaped text embedding. A random noise vector with a shape of  $[100 \times 1]$  along with the achieved text embedding is passed to the generator. The generator generates images with a resolution of 128x128, then the discriminator detects whether the generated images are real or fake by comparing the generated images with ground truth images. Based on the difference between generated and ground truth images the loss is calculated and is back-propagated through the generator and discriminator as shown in Fig. 2.

#### Algorithm 1 Bangla Face Description Generation Algorithm

```

CelebABangla    ▷ Dataset containing Bangla attributes
attributes      ▷ 40 facial attributes
for row in CelebABangla do
    description ← ""    ▷ textual description of face
    if row[22]==1 then
        gender ← "male"
    else
        gender ← "female"
    end if
    if row[41]==1 then
        age ← "old"
    else
        age ← "young"
    end if
    for i = 0 to length(attributes) do
        if gender=="male" then
            if age=="young" then
                description.append(YoungMaleSentence(attribute[i]))
            else
                description.append(OldMaleSentence(attribute[i]))
            end if
        end if
        if gender=="female" then
            if age=="young" then
                description.append(YoungFemaleSentence(attribute[i]))
            else
                description.append(OldFemaleSentence(attribute[i]))
            end if
        end if
    end for
end for

```

#### A. Embedding Strategy

The proposed dataset comprises image-text pairs, where a single pair contains textual description  $T$  of the facial image  $I$ . In this study, a text encoder denoted as  $TE$  was employed in conjunction with a Deep Convolutional Generative Adversarial Network (DCGAN). The text  $T$  is passed through  $TE$  in order to obtain the corresponding text embedding  $E$ . Ultimately, the DCGAN was trained through the utilization of  $I$  and  $E$ .

$$E = TE(T) \quad (1)$$

In FGTD [1], text embeddings were generated for a given text description  $T$  consisting of a series of sentences  $S_i$ , and embeddings  $E_{S_i}$  were computed, where  $i \in \mathbb{N}$  and  $\mathbb{N}$  is the set of all natural numbers. The arithmetic average of the embedding vectors was utilized as input for the conditional GAN, as depicted in Fig. 3(a). However, it was anticipated that the process of obtaining the mean of embeddings results in a reduction of significant semantic information that is initially present in the sentence embeddings,  $E_{S_i}$ . In order to mitigate the loss of information, our proposed embedding strategy (as depicted in Fig. 3(b)) which involves the utilization of a text encoder to generate a text embedding,  $E$ , by processing the complete textual description  $T$  as shown in Equation 1. Thus a text embedding is obtained without losing semantic information caused by the mean operation. Since  $E_T$  is an

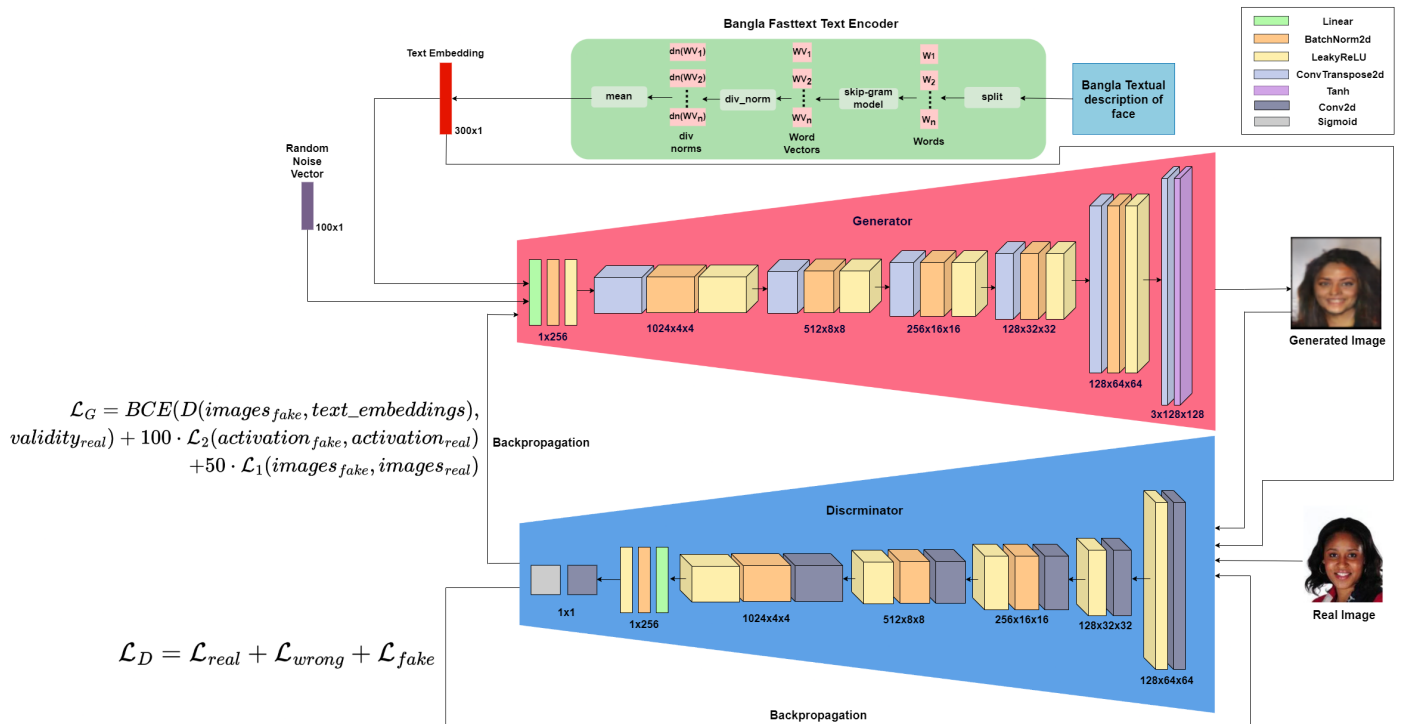


Fig. 2. Neural architecture of the proposed system: Bangla Fasttext + DCGAN.

embedding of the entire textual description  $T$ , it has a better one-to-one correlation between the text description and the final embedding.  $E_T$  is directly passed to DCGAN. Within the section pertaining to quantitative results, it is demonstrated that the proposed text embedding strategy exhibits superior performance in comparison to the strategy employed in FGTD [1].

### B. Text Encoder

A work [8] from 2021 suggested that using a pre-trained text encoder enhances the performance of text-to-image synthesis. The proposed system employs Bangla FastText [2] as pretrained text encoder. Bangla FastText is trained using 20 million Bangla data. As demonstrated in Fig. 4(a), the Bangla Fasttext sentence encoder first splits the facial descriptions into words. It then computes word embeddings using a skip-gram model. Afterwards, the word embedding vectors go through an operation  $div\_norm$  defined by Equation 2.  $div\_norm$  essentially prevents a distribution from being dispersed by dividing a vector by its euclidian norm if the euclidian norm is greater than zero. Finally, the mean of  $div\_norms$  is passed on as a  $[300 \times 1]$  sentence embedding vector.

$$div\_norm(x) = \begin{cases} \frac{x}{\sqrt{\sum_{i=0}^n x_i^2}} & \text{if } \sqrt{\sum_{i=0}^n x_i^2} > 0 \\ x & \text{if } \sqrt{\sum_{i=0}^n x_i^2} \leq 0 \end{cases} \quad (2)$$

In our experimental models, two other pretrained Bangla

text encoders were also used provided by sbnltk<sup>†</sup>: sbnltk sentence transformer hd (trained on 3,00,000+ human data) and sbnltk sentence transformer gd (trained on 3,00,000+ google translated data). Both of these models have the same neural architecture but were trained on different datasets. As depicted in Fig. 4(b), the sbnltk sentence transformer first generates tokens from sentences. The tokens are passed on to a pretrained multilingual model, XLM-RoBERTa [25] which has 12 hidden encoder layers. Finally, a pooling layer gives us the sentence embedding vector of length 768. Despite the superior neural architecture of XLM-RoBERTa, sbnltk sentence transformer is trained on lesser amount of Bangla text corpus, which may have led it to have learned an inadequate probabilistic distribution of text written in Bangla; compared to Bangla FastText. For this reason, Bangla FastText have been incorporated in our proposed system.

### C. GAN Architecture

Our proposed method has DCGAN [5] as its GAN architecture. The generator of DCGAN has a sequence of transpose convolution, batch normalization, and LeakyReLU layers. In the end, a Tanh activation function gives us generated or fake images. Strided convolutions used in the generator allows the network to learn its own spatial upsampling. The Discriminator mainly has a sequence of blocks containing convolution, batch normalization, LeakyReLU layers, and a sigmoid activation in the end to classify real/fake images. The discriminator uses strided convolution to learn its own spatial downsampling. Batch normalization employed in both generator and discriminator normalizes the input to each unit to have zero mean and unit variance to stabilize the training process. The use

<sup>†</sup><https://github.com/Foysal87/sbnltk>



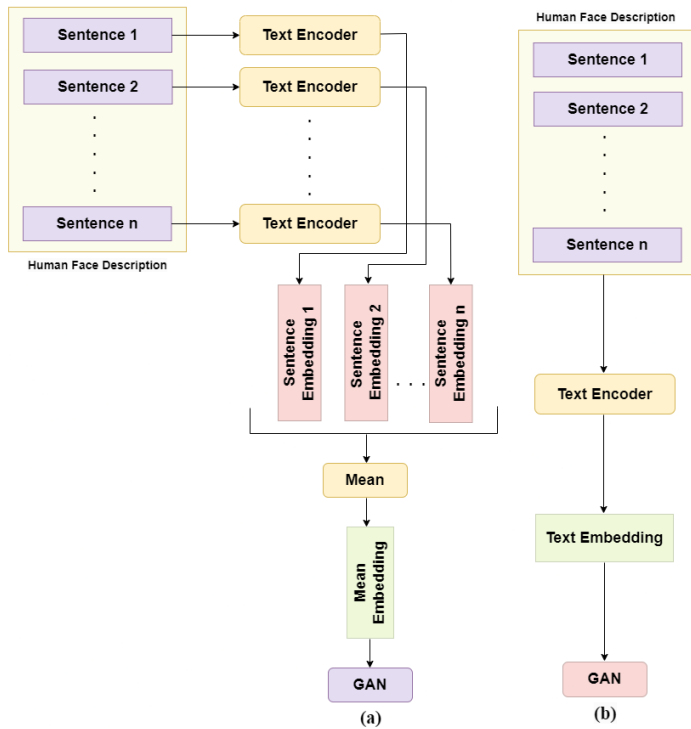


Fig. 3. (a) Text embedding strategy used in FGTD [1], (b) Proposed embedding strategy.

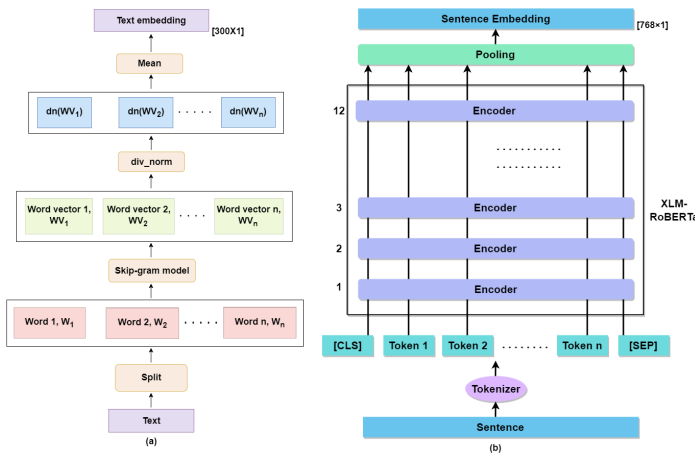


Fig. 4. (a) Bangla FastText architecture, (b) Sbnltk Sentence Transformer neural model.

of an unbounded activation, Leaky ReLU allows DCGAN to converge fast and learn the color space of the distribution of training images.

To train the Generator of DCGAN, Adam optimizer was utilized with learning rate,  $\alpha = 0.0002$  and  $\beta_1 = \beta_2 = 0.5$ . For training the Discriminator of DCGAN, Adam optimizer was utilized with learning rate,  $\alpha = 0.0001$  and  $\beta_1 = \beta_2 = 0.5$ .

#### D. Loss Functions

The loss function of the generator of our proposed DCGAN+Bangla FastText method is shown in Equation 3.

$$\mathcal{L}_G = BCE(D(images_{fake}, text\_embeddings), validity_{real}) + 100 * \mathcal{L}_2(activation_{fake}, activation_{real}) + 50 * \mathcal{L}_1(images_{fake}, images_{real}) \quad (3)$$

Here  $BCE$  in Equation 3 is the Binary Cross Entropy Error.  $images_{fake}$  are images generated from input noise and text embeddings passing through the Generator of DCGAN.  $input\_noise$  is a 100-dimensional vector which comes from a standard normal distribution with mean 0 and variance 1.  $text\_embeddings$  are generated from textual descriptions of faces which went through a text encoder (Equation 4). The dimensions of  $text\_embeddings$  are  $[300 \times 1]$ .  $validity_{real}$  is a vector where each element equals 1 (Equation 5). The dimensions of  $validity_{real}$  are  $[batch\_size \times 1]$ . The  $BCE$  loss mentioned here uses discriminator  $D$  to assess how realistic the generated images are in response to text embeddings. Higher BCE loss penalizes the generator network more.

$$images_{fake} = Generator(input\_noise, text\_embeddings) \quad (4)$$

$$validity_{real} = \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix}_{[batch\_size \times 1]} \quad (5)$$

$\mathcal{L}_2$  loss is the Mean Square Error (MSE). By passing  $images_{fake}$  and  $text\_embeddings$  through the Discriminator of DCGAN in Equation 6,  $activation_{fake}$  was obtained. By passing  $images_{real}$  and  $text\_embeddings$  through the Discriminator of DCGAN,  $activation_{real}$  was obtained in Equation 7. The  $\mathcal{L}_2$  loss is a comparison of how different the activations are from the discriminator with regards to real and fake images. Since this loss can potentially prove to be crucial in the training process, it is multiplied by 100 in Equation 3.

$$activation_{fake} = Discriminator(images_{fake}, text\_embeddings) \quad (6)$$

$$activation_{real} = Discriminator(images_{real}, text\_embeddings) \quad (7)$$

$\mathcal{L}_1$  loss is defined as the mean absolute error. in Equation 3,  $\mathcal{L}_1$  loss measures how different the generated images are compared to real images. Since this loss has lower relevance than  $\mathcal{L}_2$  loss and higher significance than  $BCE$  loss, it is given a multiplier 50 in Equation 3.

Performing a weighted sum of  $BCE$  loss,  $\mathcal{L}_2$  loss and  $\mathcal{L}_1$  loss in Equation 3 equips the generator of DCGAN with a



robust loss function to help it generate more realistic images which are semantically aligned with textual descriptions.

The loss function illustrated in Equation 8 was used to train the discriminator network of DCGAN.

$$\mathcal{L}_D = \mathcal{L}_{real} + \mathcal{L}_{wrong} + \mathcal{L}_{fake} \quad (8)$$

Where, For computing  $\mathcal{L}_{real}$ ,  $images_{real}$  and  $text\_embeddings$  were passed through the Discriminator of DCGAN to get  $output_{real}$  and  $activation_{real}$  in Equation 9.  $output_{real}$  is compared with  $labels_{real}$  to compute *BCE* loss, which is our  $\mathcal{L}_{real}$  loss(Equation 10).  $labels_{real}$  are textual descriptions of faces corresponding to a batch of facial images.  $\mathcal{L}_{real}$  loss essentially determines how close the outputs of the discriminator are compared to true labels.

$$output_{real}, activation_{real} = Discriminator(images_{real}, text\_embeddings) \quad (9)$$

$$\mathcal{L}_{real} = BCE(output_{real}, labels_{real}) \quad (10)$$

When calculating  $\mathcal{L}_{wrong}$  in Equation 11,  $validity_{fake}$ , a vector of 1s and dimensions  $[batch\_size \times 1]$  are taken.  $output_{wrong}$  is obtained by passing  $images_{wrong}$  and  $text\_embeddings$  through the Discriminator of DCGAN.  $images_{wrong}$  are images which are different from  $images_{real}$  and do not correspond to  $text\_embeddings$ . *BCE* loss between  $output_{wrong}$  and  $validity_{fake}$  are calculated to acquire  $\mathcal{L}_{wrong}$ (Equation 12). The task of  $\mathcal{L}_{wrong}$  is to ensure that the discriminator is classifying the wrong images correctly.

$$output_{wrong} = Discriminator(images_{wrong}, text\_embeddings) \quad (11)$$

$$\mathcal{L}_{wrong} = BCE(output_{wrong}, validity_{fake}) \quad (12)$$

For the purpose of determining  $\mathcal{L}_{fake}$ , first  $output_{fake}$  is obtained by passing  $images_{fake}$  and  $text\_embeddings$  through the Discriminator of DCGAN in Equation 13. In Equation 14, *BCE* loss between  $output_{fake}$  and  $validity_{fake}$  is calculated to get  $\mathcal{L}_{fake}$ .  $\mathcal{L}_{fake}$  instructs the discriminator to classify fake images correctly.

$$output_{fake} = Discriminator(images_{fake}, text\_embeddings) \quad (13)$$

$$\mathcal{L}_{fake} = BCE(output_{fake}, validity_{fake}) \quad (14)$$

A linear combination of  $\mathcal{L}_{real}$ ,  $\mathcal{L}_{wrong}$  and  $\mathcal{L}_{fake}$  in Equation 8 form a strong loss function to assist the discriminator of DCGAN to adjust its parameters to attain superior classification performance.

## V. RESULT ANALYSIS

In this section, a comprehensive discussion of the experimental details during training and validation of the proposed model is provided.

### A. Experimental Setup

During the process of training and testing the model, the hardware configuration utilized comprised an Intel Core i7 7700K CPU, 16 GB of DDR4 RAM, and an Nvidia RTX 3060 GPU equipped with 12 GB of VRAM. The proposed system is implemented and developed using the Anaconda 22.11.1 environment, which runs on Windows 10 and has Python 3.9.15 installed.

Prior work related to text-to-face synthesis utilizes English text descriptions where they employ sBERT [1], Roberta [15], GPT2 and XLNet [8] etc. as text encoders. However, these text encoders are not usable when considering Bangla text description. Thus, in this study, Bangla FastText and sbnltk text encoders are used in combination with several GAN architectures to provide a comprehensive analysis of performance between our proposed system and other systems. Some details about the models used for comparison are presented in Table III where Model-1 is the proposed model. Keeping limited computational resources in mind, DCGAN [5] (30 Million Parameters), SAGAN [6] (18M Parameters) and DFGAN [16] (110M Parameters) architectures were chosen to perform the experiments. FGTD [1]'s implementation of DCGAN, SAGAN, and DFGAN were used in this research endeavor and sbnltk and Bangla FastText replaces the text encoder of FGTD to take Bangla text descriptions as input.

TABLE III. CONFIGURATION OF DIFFERENT EXPERIMENTAL MODELS

Experimental Models	Text encoder and GAN utilized	Batch size	VRAM consumption while training
Model-1 (Proposed system)	DCGAN + Bangla FastText	64	4.5 GB
Model-2	DCGAN + sbnltk HD	64	4.7 GB
Model-3	DCGAN + sbnltk GD	64	4.7 GB
Model-4	SAGAN + Bangla FastText	16	7.8 GB
Model-5	SAGAN + sbnltk HD	16	9 GB
Model-6	SAGAN + sbnltk GD	16	9 GB
Model-7	DFGAN + sbnltk GD	8	10 GB

To train the Generator of SAGAN, Adam optimizer was used with learning rate,  $\alpha = 0.0001$  and  $\beta_1 = 0$ ,  $\beta_2 = 0.9$ . For training the Discriminator of SAGAN, Adam optimizer was utilised with learning rate,  $\alpha = 0.0004$  and  $\beta_1 = 0$ ,  $\beta_2 = 0.9$ . For training the Generator of DFGAN, Adam optimizer was utilised with learning rate,  $\alpha = 0.0001$  and  $\beta_1 = 0$ ,  $\beta_2 = 0.9$ . For training the Discriminator of DFGAN, Adam optimizer was utilised with learning rate,  $\alpha = 0.0004$  and  $\beta_1 = 0$ ,  $\beta_2 = 0.9$ .

The aforementioned GAN architectures were paired with Bangla FastText [2], sbnltk sentence transformer HumanTranslated Data (HD), and sbnltk sentence transformer GoogleTranslated Data (GD) text encoders.

## B. Evaluation Metrics

To evaluate our models, 5 different conventional evaluation metrics were utilised including Inception score (IS), Fréchet Inception distance (FID), Learned Perceptual Image Patch Similarity (LPIPS), Face Semantic Similarity (FSS) and Face Semantic Distance (FSD).

1) *Inception score (IS)*: IS is used to measure the quality and diversity of the generated images where a higher score of IS suggests that the generated images are of high quality and diverse. IS is calculated using Equation 15.

$$\text{Inception Score} = \exp(\mathbb{E}_x \text{KL}(p(y|x)||p(y))) \quad (15)$$

Here,  $p(y|x)$  is the conditional class distribution of the generated images,  $p(y)$  is the marginal class distribution of the generated images, and KL is the Kullback-Leibler Divergence. PyTorch ignite's implementation<sup>‡</sup> of inception score was used.

2) *Fréchet Inception Distance (FID)*: FID compares the similarity of generated images to the real ones. FID is a more accurate performance metric compared to IS and unlike IS, a lower FID score means that the generated images are more similar to the real images. FID is calculated using Equation 16.

$$d^2 = \|\mu_X - \mu_Y\|^2 + \text{Tr}(\Sigma_X + \Sigma_Y - 2\sqrt{\Sigma_X \Sigma_Y}) \quad (16)$$

Where  $d^2$  indicates the distance has squared units.  $\mu_X$  is the feature-wise mean of the real image.  $\mu_Y$  indicates the feature-wise mean of the generated image.  $\Sigma_X$  is the covariance matrix of the feature vector of the real image.  $\Sigma_Y$  is the covariance matrix of the feature vector of the generated image. Trace linear algebra operation is indicated by  $Tr$ .

3) *Learned Perceptual Image Patch Similarity (LPIPS)*: LPIPS essentially measures the similarity between the activations of two image patches where the two images are the real image and the generated image, respectively. Like FID [26] score, a lower LPIPS score indicates that image patches are perceptually similar. The formula used to calculate LPIPS is in equation 17.

$$d(x, x_0) = \sum_l \frac{1}{H_l W_l} \sum_{h,w} \left\| \omega_l \odot (\hat{y}_{hw}^l - \hat{y}_{0hw}^l) \right\|_2^2 \quad (17)$$

Where  $d$  is the LPIPS distance between real image  $x$  and generated image  $x_0$ . Features are extracted from layer  $l$  of Alexnet. In the channel dimension, unit normalization is applied.  $\odot$  indicates the Hadamard product. The number of activated channels are scaled by the vector  $\omega_1$ . For calculating LPIPS, `lpips-pytorch`<sup>§</sup> was used to evaluate the generated images using a pre-trained Alexnet model.

4) *Face Semantic Similarity (FSS)*: FSS measures the similarity between the generated face and the real face with regard to their facial features. In the case of FSS, a higher score of FSS means that the images are more similar. Equation 18 is utilized to compute FSS.

$$\text{FSS} = \frac{1}{N} \sum_{i=0}^N \cos(\text{Facenet}(F_{G_i}) - \text{Facenet}(F_{GT_i})) \quad (18)$$

5) *Face Semantic Distance (FSD)*: FSD is used to measure the dissimilarity between the generated face and the real face with respect to their facial features. Regarding FSD, a lower score implies that images are more similar. The formula for determining FSD is presented in Equation 19.

$$\text{FSD} = \frac{1}{N} \sum_{i=0}^N |\text{Facenet}(F_{G_i}) - \text{Facenet}(F_{GT_i})| \quad (19)$$

Here,  $\text{Facenet}()$  indicates using a pre-trained Facenet model to extract a semantic vector of the input face.  $F_{G_i}$  is one of the generated faces,  $F_{GT_i}$  is the ground truth of the synthesized face image.  $\cos()$  indicates calculating the cosine similarity of two vectors. For calculating FSS and FSD, a pretrained VGGFace2 model provided by `facenet-pytorch`<sup>¶</sup> was used.

## C. Qualitative Results

Fig. 5 comprises images synthesized using the proposed system. The initial column denotes the input Bangla text descriptions, while the fourth column represents the corresponding translation of the stated Bangla descriptions. The images presented in the second column were produced through the utilization of the mean embedding approach of FGTD. On the other hand, the images displayed in the third column were generated by employing our proposed embedding strategy, which is elaborated in subsection IV-A. The figure presented provides clear evidence that the utilization of our proposed embedding strategy yields superior outcomes in generating accurate images that correspond to the input text. Specifically, the first, second, and fourth images of the third column accurately depict the gender as specified in the input text.

The visual representation in Fig. 6 illustrates that model-2 and model-3 have generated facial images that exhibit a degree of realism. The images generated by models 4, 5, and 6 exhibit noise and lack realism, which can be attributed to non-convergence, as noted in [27]. The potential reason for the absence of intricate features in almost all of the produced images may be attributed to the utilization of low-resolution images (solely 128x128) during the training process, coupled with the intricate structural composition of Bangla facial descriptions. Based on a visual assessment, it can be concluded that the proposed model, namely model-1, generated the most authentic and precise images. The model configuration details are presented in Table III, while their corresponding explanation can be found in subsection V-A.

<sup>‡</sup><https://pytorch.org/ignite/generated/ignite.metrics.InceptionScore.html>

<sup>§</sup><https://github.com/S-aiueo32/lpips-pytorch>

<sup>¶</sup><https://github.com/timesler/facenet-pytorch>

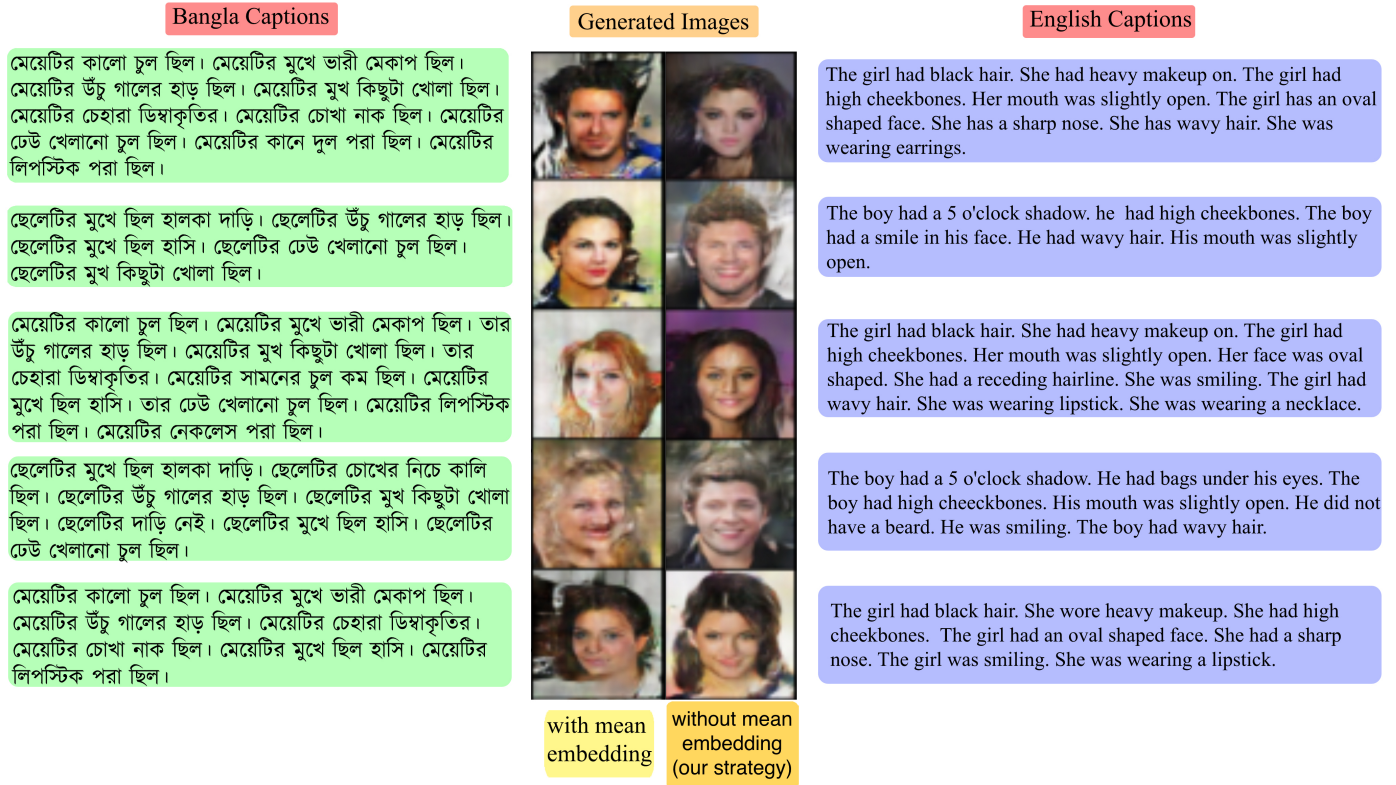


Fig. 5. Comparison of generated images between FGTD and proposed embedding strategies.

#### D. Quantitative Results

Table IV demonstrates that Model-1, which is proposed in this research, surpassed the other models in FID, Inception Score, and FSD metrics. This can be attributed to the stable training of DCGAN and the rich sentence embeddings of Bangla FastText. However, Model-7 shows moderate improvement in LPIPS and FSS performance metrics due to its matching-aware gradient penalty policy [16]. Nonetheless, the proposed model has a better overall performance.

TABLE IV. PERFORMANCE ANALYSIS AMONG DIFFERENT MODELS AND OUR PROPOSED MODEL

Experimental Models	FID ↓	IS ↑	LPIPS ↓	FSD ↓	FSS ↑
<b>Model-1 (Proposed system)</b>	<b>126.71</b>	<b>12.361</b>	21.8291	<b>20.23</b>	0.343
Model-2	165.87	11.676	21.6	20.35	0.34
Model-3	145.36	7.82	26.6	22.3	0.25
Model-4	184.17	9.05	6.25	21.81	0.303
Model-5	191.26	8.76	7.11	20.28	0.272
Model-6	210.93	8.28	6.6	21.93	0.233
Model-7	155.16	4.78	<b>3.22</b>	20.37	<b>0.42</b>

Bangla FastText performed better compared to sbnltk sentence transformer likely due to its robust pretraining procedure. Furthermore, it can be observed from Fig. 8 that the utilization of the proposed embedding strategy results in a superior FID score. The performance of our models is less significant in comparison to the state-of-the-art English text-to-face models,

which can be caused by the intricate nature of Bangla textual descriptions. The FID score graph presented in Fig. 7 indicates that the proposed DCGAN+Bangla FastText method exhibits superior performance.

## VI. DISCUSSION

It is clear from Fig. 9 that Both DCGAN and SAGAN suffered from non-convergence [27]. After about 47 epochs, DFGAN fell into mode collapse. Moreover, None of our models reached Nash equilibrium [27]. The last blocks of both generator and discriminator were omitted in the implementation of DFGAN in FGTD [1]; which may have made DFGAN more prone to mode collapse [27] and unstable training [27]. Although Transformer based models generally perform better than FastText-based models, Bangla FastText [2] performs better than sbnltk sentence transformer due to the superior training dataset, hyperparameter tuning, and preprocessing strategy used in Bangla FastText.

## VII. LIMITATIONS OF OUR WORK

The quality of the generated images is low due to the proposed system's inability to map the text space to the generated facial image space accurately. Larger GAN architectures are relatively more capable of generating more realistic images. Further research can be done by employing such architectures to enhance the results of Bangla text-to-face synthesis.

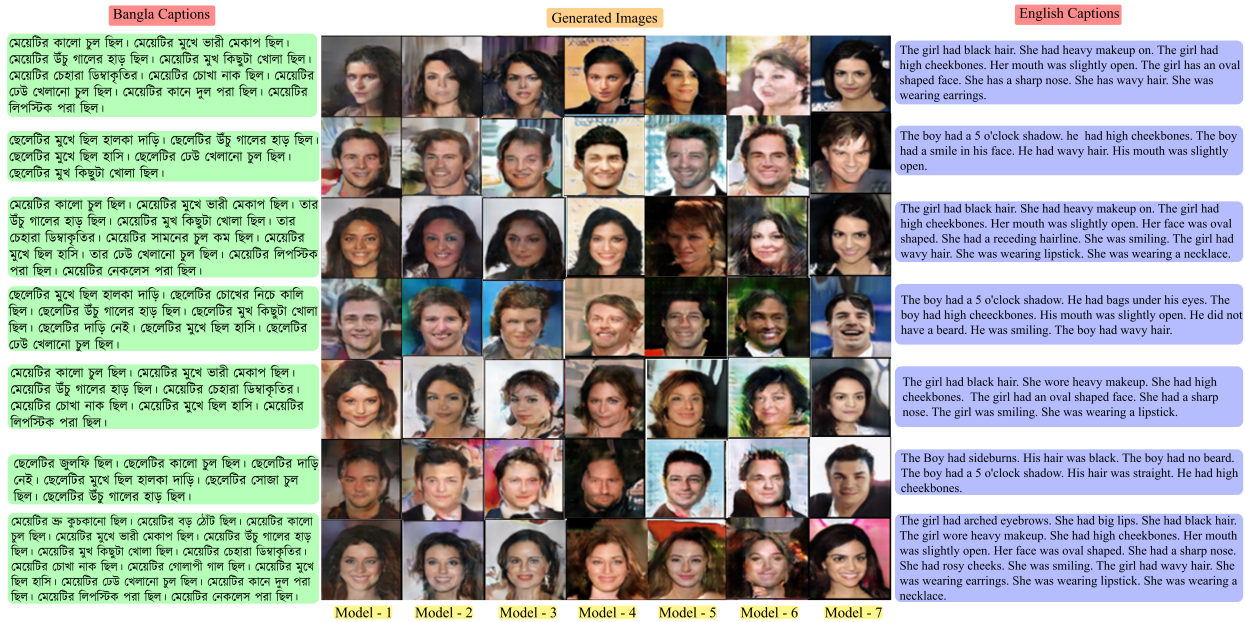


Fig. 6. Comparison of generated images among various experimental models.

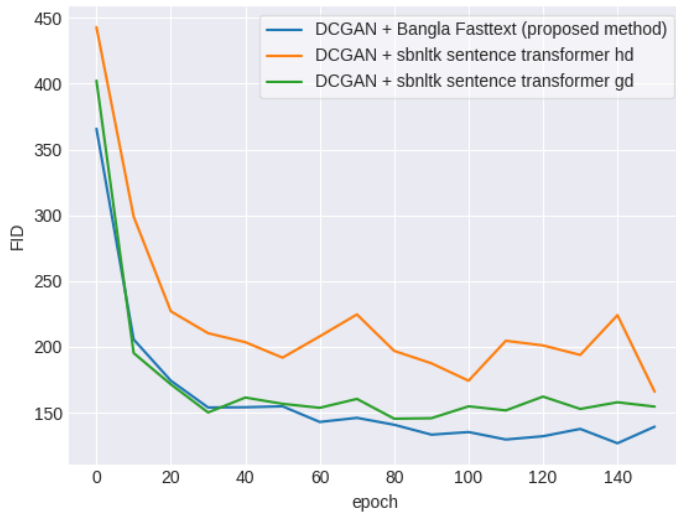


Fig. 7. Comparison of FID between our proposed model and other models considering FID.

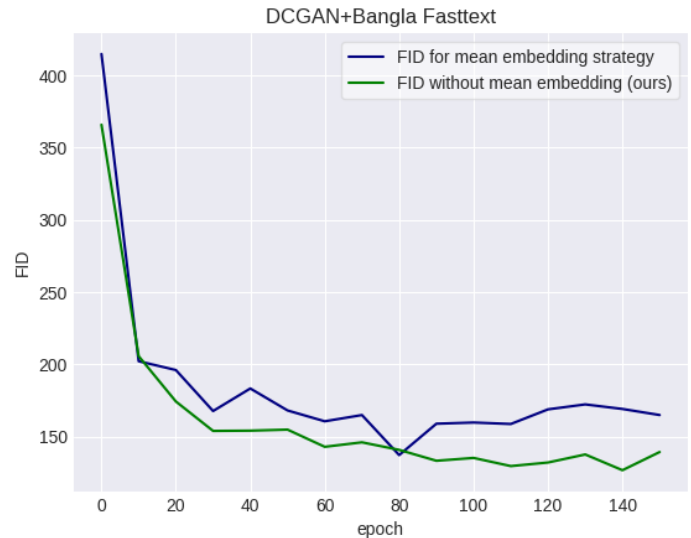


Fig. 8. Comparison of FID scores between FGTD [1] and our proposed embedding strategies.

### VIII. CONCLUSION

This study presents a new approach that employs DCGAN + Bangla FastText to produce facial images based on textual descriptions in the Bangla language. A comprehensive performance comparison is provided between our proposed model and various utilizations of DCGAN, SAGAN, and DFGAN models in conjunction with Bangla FastText, sbnlk sentence transformer hd and sbnlk sentence transformer gd pre-trained Bangla text encoders. Furthermore, a new textual embedding approach is suggested. The superiority of the suggested embedding approach is established through both qualitative and quantitative results. The models presented in

Table III were trained and evaluated using the CelebA Bangla dataset that is proposed in this research. The evaluation of generated face images involves the utilization of five distinct performance metrics, specifically FID, IS, LPIPS, FSS, and FSD. The study revealed that among all the models tested, the proposed model (DCGAN + Bangla FastText) exhibited the highest performance, attaining a FID, IS and FSD score of 126.71, 12.361 and 20.23 respectively. The proposed system's performance is moderate, likely due to the intricate structure of textual descriptions in the Bangla language. The use of diffusion models, variational autoencoders, pre-trained GANs, generating higher resolution images (256x256, 512x512, or



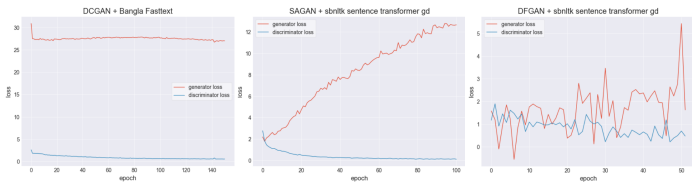


Fig. 9. Losses at different epochs of our experimental models.

1024x1024) in conjunction with large pre-trained language models can be investigated in future research for the task of Bangla text-to-face synthesis.

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# Microbial Biomarkers Identification for Human Gut Disease Prediction using Microbial Interaction Network Embedded Deep Learning

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**Abstract**—Human gut microorganisms are crucial in regulating the immune system. Disruption of the healthy relationship between the gut microbiota and gut epithelial cells leads to the development of diseases. Inflammatory Bowel Disease (IBD) and Colorectal Cancer (CRC) are gut-related disorders with complex pathophysiological mechanisms. With the massive availability of microbiome data, computer-aided microbial biomarker discovery for IBD and CRC is becoming common. However, microbial interactions were not considered by many of the existing biomarker identification methods. Hence, in this study, we aim to construct a microbial interaction network (MIN). The MIN accounts for the associations formed and interactions among microbes and hosts. This work explores graph embedding feature selection through the construction of a sparse MIN using MAGMA embedded into a deep feedforward neural network (DFNN). This aims to reduce dimensionality and select prominent features that form the disease biomarkers. The selected features are passed through a deep forest classifier for disease prediction. The proposed methodology is experimentally cross-validated (5-fold) with different classifiers, existing works, and different models of MIN embedded in DFNN for the IBD and CRC datasets. Also, the selected biomarkers are verified against biological studies for the IBD and CRC datasets. The highest achieved AUC, accuracy, and f1-score are 0.863, 0.839, and 0.897, respectively, for the IBD dataset and 0.837, 0.768, and 0.757, respectively, for the CRC dataset. As observed, the proposed method is successful in selecting a subset of informative and prominent biomarkers for IBD and CRC.

**Keywords**—Biomarker discovery; microbial interaction network; graph embedding feature selection; inflammatory bowel disease; colorectal cancer

## I. INTRODUCTION

The human gut microbiome represents a complex community of trillions of microorganisms, some of which are well known to affect general health. With rapid mutations and a rise in resistance, there is a disruption in the steady relationship between the microbiome and body cells, which can be linked to several diseases [1]. Metagenomics, broadly, is the study of the structure and function of the genetic material of organisms extracted from multiple environmental samples. The metagenomic data presents each sample with its microbial taxonomic composition. Microbiome-wide association studies (MWAS) on the metagenomic data help identify the disease-associated microbial biomarkers. These biomarkers assist in the early diagnosis of diseases, and the development of treatment.

While there is a steady increase in the available and accessible data, the interpretation of the biological data is becoming considerably slower. Machine Learning (ML) tools can be used

to handle, organize and extract meaningful information from unorganized biological data in an efficient manner. Recently, even deep learning methodologies have garnered attention especially due to their learning capabilities and abilities to identify specific patterns directly from the data, thus avoiding manual feature engineering.

As ML continues to be widely used for biomarker identification and classification of disease; a higher accuracy of identified biomarkers will lead to higher accuracy of disease prediction. But, the biggest challenge faced is the high dimensionality of the metagenomics data, coupled with low sample size. The high dimensionality in the metagenomics dataset is represented by the large number of features which are the taxa of microbes.

Feature selection is the process of reducing the number of input variables by selecting informative features. This benefits classification models to predict more accurately since there exist fewer misleading features. It helps in improving performance, and reducing the computational load and cost of the model. It also helps by minimizing training time, and overfitting due to the reduction in noisy data. Above all, feature selection methods play an important role in identifying the subset taxa in the metagenomics dataset that form the set of potential biomarkers.

The main drawback of some of the well-known feature selection mechanisms is the fact that they do not take into consideration the interaction and the effect of interaction between the features (taxa) [2]. However, in the case of microbial communities, their structure and functions are heavily dependent on ecological interactions and microbial relationships (such as mutual, competition, synergism, etc.) in various environments making it a crucial factor to be taken into account when dealing with selecting appropriate features (biomarkers) with highest predictive influence [3]. By understanding microbial interactions, an insight into the dynamic properties of microbes and their functions are obtained [4]. Microbial Interaction Networks (MIN) are graph-based interaction networks that map the relationship and association between the gut microbes (features). Studies have shown that by embedding the resultant MIN into a neural network, the high-dimensionality vector can be mapped to a low-dimensionality vector. Moreover, this retains relevant information about the topology thereby improving the reliability of the network and facilitating the extraction of prominent biomarkers [5].



Inflammatory Bowel Disease (IBD) results from the interaction between environmental and genetic factors that influence immune response [6]. There are two major diseases that come under the umbrella of IBD namely, Ulcerative Colitis (UC) and Crohn's Disease (CD). Colorectal Cancer (CRC) is the second deadliest form of cancer arising from the mutation of specific genes [7]. Both IBD and CRC cause disruption and inflammation of the digestive system, and can lead to multiple symptoms. Since the etiology of IBD and CRC is not fully understood and symptoms are complex, the design of new tools that make use of the available human gut metagenome data is essential for their diagnosis [8], [9]. Hence, the metagenomic analysis of the human gut microbiome helps to illuminate disease development mechanisms [9].

The objective of this paper is to extract and identify the biomarkers for IBD and CRC by constructing an MIN. The feature selection is done by embedding the MIN into a graph using a graph embedding technique in conjunction with a Deep Feedforward Neural Network (DFNN) model to calculate feature importance scores. This feature importance score is used to rank the features on the basis of how informative it is for the prediction of the presence of the disease. The proposed method for feature selection allows for capturing the ecological topology of the microbial community and generating a subset of the top features which form the set of meaningful biomarkers for the disease dataset.

All things considered, the proposed framework puts forward the following contributions.

- 1) Construction of an MIN using MAGMA to capture the interactions and associations between microbes in a microbial community.
- 2) A graph-embedding neural network architecture with a MIN embedded in the neural network forms a sparsely connected first hidden layer. The model performs feature scoring to rank the features (taxa) during training.
- 3) The efficiency of the proposed framework is studied by applying it to two different real disease datasets of IBD, and CRC and classifying using Deep Forest (DF) classifier. The results of the proposed method are compared against other embedded MIN construction models and existing works with various classifiers.
- 4) Also, the biomarkers obtained as a result of the model training and feature scoring from MAGMA+DFNN feature selection technique is cross validated with biological studies on IBD and CRC.

The paper has been organized as follows. Section II performs a literary review of various proposed works that focus on feature selection algorithms and biomarker identification techniques. The proposed methodology, and the dataset used is elaborated upon in Section III. Section IV elucidates the details of the implementation, and the evaluation criteria of the experiments. Section V details the findings of the experiment and Section VI includes a discussion segment. Finally, Section VII concludes the paper with the closing remarks.

## II. RELATED WORKS

The MWAS are not only required to conduct metagenomic sample classification tasks but also feature selection tasks. Numerous studies have been conducted on effective and efficient feature selection, and biomarker identification techniques.

This review aims to analyze the various feature selection algorithms and methodologies for biomarker identification implemented on different datasets, and identify the advantages and disadvantages of each which help to guide this work. Based on the objective of this work the literature review is divided into two sections: feature selection algorithms, and biomarker identification for human diseases.

### A. Feature Selection Algorithms

Fleuret proposed "Fast Conditional Mutual Information Maximization (CMIM)", an algorithm for a fast and reliable feature selection technique based on conditional mutual information. The algorithm reduced computational overhead by computing CMIM between the feature and class given the most recently picked feature. This method calculated the entropy based on probabilistic and histogram methods. It made use of a partial score and updated the score only if the best one found so far in the iteration was not better. This feature selection method outperformed other classical algorithms and had a decently low error rate, working well for noisy data. In combination with well-known classifiers, this feature selection method ranked high in terms of low error rates and high speed [10].

Yu and Liu proposed a novel concept of predominant correlation and introduced a fast feature selection algorithm Fast Correlation Based Filter (FCBF). The aim was to select features by using information gain to calculate the symmetric uncertainty as its main selection criterion. A feature was selected and considered good only if it was predominant in predicting class and not redundant among the relevant selected features. The algorithm was put through C4.5 and Naïve Bayes Classifier (NBC) and reported high average accuracy when compared with other feature selection techniques. It was computationally efficient and fast, with less computational time complexity, and achieved high levels of dimensionality reduction [11].

Ding and Peng proposed a feature selection method that can reduce redundancy in chosen features, while selecting features having a more balanced coverage of the feature characteristics. A basic heuristic algorithm was used. For discrete variables, it was based on mutual information while for continuous variables, it was based on F-statistic. The selected features were put through classifiers such as NBC, Linear Discriminant Analysis (LDA), and Support Vector Machine (SVM), Logistic regression was used for the comparison in terms of error reduction between the baseline features and features selected by Minimum Redundancy Maximum Relevance (MRMR) [12].

Alshawaqfeh et al. created a novel hybrid feature selection method that combined the speed of filter methods with the accuracy of wrapper methods. The hybrid method performed feature importance scoring using a filter method i.e. ratio of Between group Sum-of-Squares (BSS) and Within group Sum-of-Squares (WSS). On the selected features, a wrapper method was applied by employing an embedded Nearest

Centroid Classifier (NCC) with a forward sequential search. The resulting model showed improved performance in terms of execution time as well as classifier accuracy in comparison with other feature selection techniques [13].

### B. Biomarker Identification Techniques

Zhu et al. proposed a method for the identification of microbial biomarkers via the use of Graph Embedding Feed Forward Neural Networks (GEDFN). The aim was to reduce overfitting and noise, and to construct a reliable neural network with the ability to simultaneously assign feature importance scores for feature selection while performing accurate classification. The model made use of a modified weights initializer to perform graph embedding in the first hidden layer of the network. The dot product of the weights was done with the adjacency matrix created by the amalgamation of the resulting matrix from the Maximal Information Coefficient (MIC), MINs: SparCC, and Spiec-Easi. MIC is a statistic method that identifies relationships between pairs of variables by measuring the dependence for two-variable relationships [14]. The resulting model showed improved performance in terms of Area Under Curve (AUC) score, and classifier accuracy, when compared with state-of-the-art classifiers [4].

Abbas et al. proposed a method to identify reliable microbial biomarkers from metagenomics data for IBD using network-based feature selection. The solution was based on hybrid feature selection and incorporated ecological microbial network construction of healthy samples and IBD samples. The tools used for network construction included SparCC, Meinshausen and Bühlmann (MB), CoNet, Proxi, and Random Matrix Theory (RMT). The importance scores were calculated based on network topology and a node resilience clustering algorithm. The hybrid solution suggested combining the features selected by Random Forest Feature Importance (RFFI) and instances of the best-performing network-based feature selection framework. The selected features were fed to a Random Forest (RF) classifier, and evaluation was done based on a comparison of the AUC scores obtained. Overall, the RF classifiers using the hybrid feature selection network outperformed its counterparts [15].

Bakir-Gungor et al. aimed to increase Type 2 Diabetes (T2D) diagnostic accuracy by developing a classification model using metagenomics data. Additionally, the goal was to discover T2D biomarkers. Feature selection was done using well-known variable selection techniques such as CMIM, MRMR, Correlation Based Filter (CBF), and SelectKBest. These features were then fed to RF classifiers which yielded highly promising performances. Further, K-means clustering was applied to the selected features to generate subgroups for visualization and outputs. 15 features were commonly identified by all feature selection methods and were able to cover a large portion of important features from the samples with comparable performance with respect to the best results [16].

Acharjee et al. aimed at analyzing stable RF based feature selection methods for the identification of biomarkers and power analysis. A number of RF based feature selection methods were compared against one another and the resulting features were tested in a regression, as well as a classification

model for power analysis of the models. Overall, the Boruta method yielded the best stability with high specificity and best prediction ability among all the methods [17].

Bakir-Gungor et al. made use of ML algorithms to be able to generate a classification model to aid IBD diagnosis, discover the potential biomarkers for IBD, and identify IBD patient subgroups. First, feature selection was conducted using well-known feature selection techniques, namely FCBF, CMIM, MRMR, and XGBoost. Their performance was verified using classifiers such as RF, Decision trees, Logiboost, AdaBoost, K-means + Logiboost, and SVM. Finally, using unsupervised learning methods such as K-means clustering, hierarchical clustering, and Principal Component Analysis (PCA), visualizations, and outputs were achieved. Promising results were seen in terms of performance and predictive power, especially by the union of feature selection methods and K-means + logiboost classifier, as well as, XGBoost feature selection and K-means + logiboost classifier [8].

Zhu et al. aimed at creating a stable and robust model, Deep-Forest, for MWAS along with ensemble feature selection for biomarker identification. The ensemble feature selection method aggregated multiple different feature selectors through linear combinations of the subsets to form the final result. The features were put through Deep-Forest which is an ensemble learning model consisting of 8 random forests. The proposed model was compared against other feature selection methods and classifiers and achieved the best results among all three datasets [18].

From the literature review, it could be noted that the methods reviewed either fail to capture the ecological interaction between the microbial community for an MWAS dataset or are computationally expensive. The proposed methodology in this work emphasizes the underlying biological process, especially through the inclusion of covariates during feature selection which enables the identification of a subset of meaningful biomarkers for disease diagnosis.

Table I provides a summary of various feature selection algorithms and Table II summarizes the previous work on biomarker identification for human diseases.

## III. METHODOLOGY

Fig. 1 illustrates the overall workflow of the methodology for the extraction and validation of potential biomarkers. Firstly, prevalence measure is applied on the original dataset to generate a reduced dataset. Secondly, the MIN is constructed using the network construction tool MAGMA [19]. Thirdly, the resulting network (adjacency matrix) is embedded into a deep neural network using graph embedding (DFNN). Then, feature importance scoring is done via the DFNN model resulting in the selection of the subset of the top-scoring features which form the set of disease biomarkers. Finally, the top features are classified using DF for performance evaluation.

### A. Dataset

This paper has focused on the use of two real datasets, one on IBD and the other on CRC. For both datasets, the taxonomy classification is done against the Greengenes database and the

TABLE I. SUMMARY OF FEATURE SELECTION ALGORITHMS

Ref	Dataset	Methodology	Advantage	Disadvantage	Results
[10]	<p>1) An image dataset of 1000 images collected from the web for classification of images as face or background.</p> <p>2) Thrombin- Molecular bio-activity binary class dataset containing 1,909 samples and 2,500 features obtained from DuPont Pharmaceutical for the KDD-Cup 2001.</p>	<p>Feature selection: Fast CMIM</p> <p>Classification: perceptron, NBC, Adaboost, SVM and Nearest neighbor.</p>	<p>Ensures selection of a small subset of features that are independent or weakly dependent and is information dense. Decently low error rates worked well for noisy data and Fast algorithm.</p>	<p>May provide unfavourable results for datasets that have a mixture of independent objects that do not share informative edges.</p>	<p>CMIM+NBC: Image dataset: e1 = 0.52%, e2 = 1.52%</p> <p>Thrombin dataset: e1 = 10.45%, e2 = 11.72% (e1 = Training error, e2 = Test error)</p>
[11]	<p>10 datasets namely lung-cancer, promoters, splice, USCensus90, CoIL2000, Chemical, Musk2, Arrhythmia, Isolet, Multi-features datasets are obtained from the UCI KDD Archive and the UCI Machine Learning Repository.</p>	<p>Feature selection: FCBF</p> <p>Classification: C4.5 and NBC</p>	<p>Avoids pairwise associations, and is a symmetric measure that is not confined to only linear correlations. Selects relevant, nonredundant features. Computationally efficient and fast. FCBF can increase accuracy, and achieves a high level of dimension reduction.</p>	<p>If two features contribute information to the predominant feature, the one with the higher relevance will be selected while removing the other feature by considering it redundant</p>	<p>FCBF +C4.5 : avg acc ± 89.13% 8.52</p>
[12]	<p>Six datasets of gene expression namely, Leukemia, colon - cancer, NCI, lung-cancer, Lymphoma, and child leukemia.</p>	<p>Feature selection: MRM</p> <p>Classification: NBC, LDA, and SVM, Logistic regression</p>	<p>A method for both discrete, as well as continuous data. Higher accuracy and reduced error rates. Can identify fewer features that can cover the same characteristic space as the baseline approach</p>	<p>Highly sensitive for parametric measurement.</p>	<p>Error rates for datasets + classifier: Leukemia + all classifiers = 0%, Coloncancer + NBC= 6.45%, NCI + NBC=1.67%, Lung + NBC=2.74%, Lymphoma + LDA,SVM = 1.04%, Child leukemia + LDA=2.68%</p>
[13]	<p>OTU table consisting of fecal microbiota of 79 dogs diagnosed with IBD and 89 healthy samples obtained against Greenegens database using QIIME.</p>	<p>Hybrid feature selection: (BSS/WSS) + (embedded classifier)/NCC</p>	<p>Reduced execution time; faster with higher classification accuracy. Narrowing the search space via the hybrid feature selection</p>		<p>BSS/WSS*: Balanced Classification Rate 0.82 Recall 0.84, Specificity 0.8 *The results are approximate values from graphs</p>

TABLE II. SUMMARY OF WORKS ON BIOMARKER IDENTIFICATION

Ref	Dataset	Methodology	Advantage	Disadvantage	Results
[4]	IBD QITA (study id: 1939) dataset with a total of 1,359 metagenomic samples. Final dataset consisted of 657 IBD samples and 316 normal samples.	Network construction: SparCC + Spiece-Easi Feature selection: MIN + MIC Feature Importance+classification: GEDFN	Improve the reliability of the network by embedding prior knowledge Effectively reducing noise and overfitting and dodging compositionality bias.	SparCC is computationally expensive. There were no relevant guidance suggestions for the threshold of the association networks.No neuron threshold was considered.	AUC: 0.843, Accuracy: 79.52%
[15]	IBD QITA (study id: 1939) dataset with a total of 1,359 metagenomic samples. The final dataset consisted of 657 IBD samples and 316 normal samples.	Network construction: SparCC, MB (Spiece-Easi), RMT, CoNet, and Proxi. Feature Selection: Betweenness Centrality, Closeness Centrality, Average Neighbor Degree, Clustering Coefficient, Node Clique Number, Core Number, and critical attack set- NBR-Clust. Classification: RF	Chosen feature selection method: RFFI + best instances of NBBB framework. Optimal number of features required to specify a biomarker need not be specified as fixed information. Able to achieve the best performance using a small number of samples.	The algorithm's performance on larger problems are not defined in the study.	RFFI+MB (20 features): AUC= 0.82, Accuracy=73%, Specificity=0.76, Sensitivity=0.72
[16]	T2D microbiome data from the NCBI Sequence read Archive (accession numbers SRA045646, and SRA050230). The dataset contained 290 samples with 1,455 species.	Feature selection: CMIM, MRMR,CBF,SelectKBest. K-means to generate subgroups. Classification: RF	The combined feature selection method was able to cover a large portion of important features from the samples.	Compositionality bias.	(199 common features out of 500 features) Accuracy = 73%, F1 score = 0.79, AUC = 0.73
[17]	Use of simulated dataset and 6 published datasets - lipid metabolites,lipidomic, and colorectal cancer, IBD, and adipose tissue transcriptomics- obtained from PubMed.	RF based Feature selection: Boruta, Recursive feature elimination, permutation based feature selection with and without correction, and backward elimination based feature selection. Classification: RF	Boruta has good stability in detecting potential biomarkers Power prediction while capturing complex dependencies between the covariates and the outcome.	Boruta method tends to have a higher time complexity, especially with larger, high dimensional datasets.	Minimum Classification Error rates - Boruta Simulated dataset: 3%, metabolics dataset: 2%, colorectal cancer: 4.23%, IBD: 5%, adipose tissue:10%
[8]	Raw microbiome DNA sequencing data of 148 IBD patients, 234 control patients were obtained from the MetaHit project.	i) Feature selection: FCBF, CMIM, mRMR, and XGBoost. Subgroups: K-means, PCA, hierarchical clustering. ii) Classification: RF, Decision trees, Logitboost, AdaBoost, K-means + Logitboost, and SVM.	XGBoost feature selection achieves minimal diagnostic markers with large effect size	Compositionality bias	The union of the features with K-means and logitboost : Accuracy=91.623%, AUC=0.933, F1-score 0.89
[18]	Three different datasets for Cirrhosis of 144 patients and 118 healthy subjects, Type 2 Diabetes of 170 patients and 174 healthy samples, and Obesity of 89 patients and 164 healthy samples are obtained from MetAML package.	Feature selection + Classification: Deep Forest (data perturbation method for feature selection)	Good stability in detecting potential biomarkers Power prediction while capturing complex dependencies between the covariates and the outcome.	The prediction using layers of RF can be time-consuming due to the nature of RF.	Cirrhosis: accuracy=82.57%, AUC=0.939 Obesity: Accuracy= 67.09%, AUC=0.749 T2D: Accuracy=64.71%, AUC=0.623

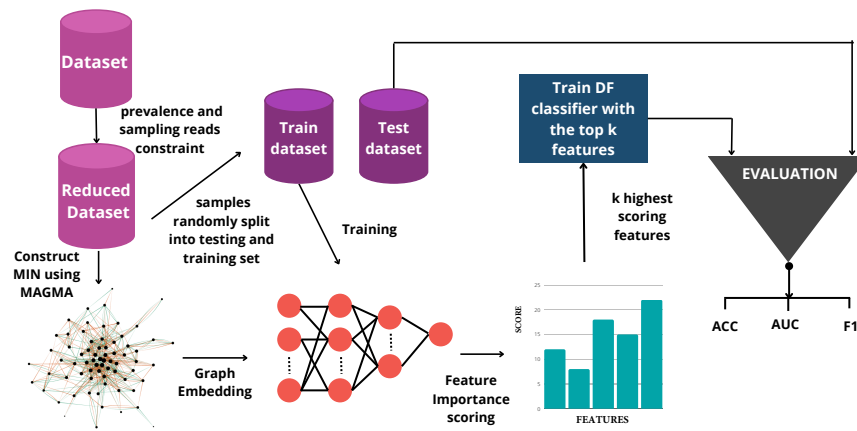


Fig. 1. Flowchart of the methodology.

comprehensive dataset is simplified in the form of an OTU table. The common structure of the OTU table consists of the number of samples in rows and the corresponding species-specific taxa that are found in the sample in the columns in a matrix format.

The IBD dataset has been procured from an online repository [20]. The original data for the IBD dataset is derived from the QIIME database under Study ID 2516 for all the proposed techniques. The dataset consisted of a total of 1359 samples out of which 336 are healthy, and 1023 are infected samples with a total of 9511 species.

The CRC dataset has been procured from an online repository [21]. The original data for the CRC (CRC1) dataset is derived from Zeller et al.'s [22] study. The dataset consisted of 182 samples out of which 90 are cancer samples and 92 are normal samples with a total of 18,170 species.

### B. Reduced Dataset

The number of taxa in the data set was reduced according to the percentage prevalence of the microbe in the samples. The number of samples is reduced by removing the samples whose sequencing depth is less than 500 reads on the remaining OTUs (sampling reads threshold). The reduced dataset is generated to reduce feature dimension and remove features that may be redundant, irrelevant, or have low impact on the sample.

For the IBD dataset, upon setting a 10% prevalence threshold and 500 sampling reads threshold, the resulting dataset contains 1359 samples and 1032 features. For the CRC dataset, upon setting a 15% prevalence threshold and 500 sampling reads threshold, the resulting dataset contains 182 samples and 1260 features. The reduced datasets are then split into an 80% training set and a 20% testing set.

### C. Construction of MIN

1) *Microbial interaction networks*: Most microorganisms do not live in isolation and thrive in communities while forming interactions and establishing ecological relationships. These ecological interactions and relationships shape microbial abundances [3]. Detection of significant undirected associations between sample populations enables the inference of

their interactions. By constructing MINs, the use of statistical methods that utilize relative data which are not independent and reflect the compositional nature of the data rather than the underlying biological process [23], is avoided. Thereby, by making use of absolute abundance data, compositionality bias is addressed. By exploring the structure and diversity, comprehensive and statistically significant associations between taxa can be achieved. Using this information, the interplay between the environment and microbial populations can be predictively modeled as a network. The edge between two nodes, which represent taxa, denotes that the connected nodes provide some type of relational additional information about the state of the other and that they are not conditionally independent [24].

Some popular MIN construction methods include SparCC [23], Spiec-Easi [24], CoNet [25], MAGMA [19], and Proxi [26]. SparCC enables the estimation of correlation values by having a mathematical model based on the calculation of log ratios. The dependencies are described using the variance between the variables [23]. Spiec-Easi makes use of the statistical method of conditional independence and covariance matrix for inference of graph-based MIN [24]. CoNet combines an ensemble method of similarity or dissimilarity measures with a permutation-renormalization bootstrap method to generate an association network [25]. MAGMA constructs the MIN based on a Gaussian copula mathematical model to graph the interaction between variables [19]. Proxi makes use of nearest-neighbor distances based on Pearson's Correlation to generate proximity graphs [26]. Among these methods, this work uses MAGMA to construct the MIN.

2) *MAGMA*: Cougal et al. proposed a method Microbial Association Graphical Model Analysis (MAGMA) for the construction of MIN.

MAGMA is able to account for data flaws such as noisy structure, overdispersion, and zero-count values, and can also handle compositionality bias. Its main working principle is based on the Gaussian copula model coupled with a generalized linear model to achieve mapping of the estimation of latent data by median values. The data is filtered to ensure that sample reads and the prevalence measure of each feature are above a particular threshold. The zero values in the data are handled by the use of a zero-inflated distribution executed

by the parametric mapping function and the overdispersion is tackled by modeling a negative binomial distribution. Additionally, the sequencing depth is modeled as a variable number by accounting for compositionality by an offset. The main feature of MAGMA is that it integrates covariates (characteristics of the participating variable) which improves the quality of inference of the categorical variables. The covariates are modeled over the mean of microbial abundances.

In this work, the dataset (Section 3.1) in the form of an Operational Taxonomic Unit (OTU) table containing  $f$  features and  $N$  samples, is presented as input to the MAGMA algorithm and the sparse precision matrix is estimated. The resulting precision matrix or inverse covariance matrix is the resulting network in the form of an adjacency matrix and is given by equation 1.

$$A = \begin{cases} 1 & \text{if, edge between nodes } n_i \text{ and } n_j \forall i, j \in \{1, \dots, f\} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

The main advantages of this network construction method are that the graphical models have minimum bias, and the model takes covariates into consideration which are important to account for any confounding in inference and beneficial in recovering the network structure. Additionally, the inference quality improves leading to fewer spurious correlations. More details on the algorithm can be found in [19].

#### D. Graph Embedding using Deep Feedforward Neural Network

1) *Overview*: Zhu et al. proposed a method to perform graph embedding feature selection by constructing a neural network that would simultaneously assign feature importance scores to the input variables while training to classify. Wrapper methods lack the capability of good generalization over classifiers and filter methods, since they are based on a discriminative methodology of eliminating features, and are independent of any ML algorithms, they are unable to find a truly optimal subset [27]. Graph embedding techniques, on the other hand, aptly represent the high dimensional vector representation of discrete variables in low dimensions while preserving relevant information like the topology of the graph and the relationship between nodes [28]. It combines the method of feature selection by importance and also feature extraction - mapping higher dimensions to lower dimension vectors - into the optimizing training step of the ML model [29]. Using this method, this paper aims to reduce overfitting, and noise and to embed priori knowledge into the neural network which would help improve the reliability of the network [4].

2) *Deep feedforward neural network architecture*: Fig. 2 depicts the model architecture of the neural network composed of an input layer, four hidden layers, and an output layer. Each neuron in the input layer corresponds to every feature or taxa, the first hidden layer corresponds to the graph embedding layer, and the output layer corresponds to the class label for the sample after prediction. The second hidden layer is composed of 128 neurons, the third layer is composed of 32 neurons and the fourth layer is composed of 8 neurons. The model has a learning rate of 0.0001 and utilizes the Adam optimizer for gradient descent. Other model hyperparameters include

Rectified Linear Unit (ReLU) activation function applied to the hidden layers and the Sigmoid activation function applied to the output layer, and a dropout of 0.5 applied to all the hidden layers except the first graph embedding hidden layer.

3) *Graph embedding*: After the MIN is constructed, the network is represented in the form of an adjacency matrix where an edge between two nodes is depicted with 1 if exists, else 0. The resulting matrix is then used as input to the graph embedding layer, the first hidden layer in the neural network. It generates a sparsely connected layer in contrast to the traditionally fully connected layers. The sparse layer is generated by performing element-wise dot product between the calculated weights and the adjacency matrix received from network construction as seen in equation 2. The dot product is used as the kernel constraint.

$$\begin{bmatrix} w_1 & w_2 & \dots & w_i \\ \vdots & \vdots & \vdots & \vdots \\ w_{i(i-1)} & \dots & \dots & w_{i*i} \end{bmatrix} \cdot \begin{bmatrix} 1 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \dots & \dots & 1 \end{bmatrix} = \begin{bmatrix} w_1 & w_2 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \dots & \dots & w_{i*i} \end{bmatrix} \quad (2)$$

$i$  = number of features

Input: weights matrix  $w$ , and adjacency matrix  $a$

Output: modified weights matrix  $w'(w_{in})$

The neurons in the first layer ( $L_1$ ) can be represented as given in equation 3 where  $X$  is the input matrix ( $n\_samples \times i\_features$ ),  $b$  denotes the initialized bias parameter, and  $\sigma$  is the activation function.

$$L_1 = \sigma(w'X + b) \quad (3)$$

#### E. Feature Importance Scoring

The feature importance score is given on the basis of the graphical connect weight method. The relative importance of each feature is scored on the basis of the sum of absolute values of the weights directly related to that feature or neuron as represented in equation 4, and 5 [4].

$$s_j = \gamma_j \sum_{k=1}^i |w_{kj}^{(in)} I(a_{kj} = 1)| + \sum_{l=1}^{h_1} |w_{jl}^{(1)}| \quad (4)$$

$$\gamma_j = \min \left( \frac{c}{\sum_{k=1}^i (a_{kj} = 1)}, 1 \right), j = 1, \dots, i \quad (5)$$

where  $s_j$  is the score of the  $j_{th}$  feature and  $w$  denotes the weight of the layer,  $w_{(in)}$  for the input layer,  $w_{(1)}$  for the weight between the first and second layer, and  $c$  denotes the penalty score for vertices with many edges. The weights are updated using a backpropagation algorithm that calculates the gradient based on the backward flow of the static cost function that was calculated by the feedforward network [4].



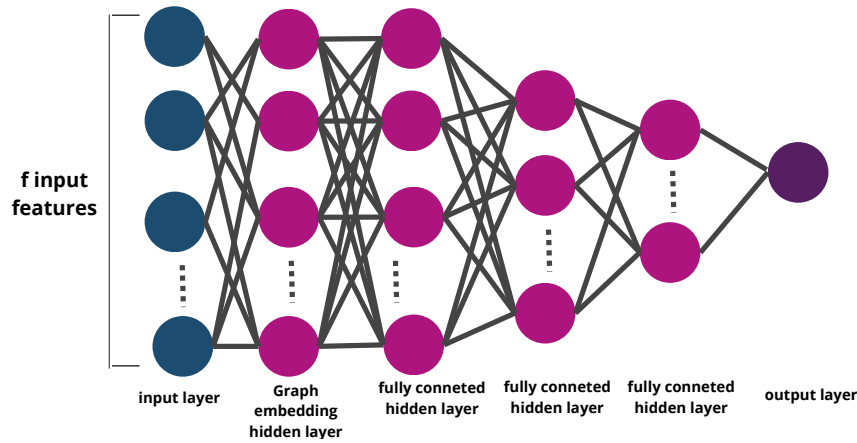


Fig. 2. DFNN architecture model.

### F. Deep Forest Classifier

Deep Forest is an ensemble learning model based on a cascading structure of decision trees. The ensemble model can generally achieve better generalization performance than single classifiers and the cascading structure enables the representation learning by the forests [18]. The DF's performance is quite robust to hyper-parameter settings and it can reach a deeper layer through layer-wise learning in the classification task compared to other traditional ML models [30].

## IV. IMPLEMENTATION, EVALUATION, AND EXPERIMENTS

### A. Implementation

The microbial network construction tool was implemented using the MAGMA package [31] in R. The neural network was modeled in Python v3.7 with the help of additional frameworks and libraries such as keras v2.8.0 and tensorflow v2.8.2, numpy, pandas, and Scikit-learn. All codes were run on Intel(R) Xeon(R) CPU @ 2.20GHz in Google Colab. The Python 3 Google Compute Engine backend was used for the Python codes and the ir Google Compute Engine backend was used for R codes. 12.7GB System RAM and 107.7GB disk space was allocated on Google colab.

### B. Evaluation

To evaluate model efficiency, statistical measures such as Accuracy, F1 score, and AUC were measured. True Positive (TP) represents the number of positive samples predicted correctly, True Negative (TN) represents the number of negative samples predicted correctly, False Positive (FP) represents the number of negative samples predicted incorrectly, and False Negative (FN) represents the number of negative samples predicted incorrectly.

Accuracy (equation 6) is used to measure the total number of correct predictions out of all observations.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (6)$$

The F1 score (equation 9) is the harmonic mean of Recall (equation 7) and Precision (equation 8) and is used as a statistical measure to rate the overall performance of classification.

$$Recall(Sensitivity) = \frac{TP}{TP + FN} \quad (7)$$

$$Precision = \frac{TP}{TP + FP} \quad (8)$$

$$F1 = \frac{2 * Precision * Recall}{Precision + Recall} \quad (9)$$

AUC is used to quantify the capability a model has in distinguishing between classes. It calculates the area under the curve made of points formed by calculating the True Positive vs the False Positive value at different thresholds. The higher the AUC score, the better the model is at accurate prediction.

### C. Experiments

In order to evaluate and establish the superiority of the proposed model in terms of feature selection, the following different models of MIN embedded in DFNN were developed.

- 1) The proposed method: Constructing the MIN using MAGMA, embedding it using DFNN to obtain the reduced features (MAGMA+DFNN), and classifying the reduced features using DF.
- 2) Constructing the MIN using SparCC, embedding it using DFNN to obtain the reduced features (SparCC+DFNN).
- 3) Constructing the MIN using Spiec-Easi, embedding it using DFNN to obtain the reduced features (Spiec-Easi+DFNN).
- 4) Constructing the MIN using SparCC and Spiec-Easi, and combining that with the network constructed using MIC, embedding it using DFNN to obtain the reduced features ((SparCC+Spiec-Easi+MIC)+DFNN).

The top k features were chosen from each of the above methods. In this work, we experimented by varying the value of k in [100, 200, 300, 400, 500]. The selected features were then put through selected classifiers like Support Vector Machine (SVM), DF, Random Forest (RF), Multi-Layer Perceptron (MLP), and XGBoost (XGB) for evaluation. Python's scikitlearn package with default settings was applied for the implementation of all the classifiers.

A baseline model with no feature selection was also experimented. The baseline model experiment was conducted by subjecting all the features of the IBD and CRC dataset through the classifiers for classification. The proposed methodology was experimentally analyzed against existing works on IBD and CRC datasets. Finally, the biomarkers obtained by the proposed method was verified against biological studies of IBD and CRC datasets. All the experiments were performed using 5-fold cross validation.

## V. RESULTS

### A. Comparative Results

In this section, the classification performance of the proposed model and other MIN construction models for feature selection over different classifiers such as RF, DF, SVM, MLP, and XGB is compared. The results are presented in terms of the evaluation metrics AUC, Accuracy, and F1 scores across all the five classifiers.

1) *IBD*: Table III presents the findings for the result obtained after the experiments for the IBD dataset. Table IIIa presents the performance across classifiers for the baseline with no feature selection applied on the dataset. As noted from the table, the maximum AUC of 0.855, highest accuracy of 0.829, and F1 score of 0.89 were resulted with the DF classifier. Table IIIb presents the results for MAGMA+DFNN feature selection technique. As noted from the table, the highest AUC, accuracy, and F1 score is 0.863, 0.839, and 0.897, respectively when classified using the DF classifier with the top 300 features. Table IIIc tabulates the results for (SparCC+Spiec-Easi+MIC)+DFNN feature selection technique. As noted from the table, the best AUC score of 0.85 was obtained using XGB with 300 features, accuracy of 0.832 using DF with 300 features, and an F1 score of 0.892 using DF with 400 features. Table III d presents the results for Spiec-Easi+DFNN feature selection method. The feature selection and classification method resulted in an AUC of 0.849 using RF with 400 features, an accuracy of 0.819, and an F1 score of 0.884 when using DF with 200 features. Table IIIe shows the results for SparCC+DFNN feature selection method. As seen from the table, the maximum values for AUC is 0.858 for 300 features, for accuracy is 0.824 for 100 features, and for F1-score is 0.889 for 500 features all with the DF classifier.

The results obtained by the proposed method (MAGMA+DFNN), put through all the classifiers (SVM, RF, MLP, DF, XGB) for different numbers of features are illustrated in Fig. 3. Additionally, the final results comparing the feature selection techniques tested using the different classifiers in terms of AUC, accuracy, and F1-score as detailed in Table III is illustrated by Fig. 4.

2) *CRC*: Table IV presents the findings for the result obtained after the experiments. Table IVa presents the evaluation metrics AUC, accuracy, and F1 scores across classifiers for the baseline with no feature selection applied. As noted from the table, the maximum AUC is 0.801 with RF, and highest accuracy is 0.746 and F1 score is 0.89 with the DF classifier. Table IVb presents the results for MAGMA+DFNN feature selection technique. It achieved the highest AUC, accuracy, and F1 score of all findings of 0.837, 0.768, and 0.757, respectively when classified using the DF classifier with the

top 400 features selected as highlighted in bold. Table IVc tabulates the results for (SparCC+Spiec-Easi+MIC)+DFNN feature selection technique. It achieved an AUC of 0.808 with RF for 300 features, an accuracy of 0.735 and F1 score of 0.742 with RF for 200 features. Table IVd presents the results for Spiec-Easi+DFNN feature selection method. The feature selection and classification method achieved an AUC of 0.803, an accuracy of 0.735, and an F1 score of 0.729 with RF for 500 features, 400 features and 400 features respectively. Table IVe shows the results for SparCC+DFNN feature selection method. It resulted in an AUC of 0.815 with DF for 400 features, an accuracy of 0.724 and an F1-score of 0.752 with SVM for 200 features.

The results obtained by the proposed method (MAGMA+DFNN), put through all the classifiers (SVM, RF, MLP, DF, XGB) for different numbers of features are illustrated in Fig. 5. Additionally, the final results comparing the feature selection techniques tested using the different classifiers in terms of AUC, accuracy, and F1-score as detailed in Table IV is illustrated in Fig. 6.

### B. Comparison Against Existing Model

The proposed methodology ((MAGMA+DFNN)+DF) is compared against the model proposed in Zhu et al.s' study [4] which makes use of a combination of SparCC, and Spiec-Easi for MIN construction along with MIC for the graph network construction, and a graph embedding deep model (GEDFN) for feature extraction from both IBD and CRC datasets. The top k features, where  $k \in 100, 200, 300, 400, 500$ , were chosen and put through selected classifiers, SVM, RF, DF, MLP, and XGB. The best results were achieved by the DF classifier for both datasets and both models. The results are presented in Table V. From the table, it could be observed that, the proposed model obtained the best classification performance.

### C. Biomarker Analysis

The top features selected by the MAGMA+DFNN model were cross-validated with biological studies to determine the reliability and accuracy of the biomarkers(features) suggested for the respective disease datasets.

1) *IBD*: Upon analyzing the top 300 features selected by MAGMA+DFNN, the top-scoring taxa were found to be related to the IBD development mechanisms. The selected taxa as seen in Fig. 7 could be suggested as potential IBD-biomarkers of human gut microbiota.

The results were cross-validated with the results from two biological studies presented by Paljetak et al. [32], and Gevers et al. [33].

The biomarkers identified by MAGMA+DFNN match with the majority of the informative biomarkers identified by Gevers et al., and Paljetak et al. in their respective studies as seen from Table VI. The biomarkers highlighted in bold denote the common subset of biomarkers from the study and the top 300 features selected by the proposed model for IBD. The top and most common IBD biomarkers identified in this study include *Bacteroides*, *Bifidobacterium*, *Lachnospiraceae*, *Ruminococcaceae*, *Enterobacteriaceae*, and *Streptococcaceae* among others.

TABLE III. IBD EVALUATION RESULTS. THE MAXIMUM VALUES ARE HIGHLIGHTED IN BOLD.

RF			SVM			MLP			DF			XGB		
AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
0.804	0.756	0.855	0.728	0.750	0.856	0.604	0.741	0.850	0.855	0.829	0.890	0.829	0.797	0.872

(A) FULL FEATURES

MAGMA	RF			SVM			MLP			DF			XGB		
# features	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
100	0.819	0.785	0.872	0.707	0.763	0.865	0.544	0.757	0.861	0.814	0.818	0.887	0.806	0.801	0.879
200	0.785	0.773	0.866	0.675	0.760	0.861	0.552	0.757	0.862	0.839	0.822	0.889	0.813	0.802	0.880
300	0.811	0.782	0.868	0.726	0.755	0.860	0.533	0.750	0.857	<b>0.863</b>	<b>0.839</b>	<b>0.897</b>	0.850	0.807	0.881
400	0.813	0.794	0.879	0.705	0.772	0.870	0.525	0.763	0.865	0.848	0.816	0.884	0.822	0.806	0.880
500	0.809	0.789	0.875	0.773	0.775	0.872	0.528	0.753	0.859	0.840	0.819	0.884	0.845	0.796	0.871

(B) MAGMA+DFNN FEATURES

Sparcc+ SpiecEasi+ MIC	RF			SVM			MLP			DF			XGB		
# features	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
100	0.799	0.793	0.877	0.647	0.750	0.857	0.512	0.747	0.855	0.824	0.805	0.876	0.829	0.789	0.867
200	0.814	0.802	0.883	0.689	0.751	0.857	0.541	0.750	0.857	0.817	0.810	0.879	0.841	0.788	0.866
300	0.809	0.754	0.853	0.713	0.746	0.855	0.532	0.759	0.863	0.847	0.832	0.891	0.851	0.806	0.879
400	0.828	0.779	0.870	0.732	0.741	0.851	0.555	0.743	0.852	0.842	0.830	0.892	0.835	0.790	0.868
500	0.814	0.775	0.867	0.695	0.764	0.866	0.537	0.754	0.859	0.826	0.820	0.885	0.840	0.799	0.872

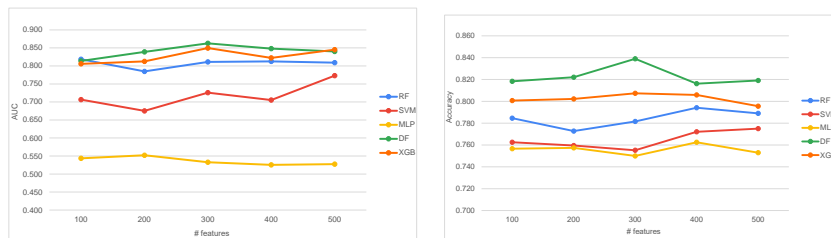
(C) (SPARCC+SPIECEASI+MIC)+DFNN FEATURES

SpiecEasi	RF			SVM			MLP			DF			XGB		
# features	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
100	0.761	0.773	0.864	0.692	0.747	0.855	0.611	0.763	0.865	0.815	0.790	0.867	0.780	0.788	0.871
200	0.825	0.785	0.872	0.711	0.749	0.856	0.589	0.748	0.855	0.838	0.820	0.884	0.835	0.805	0.881
300	0.815	0.788	0.874	0.694	0.751	0.857	0.542	0.755	0.860	0.813	0.793	0.870	0.816	0.779	0.860
400	0.849	0.771	0.865	0.713	0.750	0.857	0.517	0.755	0.860	0.824	0.815	0.882	0.832	0.798	0.874
500	0.831	0.787	0.875	0.723	0.768	0.868	0.540	0.741	0.851	0.821	0.811	0.880	0.840	0.806	0.880

(D) SPIECEASI+DFNN FEATURES

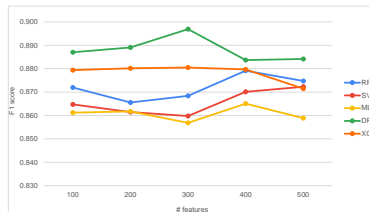
SparCC	RF			SVM			MLP			DF			XGB		
# features	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
100	0.811	0.779	0.868	0.706	0.761	0.864	0.539	0.726	0.841	0.851	0.824	0.889	0.837	0.802	0.876
200	0.839	0.801	0.881	0.729	0.749	0.856	0.537	0.739	0.850	0.845	0.809	0.877	0.851	0.809	0.879
300	0.818	0.802	0.884	0.748	0.767	0.867	0.505	0.752	0.858	0.858	0.819	0.884	0.844	0.790	0.867
400	0.810	0.775	0.866	0.734	0.761	0.864	0.545	0.764	0.866	0.854	0.818	0.883	0.856	0.801	0.876
500	0.829	0.788	0.874	0.742	0.764	0.865	0.549	0.742	0.852	0.855	0.823	0.889	0.840	0.802	0.875

(E) SPARCC+DFNN FEATURES



(a) MAGMA+DFNN - AUC

(b) MAGMA+DFNN - Accuracy



(c) MAGMA+DFNN - F1 score

Fig. 3. Evaluation metrics for the top k features where k = 100, 200, 300, 400, 500 selected by MAGMA+DFNN for the IBD dataset after being fed to classifiers.

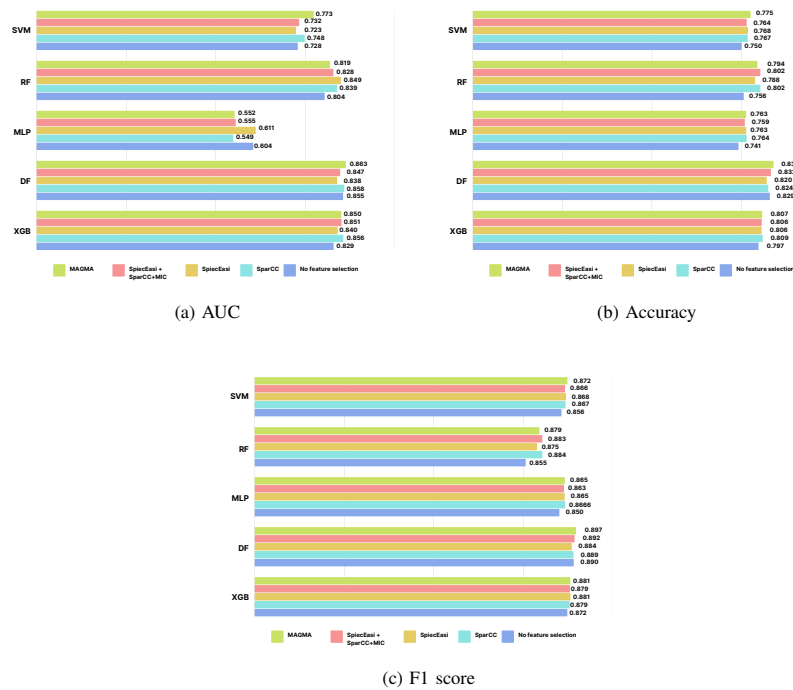


Fig. 4. Best or maximum value of a) AUC, b) Accuracy, c) F1 score for each combination of feature selection methods and classifiers regardless of the number of features for the IBD dataset.

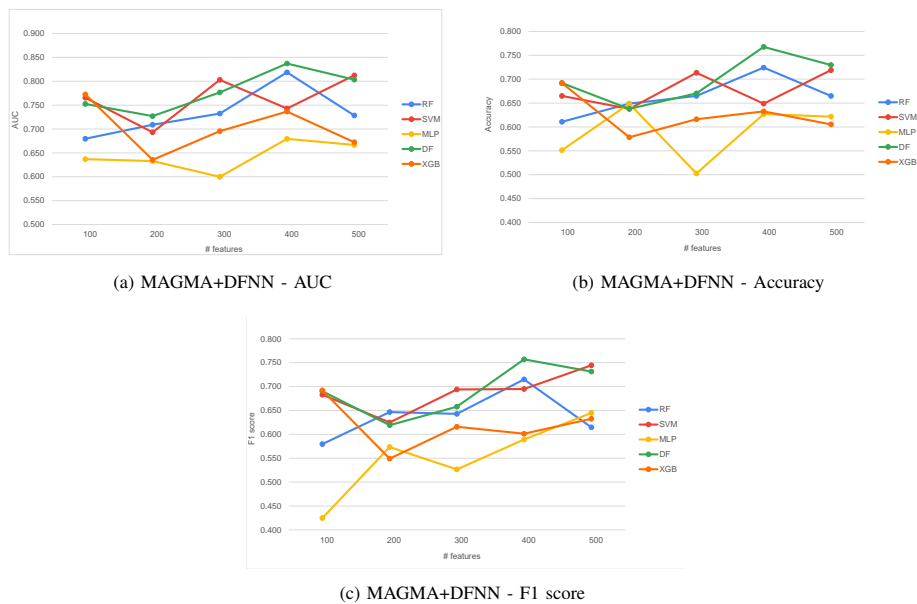


Fig. 5. Evaluation metrics for the top k features where k = 100, 200, 300, 400, 500 selected by MAGMA+DFNN for the CRC dataset after being fed to classifiers.

TABLE IV. CRC EVALUATION RESULTS. THE MAXIMUM VALUES ARE HIGHLIGHTED IN BOLD

RF			SVM			MLP			DF			XGB		
AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
0.801	0.730	0.717	0.758	0.697	0.720	0.697	0.627	0.604	0.767	0.746	0.731	0.709	0.649	0.652

(A) FULL FEATURES

MAGMA	RF			SVM			MLP			DF			XGB		
# features	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
100	0.680	0.611	0.580	0.766	0.665	0.683	0.637	0.551	0.425	0.752	0.692	0.690	0.773	0.692	0.692
200	0.709	0.649	0.647	0.693	0.638	0.625	0.633	0.649	0.574	0.727	0.638	0.619	0.635	0.578	0.549
300	0.732	0.665	0.643	0.803	0.714	0.694	0.600	0.503	0.527	0.777	0.670	0.658	0.696	0.616	0.616
400	0.819	0.724	0.715	0.743	0.649	0.695	0.679	0.627	0.589	<b>0.837</b>	<b>0.768</b>	<b>0.757</b>	0.737	0.632	0.601
500	0.728	0.665	0.615	0.812	0.719	0.745	0.667	0.622	0.645	0.803	0.730	0.732	0.672	0.605	0.633

(B) MAGMA+DFNN FEATURES

Sparcc+ SpiecEasi+ MIC	RF			SVM			MLP			DF			XGB		
# features	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
100	0.627	0.568	0.551	0.621	0.573	0.589	0.549	0.514	0.452	0.643	0.584	0.586	0.659	0.584	0.571
200	0.793	0.735	0.742	0.670	0.573	0.573	0.593	0.573	0.474	0.758	0.719	0.727	0.684	0.627	0.616
300	0.808	0.686	0.673	0.707	0.611	0.609	0.690	0.627	0.593	0.734	0.692	0.686	0.649	0.600	0.583
400	0.706	0.676	0.685	0.707	0.605	0.536	0.621	0.600	0.611	0.763	0.719	0.699	0.664	0.605	0.612
500	0.759	0.676	0.691	0.707	0.643	0.616	0.623	0.584	0.575	0.760	0.670	0.637	0.673	0.649	0.640

(C) (SPARCC+SPIECEASI+MIC)+DFNN FEATURES

SpiecEasi	RF			SVM			MLP			DF			XGB		
# features	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
100	0.695	0.643	0.622	0.715	0.616	0.628	0.593	0.546	0.349	0.730	0.697	0.694	0.720	0.654	0.674
200	0.727	0.649	0.657	0.704	0.659	0.701	0.509	0.497	0.338	0.700	0.638	0.623	0.656	0.643	0.647
300	0.667	0.622	0.610	0.692	0.627	0.623	0.609	0.535	0.494	0.713	0.659	0.656	0.738	0.681	0.681
400	0.802	0.735	0.729	0.745	0.670	0.681	0.647	0.611	0.593	0.779	0.719	0.728	0.595	0.600	0.586
500	0.803	0.730	0.716	0.765	0.692	0.699	0.669	0.638	0.556	0.757	0.692	0.685	0.668	0.627	0.633

(D) SPIECEASI+DFNN FEATURES

SparCC	RF			SVM			MLP			DF			XGB		
# features	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1	AUC	ACC	F1
100	0.732	0.643	0.634	0.684	0.595	0.656	0.519	0.535	0.444	0.714	0.600	0.577	0.648	0.611	0.592
200	0.769	0.681	0.667	0.800	0.724	0.752	0.576	0.568	0.422	0.765	0.665	0.652	0.745	0.659	0.652
300	0.717	0.659	0.634	0.785	0.714	0.747	0.585	0.546	0.508	0.776	0.703	0.702	0.708	0.659	0.659
400	0.714	0.627	0.608	0.789	0.719	0.748	0.512	0.476	0.364	0.815	0.724	0.724	0.766	0.697	0.689
500	0.724	0.643	0.622	0.788	0.719	0.705	0.584	0.524	0.478	0.772	0.686	0.694	0.694	0.665	0.684

(E) SPARCC+DFNN FEATURES

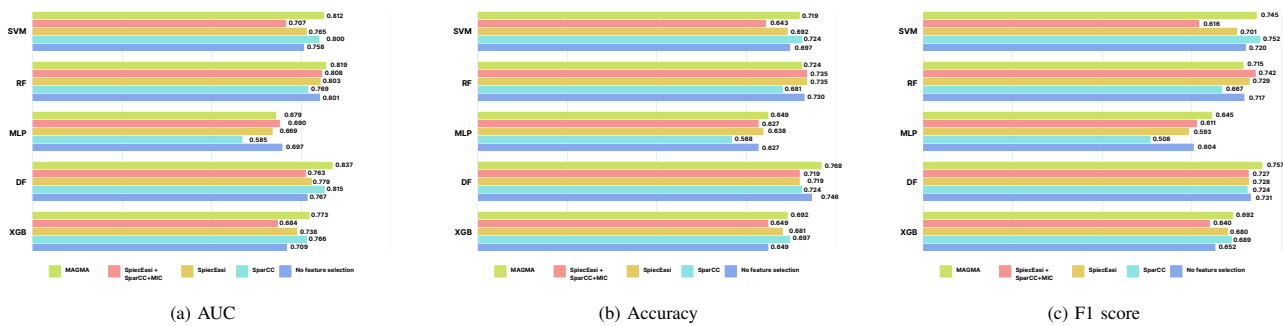


Fig. 6. Best or maximum value of a) AUC, b) Accuracy, c) F1 score for each combination of feature selection methods and classifiers regardless of the number of features for the CRC dataset.

TABLE V. COMPARISON OF THE PERFORMANCE OF THE PROPOSED METHOD WITH PREVIOUS WORK DONE ON THE IBD AND CRC DATASETS

Dataset	Feature Selection Models	#features	Classifier	Best performance metrics		
				AUC	ACC	F1
IBD	Zhu et al.[4]	300	DF	0.857	0.826	0.888
	Proposed method	300	DF	0.863	0.839	0.897
CRC	Zhu et al.[4]	300	DF	0.789	0.681	0.672
	Proposed method	400	DF	0.837	0.768	0.757

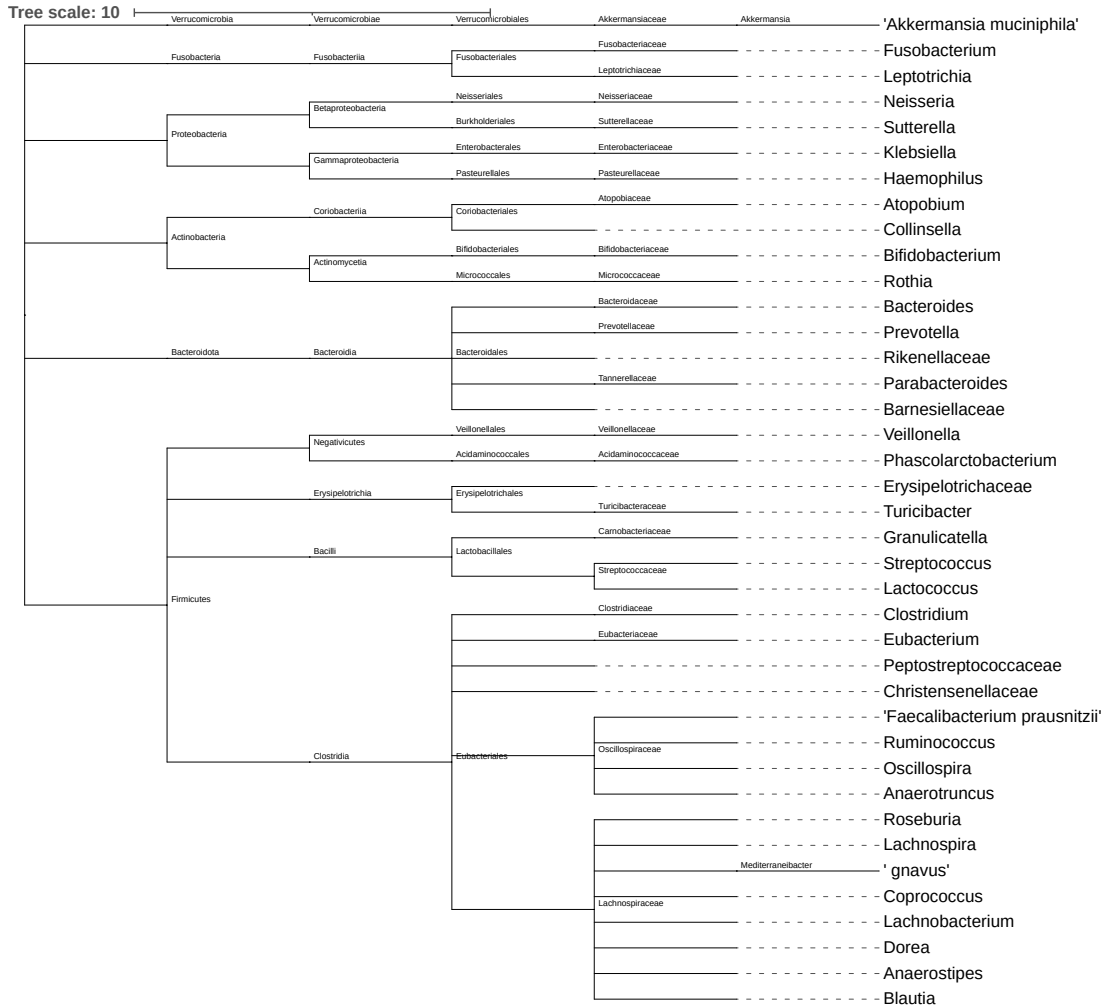


Fig. 7. Phylogenetic tree of the top 300 biomarkers selected by MAGMA+DFNN feature selection method for IBD.

Out of the top 300 features, MAGMA+DFNN was able to identify 85 distinct features in contrast to the other feature selection methods as seen in Fig. 8.

2) CRC: Upon analyzing the top 400 features selected by MAGMA+DFNN, the top-scoring taxa were found to be related to the CRC development mechanisms. The selected taxa as seen in Fig. 9 could be suggested as potential CRC-biomarkers of human gut microbiota. The results were cross-validated with the results from two biological studies presented by Oudah et al. [34], and Zeller et al. [22].

The biomarkers identified by MAGMA+DFNN match with

the majority of the informative biomarkers identified by Oudah et al. and Zeller et al. in their respective studies as seen from Table VII. The biomarkers highlighted in bold denote the common subset of biomarkers from the study and the top 400 features selected by the proposed model for CRC. The top and most common CRC biomarkers identified in this study include *Bacteroides*, *Bacteroidales*, *Lachnospiraceae*, *Ruminococcaceae*, *Clostridiaceae*, *Faecalibacterium*, and *Streptococcaceae* among others.

Out of the top 400 features, MAGMA+DFNN was able to identify 104 distinct features in contrast to the other feature



TABLE VI. POTENTIAL IBD BIOMARKERS IDENTIFIED BY A) PALJETAK ET AL. [32] B) GEVERS ET AL. [33]

a) Paljetak et al. [32]	b) Gevers et al. [33]
<b>Enterobacteriaceae</b> <b>Eubacterium</b> Lactobacillaceae Dialister <b>Christensenellaceae</b> <b>Ruminococcus</b> <b>Anaerostipes</b> <b>A. muciniphila</b> Adlercreutzia Lactobacillus <b>F. prausnitzii</b> <b>Turicibacteriaceae / Turicibacter</b> <b>Haemophilus</b> <b>R. gnavus</b> <b>Erysipelotrichaceae</b> <b>Blautia</b> <b>Coprococcus</b> <b>Veillonellaceae</b> <b>Phascolarctobacterium</b>	<b>Enterobacteriaceae</b> <b>Pasteurellaceae</b> <b>Veillonellaceae</b> <b>Fusobacteriaceae</b> <b>Erysipelotrichales</b> <b>Bacteroidales</b> <b>Clostridiales</b>

TABLE VII. POTENTIAL CRC BIOMARKERS IDENTIFIED BY A) OUDAH ET AL. [34] B) ZELLER ET AL. [22]

a) Oudah et al. [34]	b) Zeller et al. [22]
<b>Fusobacteriaceae</b> <b>Clostridiales</b> Bacteroides Eubacterium bifforme <b>Ruminococcus</b> <b>Prevotella</b> <b>Rikenellaceae</b> <b>S24-7</b> Veillonellaceae Coprococcus <b>Dorea</b>	<b>Fusobacteriaceae</b> <b>Peptostreptococcus</b> <b>Eubacterium</b> <b>Streptococcus</b>

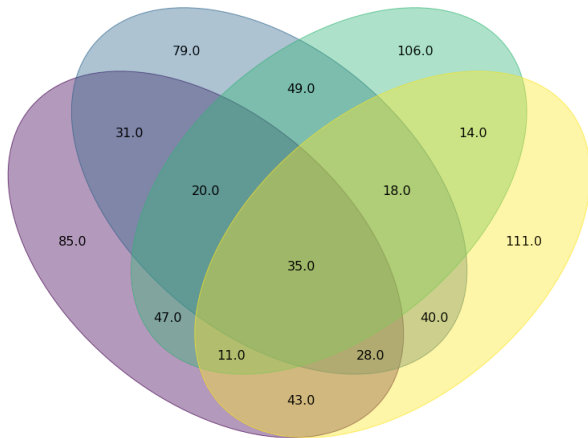
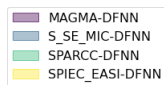


Fig. 8. Venn diagram depicting the top 300 features of IBD dataset selected by each of the feature selection algorithms.

selection methods as seen in Fig. 10.

## VI. DISCUSSION

Overall, the proposed solution ((MAGMA+DFNN)+DF) can capture a large characteristic space using a limited number of features and is able to identify the core potential IBD and CRC biomarkers. The downsides of this methodology include the fact that MAGMA is not extremely good at predicting very sparse networks with high accuracy. It is also

uncertain if the model can detect both linear and non-linear relationships. Moreover, the Gaussian copula model cannot model tail dependence which is the stronger dependence on extreme events [35].

But, in contrast to network construction tools like SparCC, MAGMA is centered around multivariate normal and does not perform pairwise associations, thereby allowing it to consider multivariate associations. It is also able to work to measure partial correlations between nodes. In comparison to state-of-the-art tools SparCC and Spiec-Easi, MAGMA showed the most tempered output and the least negative links. The spurious negative links were eliminated by taking the covariate measure into account. Embedding the suitable MIN enabled in retaining the topological structure of the network while mapping it to a low dimension and also helped to deal with overdispersion and high levels of noise in the dataset. The feature selection performance was also verified by the results of the DF classifier and comparison with biological studies. Thereby, MAGMA+DFNN can be considered as a reliable feature selection technique.

The future work, inspired by the learnings of the literature review and conducted experiments, can focus on a more thorough analysis of the construction of the MINs, and feature selection methods. The model can be improved by overcoming the aforementioned limitations of MAGMA, and incorporating and leveraging more biological information into the construction of the MIN. Additionally, the future scope includes improving the design of the neural network architecture to create a better, more precise model while dealing with the previously mentioned shortcomings for improved feature importance scoring techniques, accurate classification, and efficient and meaningful biomarker identification. Finally, as this work focuses its evaluation on smaller datasets, further efforts can be made to ensure the analysis of the methodologies on a larger, comprehensive data set.

## VII. CONCLUSION

IBD and CRC are global diseases affecting millions of humans around the world with IBD being on a steady rise and CRC being one of the most frequently maligned cancer in the world. The accurate diagnosis of these is crucial for

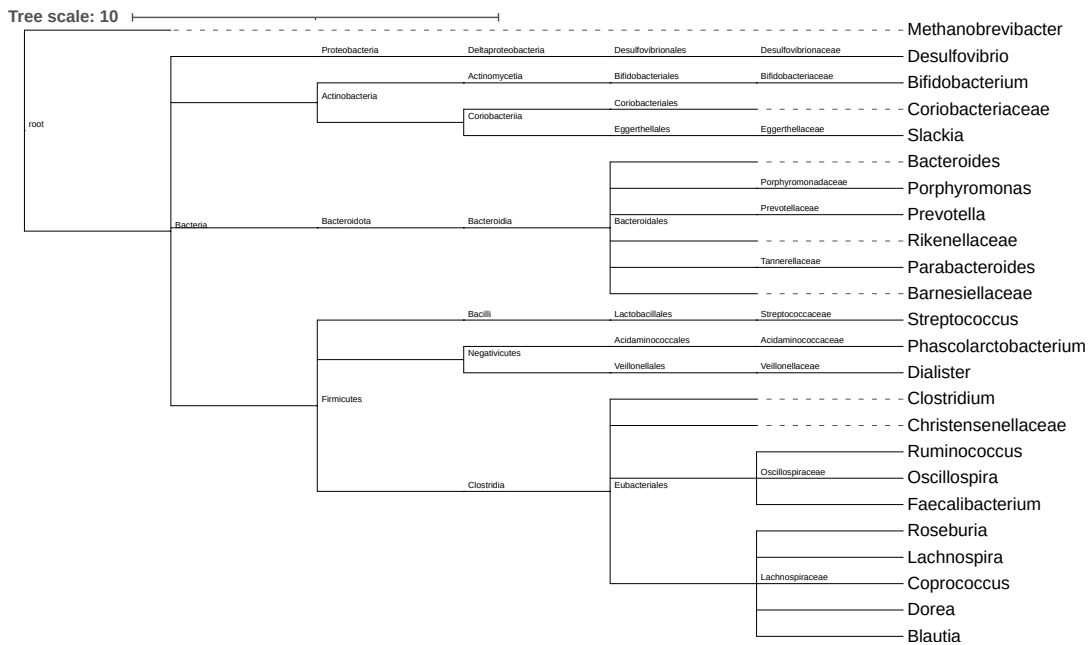


Fig. 9. Phylogenetic tree of the top 400 biomarkers selected by MAGMA+DFNN feature selection method for CRC.

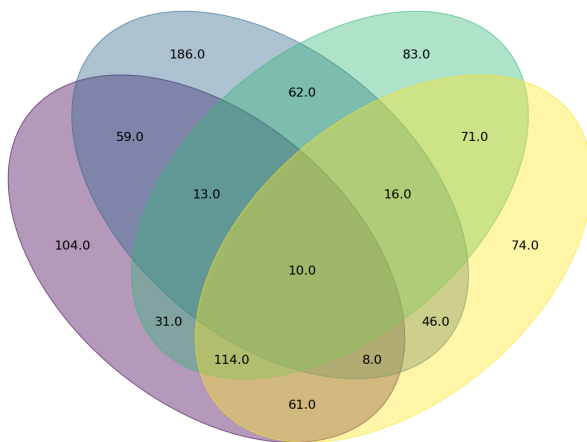
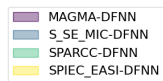


Fig. 10. Venn diagram depicting the top 400 features of CRC dataset selected by each of the feature selection algorithms.

effective treatment, creating a need to identify the informative subset of microbiota by applying fitting feature selection techniques. This work utilizes the method of embedding the MIN constructed using MAMGA+DFNN as a feature selection technique to extract prominent features for the identification of potential biomarkers. Across all of the feature selection methods considered, the proposed methodology achieved the highest AUC, accuracy, and F1-score when classified using DF across both the IBD and CRC datasets. Further, upon inspecting the resulting biomarkers identified

by the proposed approach against relevant biological studies, it is validated that these microbial biomarkers have a relationship with the diagnosis of the disease. Therefore, these results could guide further experimental investigation and contribute to the diagnosis of microbiome-related diseases.

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# Software Vulnerabilities' Detection by Analysing Application Execution Traces

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**Abstract**—Over the years, digital traces have proven to be significant for analyzing IT systems, including applications. With the persistent threats arising from the widespread proliferation of malware and the evasive techniques employed by cybercriminals, researchers and application vendors alike are concerned about finding effective solutions. In this article, we assess a hybrid approach to detecting software vulnerabilities based on analyzing traces of application execution. To accomplish this, we initially extract permissions and features from manifest files. Subsequently, we employ a tracer to extract events from each running application, utilizing a set of elements that indicate the behavior of the application. These events are then recorded in a trace. We convert these traces into features that can be utilized by machine learning algorithms. Finally, to identify vulnerable applications, we train these features using six machine learning algorithms (KNN, Random Forest, SVM, Naive Bayes, Decision Tree-CART, and MLP). The selection of these algorithms is based on the outcomes of several preliminary experiments. Our results indicate that the SVM algorithm produces the best performance, followed by Random Forest, achieving an accuracy of 98% for malware detection and 96% for benign applications. These findings demonstrate the relevance and utility of analyzing real application behavior through event analysis.

**Keywords**—Execution traces; events; vulnerability detection; malware; applications

## I. INTRODUCTION

The prevalence of malicious applications has significantly increased in recent years. Unfortunately, as digital technology continues to advance, the number of vulnerabilities in applications is also growing exponentially, thereby leaving users even more vulnerable. Since these applications handle highly personal and sensitive data, it remains a significant challenge for researchers and application providers to find effective and efficient solutions. Despite the efforts described in the existing literature to safeguard data, the threat remains very real. Moreover, in recent years, it has become even more severe as cybercriminals increasingly employ evasion techniques to bypass existing protection measures [1], [2]. Not only are the majority of available solutions limited or inadequate against the sophisticated tactics of cybercriminals, but these malicious actors are also becoming more organized and motivated [2], [3], [4], [5]. Consequently, ensuring data security and protection has become an essential and urgent concern. It is crucial, therefore, to urgently discover solutions that can minimize the exploitation of software vulnerabilities and mitigate the risk of attacks targeting user data [3], [6].

Among the techniques employed to detect malware in

recent years, machine learning has been utilized [7]. This is associated with the static approach ([8], [9]) or the dynamic approach ([1], [10], [11]), depending on the methods employed. In the literature, the hybrid approach is increasingly being utilized to leverage the advantages of both the static and dynamic approaches, thus partially mitigating the limitations inherent in each of these two approaches. As our approach involves utilizing data from the Android's manifest file for static analysis and execution traces for dynamic analysis, it can be categorized as a hybrid approach. By combining the analysis of application execution traces with machine learning techniques, we aim to enhance malware detection. Previous studies have emphasized the significance and utility of traces in monitoring computer system behavior [11], [12], [13], [14], [15].

The collected traces enable us to comprehend the functioning of a system and identify anomalies, deviations in operation, suspicious behavior, and more. Hence, traces contain pertinent and valuable information for analyzing the behavior of systems in general, as well as applications specifically during their execution. Although traces are beneficial, they are less commonly utilized for identifying malicious applications. Instead, they are typically employed for debugging, profiling, or logging purposes. This study aims to assess the hypothesis that traces of application execution are high-quality data that can be used to analyze and detect malicious applications [16]. Consequently, the solution proposed in this study is founded on capturing relevant behavioral elements (events) during application execution, based on pertinent characteristics. These events are recorded in the traces. Subsequently, the values of the behavioral features are extracted in the form of dictionary objects or converted into eigenvectors using appropriate tools for analysis with machine learning algorithms. The primary objective of this study is to effectively detect malware in order to enhance the safeguarding of private data transmitted through applications. Therefore, it presents a proactive solution that diminishes cybercriminals' attack vectors. The experimental results demonstrate the significance of execution traces in identifying software vulnerabilities. This study contributes to malware detection in the following ways:

- We present a model that effectively and efficiently identifies malware by utilizing a blend of static features (permissions and characteristics) and behavioral features (traces). The features we have selected allow us to describe the dynamic behavior of applications. Furthermore, these features are comprehensive, en-

compassing attributes extracted from the Android-Manifest file as well as features extracted during application execution.

- We have extracted five (05) relevant features to characterise the behaviour of Android applications. The numerical values of these features vary from one application to another. We use six (06) classifiers, namely Support Vector Machine (SVM), k-Nearest Neighbor (kNN), Random Forest (RF), NB, MLP and DTREE-CART, to identify malware. We compare the detection performance of these different classifiers.
- We conducted analyses on a dataset containing 8014 traces from benign and malware applications collected from Google Play (15%) and Drebin (85%). Experimental results show the effectiveness of the model with a detection accuracy of more than 98% with the SVM algorithm.

The rest of the document is structured as follows: the Section II deals with some previous studies and research into traces and vulnerability detection methods. In Section III we detail the process of collecting traces and converting them into features through trace generation, data pre-processing and feature vector formation. Section IV presents the construction of the data set and experimental setup. In addition, the results obtained will be presented in this section. We conclude the work in Section V.

## II. RELATED WORK

Over the last few years, the digital world has seen an impressive development in malicious software, which represents a major threat [3], [4]. The consequences of this malware for users are enormous. On an ongoing basis, a number of researchers have proposed methods and techniques for detecting malware in applications [7], [8], [17], [18], [10]. The aim is to improve data protection methods by reducing threats and attacks against private data. Unfortunately, their efforts are coming up against determined cybercriminals who are more innovative in their malicious behaviour [3], [2], [19], [5], [17]. They are increasingly using sophisticated techniques to bypass security solutions or evade the control systems in place. It is therefore crucial and urgent to find effective solutions to protect data. Several methods and techniques based on static and dynamic approaches are proposed [7], [19], [13], [16]. Previous works [4], [19], [16] have proposed literature reviews on both analysis approaches and their weaknesses [3], [17], on analysis techniques, [7], [20], on the use of machine learning techniques [7], [8], [17], on digital traces [11], [16]. Nevertheless, we will mention some of the work related to traces, especially as our approach is a hybrid one.

In static analysis, the source code is examined and representative features (libraries, opcodes, API calls, permissions, function calls, etc.) are extracted. In contrast to the static approach, for dynamic analysis, representative features are extracted during the execution of the application by monitoring its behaviour. Features such as system calls, file behaviour (access, create, read, modify, delete), registry access (create and modify), network traffic, are relevant data used by some authors to study application behaviour and detect malicious actions.

The authors of the works [8], [9], [10], [20], combined machine learning techniques with one or other of these approaches, depending on their methodology to improve detection. The authors Al-Hashmi et al. [10] selected several features from the extracted features and combined them with different machine learning techniques to train a model. The results obtained are encouraging with their DeepEnsemble model. Numerous other works on detecting malware in Android applications extract certain information to distinguish malicious applications from benign ones. This is the case of the work by Bassole et al. [18] and the authors [8] and [9]. These authors extracted authorisations and other functionalities as features, and combined them with machine learning methods to detect malware.

As for traces, they were used by the authors [13], [15], [14], [21], [22] and [23] in their work. The authors of the references [24], [25] [26] and [27] used traces to detect their code errors through debugging. In the studies [24] and [26], traces are used for profiling while the authors [28], [29] and [30] use them as a means of studying logging. All these techniques using traces (debugging, profiling and logging) do not provide enough information for optimal diagnosis of flaws in applications. It was in the web and network domain that the first uses of traces were useful. Hassan et al. [21] used traces to detect vulnerabilities in web sites and Zhou et al. [22], used them to analyse anomalies in TCP/IP networks. Several other studies show that traces provide more relevant results when combined with machine learning techniques [31], [32]. Studies such as that carried out by Razagallah et al. [11] show us that traces are an invaluable source of information on the execution behaviour of a program. This information can be used to detect malicious software in Android applications. The authors have therefore built up a dataset based on traces that can be exploited according to research needs.

Despite all these malware detection methods and protection measures, cybercriminals often manage to escape and exploit vulnerabilities with more sophisticated attacks. Between the repackaging of certain benign applications for malicious purposes, new families of malware, vulnerabilities (known and unknown) and inadequacies in data protection, there is a need to explore possible solutions to limit the risk of attacks.

With the ever-changing and innovative nature of malware, detection based solely on one approach or type of functionality cannot meet data protection needs. In this study, we therefore evaluate an analysis model that uses events collected during application execution to analyse the malicious behaviour of these applications (Fig. 1). This is a hybrid approach that takes advantage of both static and dynamic approaches and combines machine learning techniques. The traces generated contain sensitive information extracted and trained by the algorithms for detecting software vulnerabilities. In this way, static characteristics (permissions and features) are extracted and dynamic characteristics are captured in order to obtain data that is more relevant and better suited to improving malware detection performance.

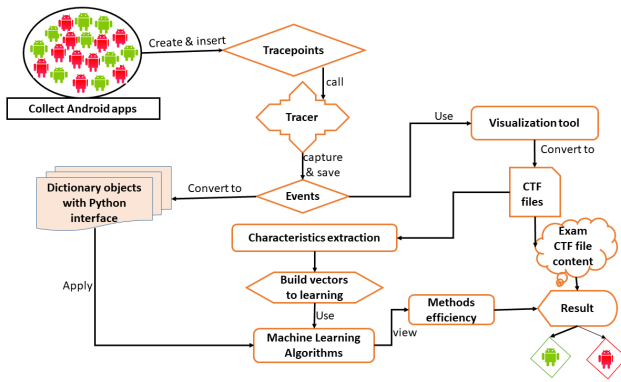


Fig. 1. Model using android application execution traces.

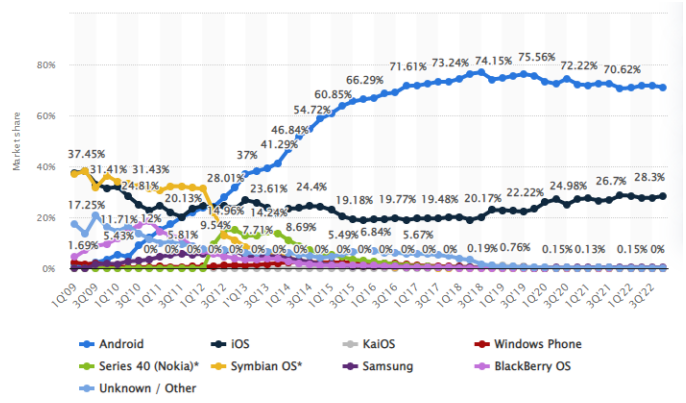


Fig. 2. Growth rate of android applications compared with other applications from 2009 to 2022.

### III. TRACE COLLECTION AND PROCESSING

In this section, we present the process for extracting features and events, the construction of our dataset, and the features selected for training the machine learning algorithms. We also present the tools and equipment used to collect the events.

#### A. Choice of Android Applications

To evaluate our model, we used execution traces generated from Android applications. Our choice is motivated by the fact that the high number of these applications with a share of over 82% of mobile applications, according to Gartner’s 2021 report<sup>1</sup>. According to this report more than 2 billion will be delivered in 2021. All this popularity (see Fig. 2) combined with Android’s security model makes users of these applications a prime target for malware writers. The scale of attacks targeting Android users is considerable [1].

#### B. Behavioural Data Extraction (Events)

Application behaviour, operations performed and system performance are among the essential and useful data provided by application execution traces. This data can be used for analysis, debugging, performance optimisation, problem detection and many other tasks related to application monitoring and diagnosis. For analysis, the features to be extracted from the events depend on the context of the application and the information you wish to use to construct the eigenvectors. In this study we have specified the behavioural features to be extracted in the features\_to\_extract list (Table I). These features are relevant, we believe, to understanding the actual behaviour of the application being run. Several events are captured and recorded in a file (the trace). All events are generated with the LTTng tracer. Also, to extract characteristics during the execution of each application, we created a dynamic environment with the Genymotion emulator version 3.3.3 with a Google Nexus 5 API 11 device. Each of the applications is installed and then run. In the Algorithm 1, we describe the process of collecting events, the building blocks of traces.

<sup>1</sup><https://www.gartner.com/en/information-technology/insights/top-technology-trends/top-technology-trends-ebook>

TABLE I. LIST OF BEHAVIOURAL DATA TO BE EXTRACTED

Event data	Type of data	Description
Timestamp	Numeric	This is the timestamp that indicates the precise moment when each event occurred. It is useful for temporal analysis of events and for understanding the chronological order in which they occurred
"Name"	String	This is the name of the event, representing the type or category of the event. It can indicate a specific action performed by the application, a function call or a system operation
PID (Process ID)	Numeric	This is the process identifier (PID), which is a unique number assigned to each process running on the system. It identifies the process that caused the event
TID (Thread ID)	Numeric	This is the thread identifier (TID), which is a unique number assigned to each thread in a process. It identifies the specific thread at the origin of the event
"Syscall" (System Call)	String	This is the set of data that represents a request from the running program to the operating system kernel to perform a specific operation. For example, read or write data, access external resources, create files, allocate memory, etc. The "syscall" field indicates the specific system call associated with the event
Retval (Return Value)	Numeric	This represents the return value of the system call (syscall). It is a numerical value that indicates the result of the operation performed by the system call, such as the success of an operation or the occurrence of an error
Duration	Numeric	Duration represents the time elapsed between the start and end of an event. It is used to measure the execution time of each specific operation

#### C. Data Pre-processing

Once the traces have been generated, the data collected must be made useful for the rest of the process. This stage is essential and requires appropriate tools to transform behavioural data into features. It is this phase that produces data that can be used by machine learning algorithms. During the pre-processing phase, only data that can contribute to improving detection or classification is retained from the data collected. This data should maximise the accuracy of the results obtained. Unnecessary data is therefore ignored. Given that the data we collected in the previous stage is unstructured data, it comes in different formats and is sometimes unreadable. Also, they generally contain redundant and unnecessary features, with missing values, symbols, punctuation and spaces. To prevent unnecessary data from negatively influencing the results, we converted the traces into Python dictionary objects. The Algo-



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**Algorithm 1: Extracting Events from an Application**

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**Entry :**  
Application : .apk  
events\_to\_extract[]: contains the list of elements to be extracted

**Output:**  
T: list of traces (content and metadata)

```
1 Load application into memory //Specify application package name
2 package_name = "MyApp"
3 source_code = decompile(app.apk)//Decompile the apk to obtain the source code
4 trace_code = insert_tracepoints(source_code)
5 //Insert tracepoints in the source code to capture the desired events (calls to special functions or macros that record events)
6 Run the application several times //(2 to 5 times)
7 Run Tracer //Configure the lttng-ust tracing tool to collect events
8 events = extract(trace_code) // collect events generated on the state of variables, function calls, errors, system events, etc.
9 T=[] // Initialise the list of traces
10 foreach event ∈ events do
11   if event ∈ events_to_extract then
12     // for an event element in the list
13     events_to_extract
14     trace = event // Create a new trace with the event
15     T.append(trace) // Add the track to the list of tracks
16   end
17   else
18     Continue with the next event
19   end
20 end
21 Return T
```

---

Algorithm 2 presents this transformation process. Once converted, machine learning algorithms use these dictionaries to identify malware from benign software. We also use the Trace compass visualisation tool to convert the traces into CTF files. As the contents of these files are readable, they are used to construct feature vectors, as indicated by the algorithm 3. In this way, machine learning algorithms can use these feature vectors to detect vulnerable applications, and therefore behaviours that are precursors to possible attacks.

#### D. Features Representation

Feature extraction creates new feature sets in which the typical malware example is better represented than the use of the original features. This feature-derived data extracted from software behavioural data improves the accuracy of malware detection. Before extracting these characteristics from the traces, we statically extracted the permissions and features of each application. This brings the total number of feature fields to five (05) for vulnerability analysis. For the detection of a vulnerable or malicious application by the machine learning model, the analysis focuses on the features taken from the

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**Algorithm 2: Convert Generated Traces into Python Dictionary Objects**

---

**Entry :**  
trace\_file : events file

**Output:**  
event\_dicts : events converted into dictionary objects

```
1 Define the path to the directory containing the traces
2 Define the name of the traces session
3 events_to_extract = [timestamp, "name", pid,tid,"syscall", retval,duration, cpu]
4 Run TraceCompass // to convert evenements
5 Load the file containing extracted events
6 events = open("trace_file", "read") //Storing events in an event variable
7 event_dicts = { } // Initialise the object dictionary
8 foreach event ∈ events do
9   if event["name"] ∈ events_to_extract then
10    //If the event name is in the list
11    events_to_extract
12    event_dict = { //create a dictionary event_dict with the variables
13      timestamp: event[timestamp],
14      "name": event["name"],
15      pid: event["fields"][pid],
16      tid: event["fields"][tid],
17      "syscall": event["fields"]["syscall"],
18      retval: event["fields"][retval],
19      duration: event[duration],
20      cpu: event[cpu]
21    }
22  end
23  else
24    continue with the next event
25  end
26  event_dicts.append(event_dict) //Adding the dictionary to the list
27 end
28 return event_dicts
```

---

execution traces and the AndroidManifest file. These fields include all the important information from the traces. These features are based on:

- C1(Searching for abnormal activity): The aim is to analyse the values in this field to identify any activity that does not conform to the expected behaviour of the application. This includes inappropriate access to system resources, attempts to modify critical files and suspicious communications with external servers. The application will be detected as vulnerable.
- C2 (Error and exception detection): This involves identifying errors and exceptions reported in the execution trace and contained in this field. If there are frequent errors in the traces, such as access violations or security exceptions, this indicates potential vulnerabilities in the application.
- C3(Verification of privileges): this field contains the values of the analysis of system calls made in the trace

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**Algorithm 3:** Transformation of Events into CTF Files to Construct Eigenvectors

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**Entry :**  
    trace\_file : input trace file  
    features\_to\_extract : list of characteristics to be extracted from events

**Output:**  
    feature\_vectors: list of eigenvectors constructed from events

- 1 Load traces // with Trace Compass from the file trace\_file
- 2 Configuring CTF conversion parameters
- 3 Convert tracks to CTF // format using Trace Compass
- 4 Loading converted CTF files
- 5 Initialise feature\_vectors as an empty list
- 6 **foreach** event belonging to the converted CTF files **do**
- 7 |     Extract the characteristics specified in features\_to\_extract to converted CTF files
- 8 |     Construct a feature vector for the event using the extracted values
- 9 |     Add the feature vector to the list feature\_vectors
- 10 **end**
- 11 Return feature\_vectors

---

and checks whether they are appropriate for the application in question. For example, system calls relating to access to files, processes or network resources may reveal unauthorised access attempts.

- C4(Searching for suspicious network behaviour): This involves examining the values in this field, which represent network communication activities in the trace. If there are suspicious outgoing connections to unknown IP addresses or domains, unauthorised protocols or unencrypted transmissions of sensitive data, then the application is considered vulnerable.
- C5(Detecting malicious behaviour): This involves comparing the permissions and features fields in the Android's manifest file with the *authorisations.txt* and *features.txt* lists. These lists contain all the permissions and features declared in the official Android documentation.

Representing the functionalities represented by each field (C1, C2, C3, C4, C5) in figures means that the counter values can be incremented if a suspect element is present. These values are used to create the data set. The final value of the counter is compared with its initial value. If the final value is equal to the initial value, this implies normal behaviour and therefore a benign application. Otherwise, for any other value different from the initial value, the model assumes that the application is vulnerable.

#### IV. IMPLEMENTATION AND RESULTS

##### A. Dataset and Experimental Setup

1) *Dataset:* To experiment with our approach, we collected a number of Android applications that included both benign and malicious apps. We acquired benign apps from Google

Play<sup>2</sup> and malicious apps from Drebin<sup>3</sup> and built a dataset of 8014 traces (benign apps and malicious apps). This approach gives us apk's that have undergone Google's verification tests before being published on its site. Nevertheless, all applications are downloaded and then analysed on VirusTotal<sup>4</sup> with a considerable number of antivirus software for detection. The results of these scans are used to group the applications into benign and malware. Applications are selected according to several criteria. For benign applications, almost all sectors of activity are taken into account (tourism, news, health, education, financial transactions, justice, culture, religion, job search, history, geolocation and entertainment, etc). Several types of malware were collected (repackaging, privileges, sending sms, stealing information, advertising, etc.). We formed a set of 8014 traces for analysis.

2) *Experimental setup:* We conducted our experiments on a computer Inter(R), Core(TM) i3-4160, CPU @ 3.60GHzx4 with with 12GB RAM running on Ubuntu 22.04.2 LTS 64 bits and GNOME 42.5. We have installed the LTTng 2.13 plotter including LTTng-tools<sup>5</sup>2.13.9, LTTng-UST<sup>6</sup>2.13.5 and LTTng-modules<sup>7</sup>2.13.9. The models are built with Python 3.10.6 and GCC 11.3.0.

*Evaluation metric:* The metrics precision (P), recall (R) and F-measure (F1), Accuracy are proposed to evaluate our method. The precision, recall and F1 for example are defined as:

$$P(\text{precision}) = \frac{TP}{TP + FP} \quad R(\text{recall}) = \frac{TP}{TP + FN}$$

$$F1 = \frac{2 * P * R}{P + R} \quad \text{Accuracy} = \frac{TP + TN}{TP + FP + FN + TN}$$

Where :

- TP (True Positive): when the actual class and the predicted class are all yes.
- TN(True Negative): when the actual class and the predicted class are all no.
- FP(False Positive): when the actual class is no and the predicted class is yes.
- FN(False Negative): when the actual class is yes and the predicted class is no.

##### B. Results

To analyse the performance of our model, we used six (06) machine learning algorithms including the K-Nearest Neighbors classifier(KNN), the Decision Tree Classifier (DTREE-CART), Naive Bayes (NB), MLP classifier, Random Forest (RFORREST) classifier, Support Vector Machine (SVM) which were selected on the basis of the results of several preliminary experiments carried out.

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<sup>2</sup><https://play.google.com/>

<sup>3</sup><https://www.sec.cs.tu-bs.de/~danarp/drebin/download.html>

<sup>4</sup><https://www.virustotal.com/>

<sup>5</sup>[git://git.lttng.org/lttng-tools.git](https://git.lttng.org/lttng-tools.git)

<sup>6</sup>[git://git.lttng.org/lttng-ust.git](https://git.lttng.org/lttng-ust.git)

<sup>7</sup>[git://git.lttng.org/lttng-modules.git](https://git.lttng.org/lttng-modules.git)

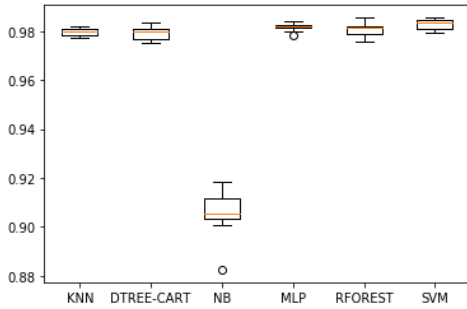


Fig. 3. The results obtained with each algorithm.

The Table II presents a comparison of the performance of the proposed approach with the precision, recall and F1 score measures for detecting software vulnerabilities on Android. The results show good performance for all the machine learning algorithms used. The best performance is given by the SVM algorithm with an F-score of 0.99 for malware detection and 0.89 for benign software detection.

TABLE II. COMPARISON OF ML ALGORITHMS

	Malware			Benign apps		
	Precision	Recall	F1-score	Precision	Recall	F1-score
KNN	0.98	0.99	0.99	0.96	0.75	0.84
DTREE-CART	0.98	0.99	0.99	0.93	0.80	0.86
NB	0.91	0.96	0.95	0.31	0.24	0.27
MLP	0.98	0.99	0.99	0.96	0.77	0.85
SVM	<b>0.98</b>	<b>1.00</b>	<b>0.99</b>	<b>0.96</b>	<b>0.77</b>	<b>0.89</b>
RFOREST	0.98	1.00	0.99	0.94	0.81	0.87

TABLE III. IMPLEMENTATION FOR ALL ML ALGORITHMS

	Macro Precision	Macro Recall	Macro F1-score	Accuracy
KNN	0.97	0.87	0.91	0.98
DTREE-CART	0.96	0.90	0.93	0.98
NB	0.73	0.70	0.71	0.91
MLP	0.96	0.89	0.92	0.98
SVM	<b>0.97</b>	<b>0.90</b>	<b>0.93</b>	<b>0.98</b>
RFOREST	0.97	0.88	0.92	0.98

The Table III shows the implementation results for all the machine learning algorithms with precision and the F1 macro score. The best performing algorithm obtained an accuracy of 0.98 and a score of 0.93 for the F1 macro. Fig. 3 shows that the SVM algorithm is better than the others. We can therefore conclude that the proposed model obtains results that show its good performance in detecting vulnerabilities. It is effective and can therefore be used to improve the protection of data passing through Android applications.

### V. CONCLUSION

Although identifying malware is a difficult and tedious task, it remains an imperative when it comes to protecting data. Our solution, based on application execution traces and machine learning techniques, meets this challenge. On the one hand, the results obtained enable us to confirm the relevance

of execution traces in analysing unexpected and unhealthy application behaviour. On the other hand, these experimental results also show that static and behavioural characteristics are more effective and efficient for detecting malware. The use of behavioural features can enable the detection of malware that escapes the control of solutions based on signatures or static approaches. This compensates for the shortcomings of static feature-based approaches.

In this way, the combination of behavioural and static features improves the level of detection of software vulnerabilities. Our model will make it possible to reduce new threats targeting Android applications. Unfortunately, there are a few limitations to our study, the future objective of which is to generalise this solution to all emerging applications and technologies. Also, to increase the number of applications and consequently the number of traces. The second objective is to have a real environment and not an emulated environment for a better user experience of this solution. We will continue to improve this approach in order to have a vulnerability detection system that is accessible to users.

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# Hybrid Encryption Algorithm for Information Security in Hadoop

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**Abstract**—Network security has gained importance in recent years. Information system security is greatly aided by the development of encryption as a solution. To safeguard the shared information, several strategies are required. Thanks to the cutting-edge Internet, networking corporations, health information, and cloud applications, our data is growing exponentially every minute. In order to handle enormous amounts of data efficiently, a new application called Hadoop distributed file system (HDFS) was created. However, HDFS doesn't come with any built-in data encryption tools, which poses serious security risks. In order to increase data security, encryption techniques are established; nevertheless, standard algorithms fall short when dealing with bigger files. In this study, huge data will be secured using a novel hybrid encryption algorithm that combines CP-ABE (encryption based on the features of the encryption policy), AES (advanced standard encryption), and RSA (Rivest-Shamir-Adleman). The suggested model's performance is compared against that of traditional encryption algorithms like DES, 3DES, and Blowfish in order to demonstrate improved performance as it relates to decryption time, encryption time, and throughput. The results of the studies demonstrate that our suggested method's algorithm is more secure.

**Keywords**—Hadoop distributed file system (HDFS); big data security; data encryption; data decryption

## I. INTRODUCTION

Megadata is typically believed to be a collection of data whose structure is too huge or too diverse and complicated to be handled by standard data processing tools [1]. The problems of Big data include acquiring, storing, analyzing, transporting, sharing and displaying the information it contains [1]. Scientists, entrepreneurs and healthcare professionals are frequently needed to utilize data from a range of sources, including megadata from worldwide literature, the Internet, medical records, patient registries and even "smart" gadgets [1]. Smart phones increased use in recent years has resulted in a sharp rise in the amount of data created by social networking services (SNS). Data including multimedia material in a variety of formats has expanded to big data scale. Big data is a contemporary industrial research hotspot. Big data started to take off and get more and more attention as the cloud age came into being. Numerous apps, sensor networks, social networking sites and enterprises big and small handle this massive volume of data [2], [3]. Big Data challenges may be described in a number of ways, not least by reference to the 4 Vs [4]: volume, velocity, variety and veracity. The work of living with large data is different for every situation.

- Volume: Data with a size of many terabytes or petabytes.

- Variety: There are several types of data. organized, semiorganized, and unorganized.
- Velocity is an abstraction layer that allows Big Data systems to store data independent of the incoming or departing flow by specifying the different speeds at which data streams might enter or exit the system.
- Veracity: The information is under question. relates to the data's credibility, taking into account data availability, confidentiality, and integrity. Companies must guarantee that the data are accurate, as well as any analysis that are done on the data.

Using a distributed, trustworthy, and scalable computing infrastructure, big data sets may be handled and stored using the open-source Hadoop framework [5]. Because of Hadoop's cheap cost, quick processing, fault tolerance, and flexibility, large clusters or public cloud services often employ it. Hadoop [6] is an open source Java-based distributed computing framework consisting of two modules: MapReduce and Hadoop Distributed File System. It is used as a framework for cloud storage (HDFS). By simply defining the map and reduce functions, users can process large amounts of data using MapReduce, enabling them to efficiently use thousands of commodity computers in parallel [7], [8], [9]. HDFS is used to store data on distributed clusters of machines. Large clusters or public cloud services such as Yahoo!, Facebook, Twitter and Amazon are the places where Hadoop is most often used [10]. The popularity of these applications has shown Hadoop's scalability, but it lacks security for data storage by design. Hadoop has weaknesses in its security features even if its processing capacity is far more than that of traditional data processing systems. As the Hadoop design is not meant to be safe, it offers no security mechanisms to protect data while it is being stored or transferred. Currently, corporations are analyzing consumer information and location data obtained in numerous areas and utilizing it for marketing activities. As a consequence, sensitive personal data may be revealed when consumer data is evaluated. There would be significant reputational harm and legal implications as a result of the data breach. In addition, businesses store and process a large amount of data, all of which has to be protected in HDFS storage using encryption, threat detection, and logging systems. These methods let systems quickly detect vulnerabilities and protect user data. To safeguard data from the generating phase through the storage phase, several solutions have developed recently. Using data fabrication methods and limiting access during data production improves data privacy. Data security and privacy are mostly ensured during the storage phase via encryption methods [11].

The structure of simple file authorization and access control techniques constitutes the security service of the Hadoop project. To protect HDFS files stored in data nodes and to move files between data nodes when performing MapReduce operations, encryption is the best option. The process of converting plain text into ciphertext is known as encryption. By allowing users to be properly authenticated and prohibiting others, the transformation of explicable data into an incomprehensible form protects data confidentiality [12]. Data confidentiality and integrity are two objectives that can be achieved in Hadoop when using encryption. There are two different types of cryptographic keys: symmetric key cryptography, sometimes called secret key cryptography. Asymmetric key cryptography, sometimes called public key cryptography [13]. Stream ciphers, such as RC4 and OTP, and block ciphers, such as the AES, DES, 3DES and BLOWFISH algorithms, are generally used in secret key cryptography methods [14]. Using encryption techniques, several researches [15], [16], [17] indicated that the file size was 1.5 times larger than the original file and that download time also increased.

#### A. The Scope of this Paper

In order to protect data on Hadoop, the main objective of this research is to solve the problem of data security in Hadoop. This was solved by recommending the implementation of a new strategy that combines HDFS files with the CP-ABE (attribute-based encryption) technique with RSA (Rivest-Shamir-Adleman) and AES (Advanced Encryption Standard) algorithms to speed up the upload and download of the encrypted file. The main contributions of this paper are summarized below:

- We present a thorough related works on encrypting data in HDFS.
- We describe the architecture of big data encryption system.
- We present a hybrid encryption technique in HDFS for Big Data security.

In the subsequent sections, we present a structured outline of the remaining content. Section 2 delves into a brief literature review, examining key studies and their findings in the field. Section 3 introduces our suggested hybrid encryption approach, providing insights into its design and implementation. The experimental results obtained from applying this approach on a substantial dataset are presented in Section 4, along with a thorough analysis. Finally, Section 5 concludes the paper by summarizing the main findings and discussing potential avenues for future research.

## II. RELATED WORKS

This section includes short appraisals of the literature on Big Data security and encryption approaches. The security and privacy aspects of Big Data applications are considerably strengthened by researchers utilizing a range of encryption technologies [18], [19], [20]. A privacy-preserving auction mechanism is utilized in the homomorphic cryptography and secure network protocol architecture proposed by W. Gao et al. [21] to increase user and third-party service provider confidence and data privacy. Data communication between the

user and third-party service providers is safeguarded by the homomorphic encryption technique. For better data security, the revised approach leverages signature-based verification. However, as the user base and file size rise, system performance declines.

The completely homomorphic encryption system presented by A. Alabdullatif et al. [22] avoids dangers and data privacy breaches in the Big Data environment from both inside and outside. The resilient cryptosystem splits computation and data into two different portions following task analysis. The system's capacity to digest data is substantially sped by this technique, which also achieves a high degree of accuracy. C. Xiao et al. [23] proposes an accelerated approach for solving a range of complicated data encryption and computing challenges. A secure data storage system with adaptive cryptographic acceleration that dynamically enhances the working modes of huge data files is given for big data encryption. Compared with comparable software and hardware gas pedals, the design work achieves a better compromise.

By the use of an encryption technique, the data analysis model described by K. Sharma et al. [24] effectively addresses the privacy concerns in the interchange of health information. The patient-centric data access control mode addresses the privacy concerns with regard to health information and the need for data encryption. The patient file is encrypted and sent utilizing a variety of domains when employing the suggested RSA-based encryption. Even if the encryption paradigm successfully addresses the security and privacy concerns, data transmission across many domains is required. Comparatively to other data transmission techniques, this raises the system cost.

The results in [25] describe the challenges the user encounters when the data is outsourced. The main goals of the research project are data privacy and secrecy, and multi-keyword searchable encryption helps to achieve these goals. The formation of the probabilistic trapdoors enhances data security and resistance to assaults. Data secrecy in huge data streams is guaranteed by the selective encryption technique described by D. Puthal et al. [26]. Data integrity and confidentiality are security factors that affect how reliable the obtained data is. To increase the efficiency of encrypting and decrypting data streams while retaining data integrity and privacy, the authors employ the selective encryption technique.

The challenges connected with employing standard cryptographic techniques have been overcome in the attribute-based encryption stated by P. Perazzo et al. [27]. The encryption paradigm addresses the need for accurate access control in a vast data environment. Flexible rules improve access control to encrypted data while simplifying the management of large data volumes. Ten unique criteria are utilized to measure performance, and cryptographic acceleration is employed to boost performance. The key benefits of this encryption system are its minimal memory and energy needs. The shortcoming of standard attribute-based encryption (ABE) approaches is overcome by the hybrid attribute-based encryption (ABE) model described by H. Deng et al. [28]. The hybrid model provided adds a new proxy encryption to turn ABE ciphertext into IDE (identity-based encryption) ciphertext, since the rules stated by standard models become outdated after a specific length of time. Data collisions are prevented and security is promoted



by using identity-based encryption and key randomization properly.

Using the CP-ABE approach, P.S. Challagidad et al. [29] investigated the difficulties of unauthorized data access and confidentiality concerns in enormous data clouds. The encryption technology addressed the demand for multi-authority access control and data secrecy. Users get precise data and access thanks to the role hierarchy algorithm and hierarchical access structure. The two key benefits of hierarchy algorithms are computation speed and minimum storage needs.

Attack detection and intrusion detection are crucial concepts to take into account while researching Big Data security due to their impact on data privacy and confidentiality. To boost data security, several attack detection models and intrusion detection methodologies have been created. Using instruction sequences, a two-stage attack detection system presented by S. Aditham et al. [30] defends communication protocols. To assess system needs, these instruction sequences are further mapped to nodes. The encryption and decryption method presented by J. S. Raj et al. [31] takes into consideration the shortcomings of attribute-based encryption matching techniques, which impair the performance of the encryption system. For outsourced data operations, a lightweight, fine-grained data sharing strategy is employed to bypass this challenge. This increases overall data security and avoids the leakage of decryption keys.

Abd al wahid, S. M. J. et al. [32] suggested a solution for encrypting all files stored in HDFS utilizing public-key cryptography to safeguard them all. Acquired data is encrypted in HDFS during the data collecting process using the suggested data encryption technique (Rabin RZ). The suggested technique is contrasted with the Paillier method and the default Rivest-Shamir-Adleman (RSA) cryptosystem, respectively. Compared with previous cryptosystems, the suggested technique provides more powerful computational complexity and lower latency than the alternatives.

In order to strengthen transaction security against unauthorized access and to verify the speedy data transaction with minimal encryption and decryption time, Motupalli, R. K. et al. [33] presented an effective mixed algorithm design utilizing the Salsa20 and AES algorithm. The impressive throughput achieved in this hybrid framework shows how effective the recommended algorithmic structure is on current platforms.

### III. BIG DATA ENCRYPTION SYSTEM ARCHITECTURE

With the user interface the system offers, the client may communicate with the large data storage system. The major functionalities of the user interface include identity authentication, which provides users with login authentication and operation authority authentication, big data management, which offers authorized users services like browsing and replicating huge data, and other interfaces. Storage cluster and metadata cluster are the two primary components of the big data storage system. Storage cluster is used to store user files and other non-metadata data, whilst metadata cluster is used to store metadata like user and file information. The hierarchical structure of the system is analogous to the large data storage system as a whole, which consists of four layers: the access layer, the application interface layer, the data management

layer and the storage layer. Users may access cloud storage systems via sites like login and data operations, which are part of the direct user-system interface provided by the access layer. To access HDFS, HBase, and MySQL, the application interface layer offers web services and APIs. In response to user requests, the application server may call the appropriate routines to perform a particular data activity or user identity authentication. The data storage systems HDFS, HBase, and MySQL that can perform the operations of adding, removing, editing, and verifying data are included in the management layer. The physical storage devices that make up the bulk of the storage layer are virtualized into a single entity that offers storage services to the outside world. It also performs status monitoring and centralized management of storage resources concurrently. The system's basic four modules for module and function design are user file systems, file sharing, user information management, and personnel management. File browsing, file uploading, download, sharing, file inquiry, file management, shared file browsing, shared file downloading and retrieving, removing sharing files, changing passwords, adding users, deleting users, resetting passwords, etc. are some of the specific features.

Fig. 1 depicts the system's general design.

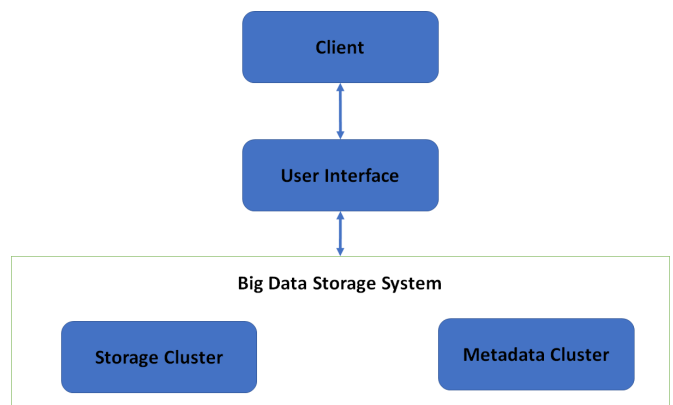


Fig. 1. Overall structure of system.

## IV. PROPOSED WORK

### A. Overview

One potential strategy to combine HDFS files with CP-ABE, RSA, and AES algorithms to speed up uploading and downloading while minimizing the size of the encrypted file could involve the following steps:

- Partitioning data into smaller chunks: Let's assume that we have a large file of size  $L$  that we want to upload or download. Instead of uploading or downloading the entire file at once, we can partition the file into  $n$  smaller chunks, each of size  $L/n$ . By doing this, we can distribute the load across multiple machines, which can significantly speed up the process. Mathematically, we can represent this as:

$$L = n(L/n)$$

- The hybrid CP-ABE, AES, and RSA encryption scheme is a secure data communication approach that utilizes three encryption methods to provide confidentiality, integrity, and access control. The scheme involves the use of a cyclic group  $G$ , a hash function  $H$ , and a bilinear pairing  $e: G \times G \rightarrow GT$  for cpABE encryption. The master key  $mk$  and user secret keys  $sk_i$  are generated using a set of equations and algorithms. The  $mk$  consists of  $(s, t, T)$  where  $s$  is a random element of  $Z_p$ ,  $t$  is a random element of  $Z_p$ , and  $T$  is a bilinear map from  $G$  to  $GT$ . The user secret key  $sk_i$  consists of  $(D_i, T^i)$  where  $D_i$  is an element of  $G$  and  $T^i$  is  $T$  raised to the power of the attribute vector of  $i$ . To encrypt a message  $M$ , a random symmetric key  $K$  is generated, and the message is encrypted using AES. The symmetric key  $K$  is then encrypted using RSA with the recipient's public key, and both ciphertexts are encrypted using cpABE with a given access policy  $\omega$ . To decrypt the message, the recipient uses their RSA private key to decrypt the encrypted symmetric key  $K$ , and the message is decrypted using the decrypted symmetric key. The security of the proposed scheme is analyzed using formal security definitions and proofs. The performance evaluation of the scheme is conducted in terms of computation time and communication overhead, and the results demonstrate that the scheme is efficient and practical for real-world applications.

For more Mathematical explanation in the hybrid cpABE, AES, and RSA encryption scheme we found four step:

- Setup:
  - Let  $p$  and  $q$  be two large prime numbers. The product of these primes,  $n = pq$ , is used as the modulus for RSA encryption:
 
$$n = pq$$
  - The totient of  $n$ ,  $\phi = (p - 1)(q - 1)$ , is used to compute the RSA public and private exponents,  $e$  and  $d$ , respectively:
 
$$\phi = (p - 1)(q - 1)$$

$e, d$  are such that  $e \cdot d \equiv 1 \pmod{\phi}$  and  $1 \leq e < \phi$ , where  $e$  is the public exponent and  $d$  is the private exponent.
  - A cyclic group  $G$  is chosen with order  $n$ , and a generator  $g$  is selected from this group. This group is used for cpABE encryption:
 
$$G = g^x \pmod{n} : x \in Z_{n^*}$$
  - A hash function  $H$  is chosen that maps a bit string of arbitrary length to an element of the group  $G$ :
 
$$H : 0, 1^* \rightarrow G$$
- Key Generation:
  - The authority generates a master key (MK) consisting of  $(p, q, n, \phi, e, d, G, g, H)$ .
  - For each user  $i$ , the authority generates a secret key SK $_i$  consisting of a set of attributes  $A_i$  and a private key  $s_i$ . These secret keys allow users

to decrypt messages that are encrypted with CP-ABE.

- Encryption:
  - To encrypt a message  $M$  for a set of attributes  $S$ , the encryptor first generates a random symmetric key  $K$  that will be used to encrypt the message with AES:

$$K = Random()$$

- The encryptor encrypts the message  $M$  using AES with the symmetric key  $K$ , producing the ciphertext  $C1$ :

$$C1 = AES\_Encrypt(M, K)$$

- The encryptor encrypts the symmetric key  $K$  using RSA with the public key  $(n, e)$ , producing the ciphertext  $C2$ :

$$C2 = RSA\_Encrypt(K, (n, e))$$

- The encryptor encrypts both  $C1$  and  $C2$  using cpABE with the policy  $P(S)$ , resulting in the final ciphertext  $C$ :

$$C = cpABE\_Encrypt(P(S), (C1, C2))$$

- Decryption:
  - To decrypt the ciphertext  $C$  for a user  $i$  with attributes  $A_i$ , the user first decrypts  $C2$  using their private key  $s_i$  to obtain the symmetric key  $K$ :

$$K = RSA\_Decrypt(C2, s_i)$$

- The user then decrypts  $C1$  using the symmetric key  $K$  to obtain the plaintext  $M$ :

$$M = AES\_Decrypt(C1, K)$$

The triple encryption approach provides better data protection when compared to traditional encryption techniques. ABE has recently attracted a lot of attention because of its decentralized access control and secure communication skills in dynamic environments. However, user-defined rules or processes cannot define the encryption process. To provide users more influence over the encryption process, access control rules are specified as ciphertext policies. Along with setting the properties, users may also control the encryption and decryption policies. These access control restrictions also provide cryptographic protection for data during transmission and storage. Only the properties are encrypted in CP-ABE; the whole block is not.

The hybrid encryption algorithms model for encrypting /decrypting files is seen in Fig. 2. The selection of input file properties is where the operation starts. Qualities are picked utilizing logical combinations and user preferences. Once the criteria have been determined, a set of rules is built expressly for these traits and encryption is executed. The AES algorithm creates a key that is used to safeguard the file after it has been encrypted for two-level security. Then, to safeguard the encrypted file, the AES key produced using the RSA process is applied. RSA AES key encryption is used to offer authentication while decrypting the encrypted file. If they do, it goes to the next stage; if not, the decryption process pauses and

records the endeavor as an intrusion. Once the characteristics of the cipher match those of the key, if the key is the same as the actual key, attributes are applied and the file is then decrypted. If not, it is likewise categorized as an incursion at this level. The final file that has been encrypted will be plain text and useable in the appropriate program.

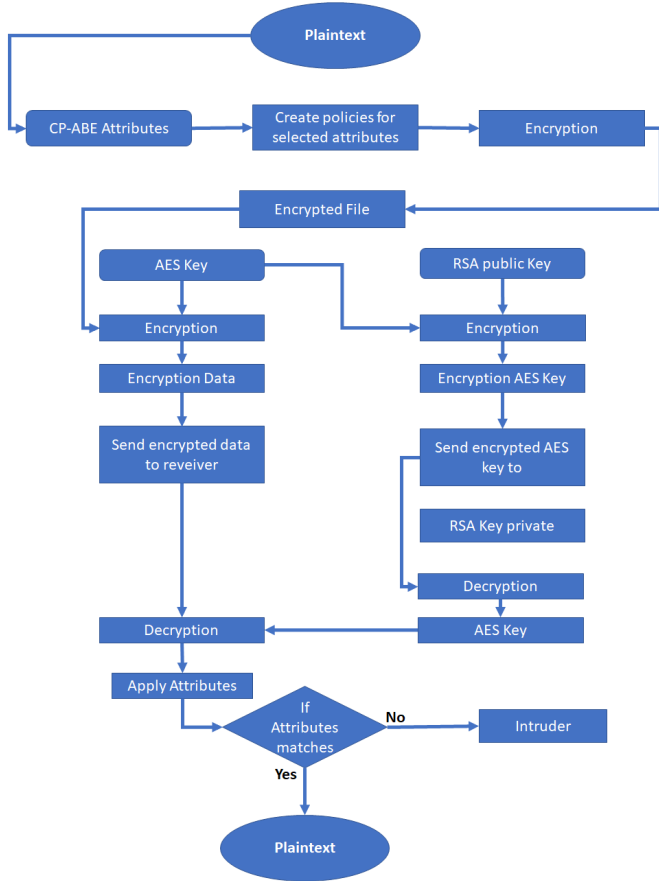


Fig. 2. Overview of the proposed hybrid encryption model.

### B. Encrypting Files in HDFS

When submitting files to the HDFS system, the encryption operation is carried out. When files are successfully encrypted, data security is increased. Fig. 3 depicts the HDFS system’s encryption process.

The actions taken during the encryption process are listed below in brief:

Step 1 : The system of distributed files is utilized in the first stage to simplify interaction between the HDFS user and the master node.

Step 2: The system of distributed files forwards the request containing the demand to create a new file to the master node.

Step 3: The master node analyzes the data node’s availability of space and picks the right data node.

Step 4: Data node information is exchanged with the distributed file system and subsequently transmitted to the HDFS client.

Step 5: Before encrypting the file, the client transmits the attributes . The file is encrypted in the data node when the characteristics are specified.

Step 6: A key is generated using the AES approach

Step 7: The AES key generated encrypted using RSA Algorithm and applied to the encrypted file in order to safeguard it.

Step 8: Using output data streams from a distributed file system, a writing process begins from a client to a particular data node.

Step 9: Data from the current data node is relocated to another data node if the write operation is complete.

Step 10: The master node stores information about the current data node and replication data node throughout the replication operation.

Step 11: Using the distributed file system, an acknowledgment is sent to the HDFS client once the data has been correctly duplicated on the secondary data node.

Step 12: After receiving the acknowledgment, the HDFS client pauses the writing process.

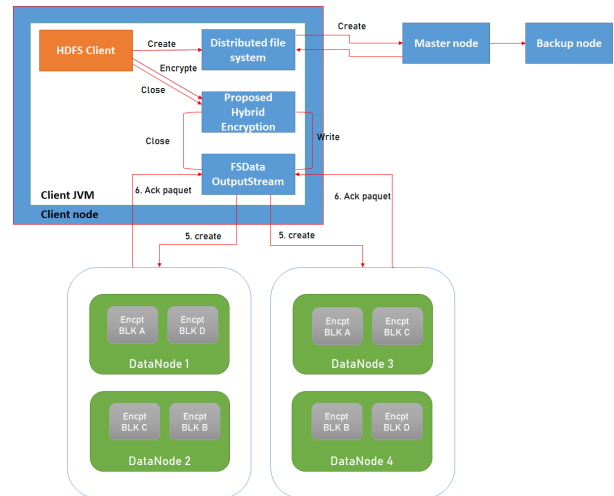


Fig. 3. Encryption process in HDFS.

### C. Decryption Files in HDFS

When reading the files from the HDFS system, the decryption phase is carried out. Before reading the operation, the file must be decrypted, and using this technique may assist identify any illegal access or intruders. Fig. 4 depicts the HDFS system’s decryption process.

The activities followed during the decryption method are explained as follows:

Step 1: The HDFS client talks with the master node across the distributed file system to begin the decryption process.

Step 2: A distributed file system sends a request comprising a request to read a file to the master node.

Step 3: The master node gives info about the data node that holds the encrypted files.

Step 4: The HDFS client begins the operation by picking data from the chosen block using the file system data input stream.

In Step 5: The client inputs the attributes to decrypt the file if the password provided for authentication matches.

Step 6: Access is regarded as an invasion or illegal access if the matching procedure is failed.

Step 7: After getting the acknowledgment, the HDFS client pauses the reading operation.

Step 8: After getting the HDFS client acknowledgment, the reading process is fully complete.

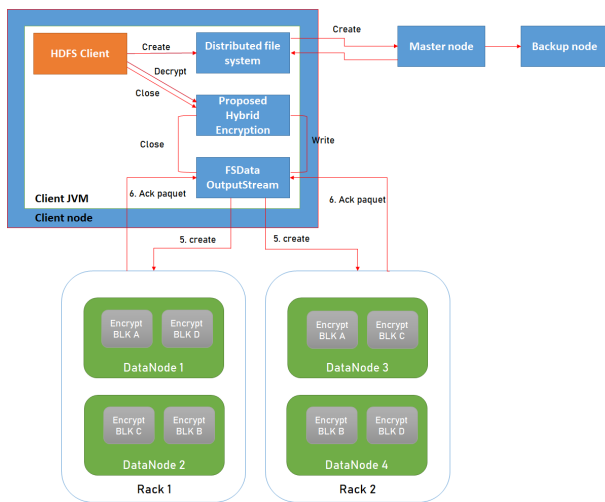


Fig. 4. Decryption process in HDFS.

#### D. Proposed Approach Pseudo Code

##### Initialization

**Data:** Plaintext to encrypt

**Result:** Encrypted cipher-text

##### Begin Algorithm

- 1: Initialize characteristics
- 2: Create a set of guidelines based on the characteristics and logical pairings
- 3: Apply characteristics to the file and use a set of rules to encrypt it.
- 4: Using the AES-generated key encrypted by RSA, secure the file. =0

#### V. EXPERIMENTS AND RESULTS

The suggested hybrid encryption technique for large data security in the HDFS environment is confirmed by tests done in the Hadoop system installed in the CPU Intel® core i5 2.40GHz, 8 processors, 16 GB memory, 128G Solid state drive and operating system CentOS release 7.5.1804. The master node is chosen as one of the nodes, while the data nodes are the other nodes. Performance evaluation of encryption and decryption is done on files of various sizes. Throughput, encryption and decryption times, efficiency, and other factors are compared to the conventional DES, 3DES, and Blowfish

##### Decryption

##### Begin Algorithm

1: begin the authentication process by matching AES keys =0

**if** user input = RSA Key AND user input = AES Key **then**

    | Allow user to process next step ;

**else**

    | Declare a threat;

**end**

Perform characteristics matching;

**if** characteristics = characteristics **then**

    | Decrypt encrypted file;

**else**

    | Declare a threat;

**end**

algorithms. We also contrasted it with a different hybrid approach, that consists of AES and OTP algorithms. The parameters used in the proposed work on five CVs files with different sizes (64 MB, 128 MB, 256 MB, 512 MB , 1024 MB) depicted in Table I.

TABLE I. PARAMETERS

Simulation No.	Parameter	Range/Value
1	Input file size	64 MB to 1024 MB
2	Memory	16
3	Key length	128, 256 bit

#### A. Data Security

Five algorithms are employed in this experiment to encrypt and decode the same data. The results show that the best algorithm is our hybrid approach, which provides the highest reliability and security for the data sent when the DES, 3DES , Blowfish hybrid algorithm (OTP and AES) and our approach algorithms are compared, the differences in encryption and decryption times evaluated in Fig. 5. The encryption-decryption timing for the five is provided in Tables III and IV with varying file sizes. Table V displays the entire processing time in minutes. From the findings shown in Table V, it's evident that our technique is superior than the other algorithms (DES 3DES, Blowfish and Hybrid) after evaluating all five algorithms and calculating the time required to finish processing on many files of varying sizes. Our hybrid approach encryption method gives the best degree of data security of the other algorithms, and its performance is substantially quicker than the DES,3DES, Blowfish and hybrid algorithms. Comparison of Encryption Algorithm is given in Table II.

Calculating how long it takes to convert plain text into ciphertext gives us the encryption time. The Table III shows that the suggested model takes the fewest amount of time for each file. A maximum file size of 1 GB of data takes around 5 minutes to encrypt, compared to 13 minutes for DES, 12.5 minutes for 3DES, 11.8 minutes for Blowfish, and 6.2 minutes for hybrid. The encryption time grows progressively as the file size increases.

TABLE II. COMPARISON OF ENCRYPTION ALGORITHM

Factors	AES	DES	3DES	RSA	Blowfish
Created by	Dr. Joan Daemen and Dr. Vincent Rijmen	IBM	Dr. Walter Tuchman	Ron Rivest, Adi Shamir, and Leonard Adleman	Dr. Bruce Schneier
Published year	2000	1977	1998	1978	1993
Structure / Scheme	Substitution-Permutation	Feistel	Feistel	Factoring prime numbers	Feistel
Key length	128, 192, or 256 bits	56 bits	112 or 168 bits	>1024 bits	32-448 bits
Rounds	10, 12, or 14	16	48 DES-equivalent	1	16
Block size	128 bits	64 bits	64 bits	Variable	64 bits
Cipher Type	Symmetric	Symmetric	Symmetric	Asymmetric	Symmetric
Key used	Same key	Same key	Same key	Different key	Same key

TABLE III. ENCRYPTION TIME TAKEN FOR EACH ALGORITHM IN MINUTES

Files size (MB)	DES ENCR	3DES ENCR	Blowfish ENCR	Hybrid ENCR	Proposed ENCR
64	0.9	0.95	0.92	0.09	0.01
128	1.9	1.95	1.92	0.6	0.1
256	2.9	2.7	2.5	1.6	0.5
512	7.5	6.8	6.1	3.5	1.3
1024	13	12.5	11.8	6.2	5

TABLE IV. DECRYPTION TIME TAKEN FOR EACH ALGORITHM IN MINUTES

Files size (MB)	DES DECR	3DES DECR	Blowfish DECR	Hybrid DECR	Proposed DECR
64	1.4	1.2	0.7	0.07	0.04
128	2.3	3.2	1.7	0.3	0.1
256	3	3.2	2.9	1.5	0.4
512	8.4	7.1	5.1	2.8	1
1024	16.4	15.4	12.6	5.7	4.5

The time required to translate ciphertext into plain text is used to compute the decryption time (Table IV). According to the investigation, the suggested model's decryption time is less than that of existing encryption techniques. To decode 1 GB of data, the decryption process takes around 4.5 minutes. DES decrypts a file of the same size in 16.4 minutes, 3DES in 15.4 minutes, Blowfish in 12.6, and hybrid in 5.7 minutes.

TABLE V. TOTAL TIME FOR EACH ALGORITHM IN MINUTES

Files size (MB)	DES	3DES	Blowfish	Hybrid	Proposed
64	2.3	2.15	2.84	0.16	0.05
128	4.2	5.15	3.62	0.9	0.2
256	5.9	5.9	5.4	3.1	0.9
512	15.9	13.9	11.2	6.3	2.3
1024	29.2	27.9	24.4	11.9	9.5

The Total time is obtained by calculating the time taken to generate a ciphertext from plain text and the time taken to convert ciphertext into plain text. It is observed in Table IV and Fig. 5 that the time taken for the proposed model is minimum for all the file size. The total time increases gradually from small to large file size, and for a maximum file size of 1 GB of data, The total time of the proposed hybrid encryption algorithm is 9.5 min, which is 2.4 min less than the hybrid

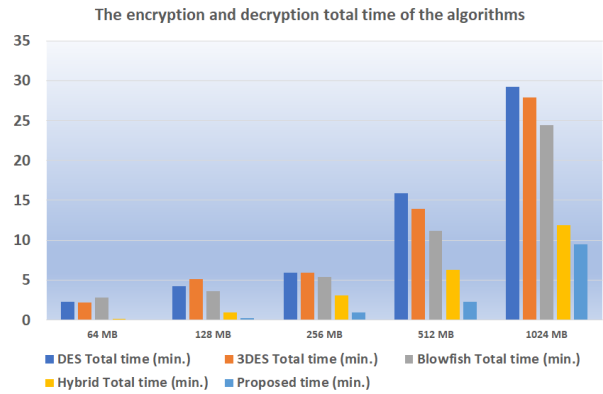


Fig. 5. The encryption and decryption total time of the five algorithms.

algorithm (OTP and AES), 14.9 min less than the Blowfish algorithm, 18.4 min less than the 3DES algorithm, and 19.7 min less than the DES algorithm.

B. Throughput

Throughput is characterized as the quantity of data traveling through a network system. It is the result of dividing all the data delivered in megabytes by the average time required to transfer all the data in minutes. Throughput value in (MB / min) for each algorithm as indicated in Table VI. The throughput study is given in Fig. 6.

TABLE VI. THROUGHPUT VALUE OF THE ALGORITHMS

Algorithm	DES	3DES	Blowfish	Hybrid	Proposed
Throughput value	34.50	36.07	41.80	88.72	153.20

According to the tests done in this article, the hybrid encryption algorithm may be utilized in software applications, system design and other fields essential for data security exchange, which can effectively safeguard data, in addition to quick performance and execution time, as the results showed that the our approach encryption is 77.48% faster than the DES algorithm, 76.84% faster than 3DES algorithm, 72.71% faster than Blowfish and 42.08% faster than hybrid algorithm.

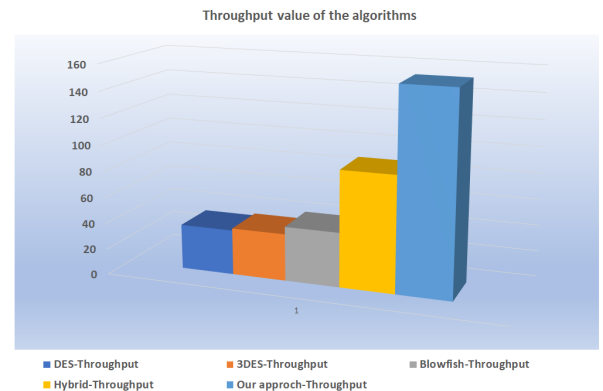


Fig. 6. Throughput value of the algorithms.

## VI. CONCLUSION

In this work, a hybrid encryption method for the Hadoop distributed file system environment's megadata security was presented. When publishing files to the HDFS data node, three-level encryption using the CP-ABE, AES, and RSA algorithms was made possible. The properties supplied for the input file were encrypted using CP-ABE. Additionally, a Rsa key was used to encrypt the key generated using the standard Advanced encryption method. By using this AES key as the password for the encrypted file, data security is increased, and the intruder may be located throughout the decryption process. The effectiveness of the proposed approach has been confirmed in terms of throughput, decryption time, and encryption time. The proposed hybrid encryption model outperformed DES, 3DES, Blowfish, and other conventional Hybrid techniques. The tiny limitation noted in the proposed research is that the CP-ABE approach relies on policies and characteristics, and if the attributes are not selected properly, there may be discrepancies in performance on different runs. Additionally, using optimization techniques to raise other performance metrics may improve the research effort. However, there are promising avenues for future research in this field. Integrating advanced machine learning techniques, exploring post-quantum cryptography, evaluating the impact of blockchain, and addressing scalability challenges are key directions for further investigation. By pursuing these future endeavors, we can strengthen the security of data stored in Hadoop clusters, mitigating emerging threats and ensuring the confidentiality and integrity of sensitive information.

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# Review of Unsupervised Segmentation Techniques on Long Wave Infrared Images

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**Abstract**—This paper studies the different unsupervised segmentation algorithms that have been proposed and their efficacy on thermal images. The scope of this research is to develop a generalized approach to blindly segment urban thermal imagery to assist the system in identifying regions by shape instead of pixel values. Most methods can be classified as thresholding, edge-based, region-based, clustering, or texture analysis. We explained methods, worked before applying the methods of interest on thermal images of 8-bit and 16-bit resolution, and evaluated the performance. The evaluation section discusses where each method succeeded, where it failed, and how the performance can be enhanced. Finally, we study the time complexity of each method to assess the feasibility of implementing a fast, and generalized method of pixel labeling.

**Keywords**—Unsupervised segmentation; thermal images; texture analysis; pixel labeling; Gabor; GMM; image analysis; K-Means; MRF; Otsu's; DNN; region-based clustering

## I. INTRODUCTION

Image segmentation [1] is an area of focus primarily due to its potential usefulness in numerous fields of application. Given that images allow for the transfer of information, understanding them and the associated methods of extracting information is essential. Image segmentation often serves as the first step in the process of image interpretation. It aims to change, simplify, or partition the representation of an image into a more meaningful collection of segments for enhanced analysis [2], [3]. The importance and applicability of image processing cannot be overemphasized. In practice, many image processing algorithms do not focus on the entire image but only require information from the image regions that share certain features. For example, consider an application such as medical imaging where surgery decisions need accurate information about the images to either initiate or speed up patient recovery [4], [5]. Image segmentation supplies the critical image processing function of aiding object location and boundaries in patient imagery in these situations. It effectively assigns labels to every image pixel and enables necessary identifications such as foreground and background regions and other objects of interest in the scene [6].

As implied by the name, the outcome of an image segmentation procedure is a set segment that, when combined, covers the whole image. Each one of these individual segments is called a mask [7]. Masks are pixels in a particular region that share certain texture, color, and intensity characteristics. Image segmentation converts images into sets of masks which can then be interpreted as labeled images. Consequently, the labeled regions produced by the segmentation allow one the

capability of only processing the important parts of an image rather than processing the whole image [5].

So far, there has been a plethora of effective segmentation techniques developed for multiple applications and platforms. These techniques include threshold segmentation [8], region [9], and edge-based segmentation [10], clustering, texture-based segmentation [11], and Partial Differential Equation (PDE) based segmentation [12]. There are a plethora of segmentation approaches. However, the underlying question becomes how does one identify the technique that offers the best image analysis results and performance?

This paper will apply the aforementioned methods to long-wave infrared images (LWIR) and analyze the results. We will discuss each of these methods in general and provide variation details concerning implementation, effect on accuracy, the difference in performance on eight vs. 16-bit data, number of tunable parameters, response to texture and uniform surfaces, and lastly, their time complexities.

In this paper, we present a comprehensive review of unsupervised segmentation techniques applied to long-wave infrared (LWIR) images. The paper has main six sections, starting with the motivation section and ending with the conclusion. The motivation for this study arises from the growing need for effective image analysis in LWIR applications. The literature review section provides an overview of the existing research, highlighting unsupervised segmentation techniques specifically designed for LWIR images. The evaluation section presents the comparative analysis results, showcasing the effectiveness of each technique. The discussion section offers insights into the findings, identifying trends and potential areas for improvement. The conclusion summarizes the key takeaways from the review, emphasizing the most promising techniques. This review serves as a valuable resource for researchers and practitioners in LWIR image segmentation, facilitating the development of accurate and efficient segmentation methods.

## II. MOTIVATION

LWIR is one of the three commonly defined wavelength bands in which infrared imaging operates. The other two are Medium Wavelength Infrared (MWIR) and Very Long Wavelength Infrared (VLIR). LWIR infrared is commonly defined as covering the wavelengths that range from 8,000nm to 14,000nm ( $8\mu\text{m}$  to  $14\mu\text{m}$ ) [13]. Generally, LWIR cameras detect the thermal emissions of animals, vehicles, and people as they stand out when the environment's temperature differs by an amount greater than the camera's sensitivity. LWIR imaging is commonly utilized as a solution for night vision,

thermal imaging, and in degraded visual environments because the longer wavelengths make it less susceptible to scattering from obscurants, such as fog, rain, smoke, dust, and sand. LWIR imaging is instrumental in distinguishing targets at night since traditional imaging employs visible light and cannot reveal sufficient information in these scenarios due to a lack of signal.

The fields of computer vision and image processing are responsible for developing many methods designed to resolve the problems arising in the image segmentation process. However, for infrared/thermal images, the traditional techniques face some additional restrictions, which result in the segmentation being a more challenging problem. For example, when attempting to apply pixel-based segmentation methods to infrared images, the lack of disparity in pixel intensities poses a challenge in grouping/defining the objects' pixels with respect to their background. That can mainly be due to insufficient temperature differences between the object and the background. Another example occurs when utilizing image gradients as edge indicators. In these cases, the LWIR segmentation may fail to accurately identify appropriate object boundaries within the scene due to the non-uniform nature of the pixel intensities and the resulting the poor edge identification.

In this study, we focus on evaluating traditional segmentation algorithms and their feasibility in segmenting thermal images. The challenges mentioned above will be the main scope of this work to create a user-friendly tool to provide labeled data with minimal human input. For some algorithms, the human input will be selecting the number of thresholds, clusters, or objects. Meanwhile, other methods, such as region-growing, will take starting seeds as inputs. Texture segmentation takes sample texture patches as inputs. Ideally, the tool will include a standalone method that will only require the semantic labels from the user.

### III. LITERATURE REVIEW

In this treatment, we have reviewed publications from the last 20 years addressing image segmentation. This period can be divided into the pre-popularization and post-popularization of the deep learning era. The authors note that the deep-learning methods are very efficient with RGB representations of visible light images and are widely used due to this fact. More importantly, the authors note that very few deep-learning algorithms are applied to segment infrared images. This is most likely due to the difficulties mentioned above associated with infrared image segmentation.

The next sections present common methods used in unsupervised segmentation. We discuss thresholding as the first and most common pre-processing step, then discuss other prevalent and promising segmentation techniques. Lastly, we evaluate these techniques by visually analyzing the results and providing quantitative performance evaluation, and discussing scenarios where each method fails in the results sections.

This section explains the methods examined in this study, including the different variations of the same general approach. We begin with thresholding since it is an essential step in most segmentation approaches. Section III-B discusses the various edge detection approaches. Sections III-C, III-D, and III-F

delve into region growing, clustering, and texture analysis, respectively.

#### A. Thresholding

Thresholding image segmentation techniques have gained significant attention due to their simplicity and effectiveness. They are especially useful when dealing with images that have distinct foreground and background intensities. The basic idea behind thresholding [14] is to select a threshold value that separates the desired objects or regions from the rest of the image. Thresholding is the simplest and probably the most common image segmentation technique. The underlying principle relies upon setting a number of pixel intensity thresholds to divide the image pixels into multiple categories. Each category or mask is intended to represent a region of the input image with common features. Common features include color/grayscale characteristics or other common transformation characteristics. If the technique is based on a single threshold value, the effective result is to change a grayscale image into a binary one. If more than one threshold is desired, the thresholding is referred to as multi-level. Binary segmentation and other multi-level thresholding techniques all share the same core issue of effectively selecting optimal thresholds based on certain criteria [1]. Thresholding techniques can be categorized based on global, local, or image histograms. Global Thresholding is the simplest form of thresholding, where a single threshold value is applied to the entire image. Pixels with intensities above the threshold are classified as foreground, while those below the threshold are classified as background. Local thresholding, also known as adaptive thresholding, is a technique used for image segmentation where different threshold values are determined for different regions or pixels of an image. Unlike global thresholding, which applies a single threshold value to the entire image, local thresholding takes into account the local characteristics of the image to handle variations in illumination, contrast, and noise. In local thresholding, the threshold value for each pixel is computed based on the neighborhood around that pixel. The neighborhood can be defined as a fixed window size or a variable size depending on the algorithm or application. The threshold is calculated using statistical measures such as the mean, median, or standard deviation of the pixel intensities within the neighborhood. The main advantage of local thresholding is its ability to adapt to local variations in image properties. This makes it particularly useful in situations where the lighting conditions or intensity characteristics change across different regions of the image. By adjusting the threshold values locally, local thresholding can effectively segment objects or regions with varying illumination or contrast levels. Image histogram thresholding techniques analyze the histogram of the image to determine the threshold values. These techniques can be either global or local. They involve examining the distribution of pixel intensities in the histogram and selecting appropriate threshold values based on certain criteria or statistical measures. Examples of image histogram thresholding methods include Otsu's method, which finds an optimal threshold by maximizing the between-class variance, and the Maximum Entropy method, which selects the threshold that maximizes the entropy of the image.

The most popular variable thresholding method is Otsu's maximum variance approach. Formulated by Nobuyuki Otsu,

the Otsu method is also known as the variance threshold and is a popular algorithm in image segmentation. The optimal threshold is obtained by maximizing class variance functions [5]. It partitions the input image grayscale levels into foreground and background regions. The maximum inter-class variance difference between the two is obtained when the threshold is set to the “optimal” value. It is the preferred method for real-world images based on shape measures and uniformity. However, if the variances among classes differ significantly, the Otsu method cannot offer suitable thresholds for separating the classes [1]. Despite these shortcomings, the Otsu method has a simple algorithm that makes it feasible, convenient, and widely implemented. We will briefly summarize the implementation steps. The first step is to determine the highest grayscale intensity value in the image and denote that level as  $L - 1$ . The threshold  $K$  is then calculated by considering each gray level from 0 to  $L-1$ . Then the threshold probability is calculated and summed by the weight.

The average gray level of the pixel  $\mu_i$  is then calculated as the following:

$$\begin{aligned}\omega_2 &= \sum_{i=k+1}^{l-1} p_i \\ \mu_1 &= \frac{1}{\omega_1} \sum_{i=k}^{L-1} ip_i \\ \mu_2 &= \frac{1}{\omega_2} \sum_{i=k}^{L-1} ip_i\end{aligned}\quad (1)$$

The overall gray value of the image  $\mu$  is given by  $\mu = \sum_{j=0}^{i-1} ip_i$ . Follow-on stages calculate the variance  $\sigma_B$  and finally the maximum threshold  $T$ .

$$\sigma^2 = \omega_1(\mu_1 - \mu)^2 + \omega_2(\mu_2 - \mu)^2 \quad (2)$$

The optimal threshold is obtained by maximizing  $\sigma^2$ .

In multiple/bi-modal thresholding, multiple threshold values such as  $T_0$ ,  $T_1$ ,  $T_2$ , and  $T_3$  exist. Calculation of these levels permits the subsequent multiple category image representation. For example, if a segmented image containing three levels is desired, the output image  $B(x, y)$  can be obtained from the pixels of an input image  $A(x, y)$  using the following formula:

$$B(x, y) = \begin{cases} m & \text{if } A(x, y) > T_1 \\ n & \text{if } T_0 < A(x, y) \leq T_1 \\ 0 & \text{if } A(x, y) \leq T_0 \end{cases} \quad (3)$$

Threshold values can be calculated from the peak values of the image histogram when obvious differences exist in the gray levels of the background and foreground. Both the object and the background contribute to peaks in the histogram. The boundary between them produces a valley. Image segmentation yields perfect results when the segment threshold is at the valley. The threshold method is advantageous because of its simplicity and faster-operating speed. When both the target and the background have high contrast, one can easily obtain the

segmentation effect [5]. However, the technique is not without limitations. First, this technique does not provide accurate results for image segmentation when grayscale differences are insignificant. The underlying reason is that it only considers the pixel intensity information and ignores the spatial information contained in the image. Its sensitivity to grayscale unevenness and noise explains why it is fused with other methods to process images [1]. Additionally, in cases requiring more than two segments, the multiple threshold method is not applicable for images with low cluster variances.

Although both the maximum variance and bi-modal method take a short time, the former offers a more robust algorithm because it can segment the foreground from the background faster and more accurately when dealing with images where image contrast is not obvious.

As mentioned above, another limitation of threshold-based methods is that they tend to focus on intensity alone and ignore the relationship among pixels. This is especially problematic in cases where it is not immediately obvious that the identified pixels are contiguous. There is also the possibility of including extraneous pixels which are not part of the target region. Similarly, one can easily miss isolated pixels in the target region. The effects worsen as noise increases because the intensity of the pixel does not necessarily depict normal intensity [15]. Thus, thresholding can lead to too much information loss or the inclusion of an excess number of extraneous pixels. Over and above, in global thresholding, changes in the illumination may make some parts darker and others brighter in ways unrelated to the objects within the image [16]. This challenge is addressed by the inclusion of a variable threshold applied across the image.

## B. Edge-based Segmentation

Edge-based segmentation is an image processing method based on identifying object boundaries or edges in an input image. In almost all cases, this technique works by detecting discontinuities in brightness [17]. The method effectively detects and links edge pixels to form contours.

A major feature of an image is its edges. Edges are a crucial aspect of many computer vision and pattern recognition algorithms. As such, the detection of edges is an essential step in image processing [15]. The process may be enumerated as follows:

(1) The primary stage involves identifying edges present in the thermal image. To achieve this, different algorithms designed for edge detection, like the Canny edge detector, Sobel operator, or Laplacian of Gaussian (LoG), can be employed. However, when it comes to thermal images, only a limited number of these algorithms produce satisfactory outcomes. One such effective combination is the utilization of Gabor with Histogram of Oriented Gradients (HOG) technique [18]. This algorithm analyzes the gradients and extracts features of the image to identify regions of rapid intensity changes, which are indicative of edges.

(2) Edge Linking: Once the edges are detected, the next step is to link or connect the individual edge segments to form continuous boundaries. This can be done using techniques like edge linking by Hough transform, region growing, or contour

tracing algorithms. The goal is to create closed curves or contours that represent the boundaries of the objects or regions of interest.

(3) Edge Refinement: In some cases, the detected edges may contain noise or artifacts. Therefore, edge refinement techniques can be applied to enhance the quality and accuracy of the edges. These techniques may involve smoothing or filtering the edges, filling gaps, or removing small or spurious edge segments.

(4) Region Segmentation: Once the edges are obtained and refined, they can be used to segment the image into different regions or objects. This can be achieved by performing operations such as region growing, active contours (snakes), or graph cuts, which utilize the information provided by the detected edges to partition the image into meaningful segments.

Given that images have many redundant data, Kaganami and Beiji pointed in [19] out that the essential information is on the edges of an image. They correspond to texture, object boundaries, as well as changes in surface orientation [15]. In essence, an edge usually corresponds to points in the image wherein the grayscale values differ considerably from pixel to pixel. For this reason, detecting edges helps to extract valuable image feature information in regions in which there are sudden and rapid alterations [20].

Finally, edge detection is an integral step toward understanding the characteristics of an image. Edges have important features and contain information that is meaningful for determining the spatial relationship of neighboring pixels. They can be used to decrease significantly the amount of memory required to store the image, filter out less pertinent information, and preserve the vital structural properties of the image. We will explore some edge detection methods in the following sections.

1) *Gradient Edge Detection Method*: Various methods in the literature use convolutional kernels to extract edge features from images. However, most of them belong to two groups: gradient-based methods and Laplacian-based methods. Gradient-based methods, as Jahne mentioned in [15], detect the edges of an image by searching for both the minimum and the maximum values in the image's first derivative. For instance, the popular Sobel, Prewitt, and Roberts operators detect horizontal and vertical edges of an image based on the value of this derivative. Appropriate thresholding can be used in separating sharp edges [19]. As an edge-detection method, the Sobel edge operator shown in equation 4 carries out a two-dimensional spatial gradient measurement on a particular image and hence emphasizes regions of high spatial frequency, which correspond to the image edges. This operator finds the estimated absolute gradient magnitude at every point in an input grayscale image [21]. Theoretically, the Sobel operators are two  $3 \times 3$  convolution kernels. One kernel is essentially the other kernel rotated by ninety degrees. The Sobel operator is illustrated in the following kernels:

$$G_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix} \text{ and } G_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad (4)$$

The Prewitt operator computes the maximum response of a set of convolution kernels to find the local edge orientations for every pixel. It is suitable for estimating both the orientation and magnitude of the edge of an image [20]. For this operator, one kernel is sensitive to image edges in the horizontal direction and the other to the vertical direction. The directional kernels are illustrated below:

$$G_x = \begin{bmatrix} +1 & 0 & -1 \\ +1 & 0 & -1 \\ +1 & 0 & -1 \end{bmatrix} \text{ and } G_y = \begin{bmatrix} +1 & +1 & +1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \quad (5)$$

The Kirsch edge detector uses four filters to detect edges. These filters are essentially a rotation of a basic compass convolution filter [20]. Kirsch convolution kernels are shown below:

$$N = \begin{bmatrix} +5 & +5 & +5 \\ -3 & 0 & -3 \\ -3 & -3 & -3 \end{bmatrix}, W = \begin{bmatrix} +5 & -3 & -3 \\ +5 & 0 & -3 \\ +5 & -3 & -3 \end{bmatrix} \quad (6)$$

$$S = \begin{bmatrix} -3 & -3 & -3 \\ -3 & 0 & -3 \\ +5 & +5 & +5 \end{bmatrix} \text{ and } E = \begin{bmatrix} -3 & -3 & +5 \\ -3 & 0 & +5 \\ -3 & -3 & +5 \end{bmatrix}$$

The direction of the edge operator is defined by the mask that produces the maximum edge results.

2) *Laplacian Edge Detection Method*: The Laplacian method detects the edges by looking for zero crossings in the second derivative of the image's pixel intensity values. Common approaches include the Laplacian-of-Gaussian (LoG) and Marr-Hildreth [22].

To find the edges of an image, the Marr-Hildreth method of edge detection will first filter the image with the LoG filter matrix, which is calculated using the input value of the standard deviation [19]. The standard deviation value determines the filter matrix's width. It also controls the amount of smoothing that the Gaussian component produces. The LoG filtering then smooths the image and enhances all of its edges. The Laplacian of Gaussians response can be estimated by convolving the image with the kernel 7.

$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \text{ and } \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} \quad (7)$$

As soon as filtering is completed, edge localization is processed by finding zero crossings at every pixel for every direction [21]. Overall, Marr-Hildreth edge detection is used in finding edges through second-order differentiation. In most edge-detection approaches, the main idea is to compute local image change indicators, which include both first-order and second-order derivatives. In image processing, the gradient is the first-order derivative of choice, and it could be utilized in detecting the presence of an edge in an image [21]. Conversely, second-order derivatives are usually calculated with the use of the Laplacian. Notably, the second derivative's sign determines if the pixel of an image is on the light or dark side of an edge [22].

3) *Canny Edge Detection*: Canny edge detection, which was introduced by J Canny in [23] is a multi-stage approach to detect edges in images using the gradient calculated by the Sobel operator in the X and Y direction followed by non-max suppression, double thresholds, and edge tracking by hysteresis. As the case for any gradient operation, Gaussian smoothing is a critical preprocessing step since all gradients are sensitive to noise. Then the intensity of the edges is calculated by finding the gradient in the image by convolving the Sobel kernel in (4) in the x and y directions. The magnitude matrix  $G$  and the gradient slope  $\theta$  is calculated as the following:

$$\|G\| = \sqrt{I_x^2 + I_y^2} \quad (8)$$

$$\theta = \arctan\left(\frac{I_y}{I_x}\right) \quad (9)$$

In the next step, non-maximum suppression uses the pair of magnitude and direction of the gradient to find the most intense pixel in the direction of the gradient  $\theta$ , and the rest of the less-intense pixels are removed or set to zero. This will result in thinner edges with varying edge intensities. The double-threshold stage suppresses false-edge pixels, and eliminates variations in edge intensities. In the final step, the edges pixels are connected by applying hysteresis. Low intensity pixels that fall between string edges are considered strong while the ones with no neighboring edge-pixels are set to zero. This will result in final edge array. Canny edges operate on grayscale images. In the results section, we demonstrate how Canny edges are highly sensitive to noise and shadowing effects in thermal images.

### C. Region-based Segmentation

An image is partitioned into regions based upon the similarity of the pixels. In essence, this technique groups sub-regions or pixels into more prominent regions based on pre-set criteria. The procedure usually begins with a set of seed points. New regions are grown from these points by attaching to every seed those adjacent pixels that have properties comparable to the seed, for instance, particular ranges of gray level or intensity. In other words, the region growing image segmentation approach entails growing regions by recursively including nearby pixels which are similar and linked to the seed pixel [24]. Notably, connectivity is required to ensure that pixels do not connect in different parts of the image.

In region growing, homogeneity of regions is the main criterion for segmentation. The homogeneity criteria are as follows: shape, texture, color, gray level, and model. Pixel aggregation is the simplest of all the region growing approaches. After one region has been fully grown by appending adjacent pixels, another seed pixel that does not yet belong to any region will be chosen and then begins the process once more. The entire process continues until every pixel belongs to some particular region [21]. It is a bottom-up approach. Region growing approach requires human interference in choosing the starting seeds.

1) *Split-and-Merge Segmentation*: The split-and-merge approach is the opposite of the region growing technique. This approach entails separating the image into regions based on

a particular similarity measure. The regions are then merged based upon a different or the same similarity measure [25]. Another name of this technique is quadtree division. Initially, some criteria for what is a uniform area are set. Then, the whole image is split into four sub-images. Every sub-image is checked, and if they are not uniform, they are divided into four new sub-images. After every iteration, the adjacent regions are compared. They are then merged if they are uniform as per the similarity measure. The split-and-merge approach entails splitting an image recursively into smaller and smaller parts until every individual region is coherent and then merging them recursively to produce more significant coherent regions [26].

When merging the regions, the approach can begin with small regions, such as 4 x 4 or 2 x 2 regions, and regions which have similar characteristics, for instance, variance or gray level is then merged [24]. Splitting and merging are usually utilized iteratively.

2) *Watershed Segmentation*: The term watershed is broadly understood as a ridge that divides areas drained by a variety of river systems. The geographical area that drains into a reservoir or river is known as a catchment basin. Catchment basins and watersheds have a connection to image processing [27]. A watershed transform is a crucial tool that can be used to solve image segmentation problems. The watershed transform method grows regions of pixels around an image's local minima. It ensures that the boundaries of nearby areas lie by the side of the crest lines of the gradient image. This method of image segmentation combines features of both the region-based and edge-based segmentation methods. An image in watershed segmentation is considered as a topographic landscape that has valleys and ridges. The landscape's elevation values are defined by their gradient magnitude or gray levels of the respective pixels. The watershed transform decomposes a given image into catchment basins. A catchment basin, for every local minimum, consists of all the points whose path of steepest descent ends at this minimum [28] similar to the previous example. Basins are separated from each other by watersheds. The watershed transform decomposes an image; hence it allocates every pixel to a watershed or a region. Numerous small regions come up with noisy medical image data, and this is typically referred to as the over-segmentation problem [27]. It is the main drawback of the watershed segmentation approach.

The advantage of region-based image segmentation is that region-based methods are usually better in noisy images, where detecting borders is complex. Moreover, region-based image segmentation approaches tend to be more robust than edge-based approaches because regions typically cover more pixels than edges. Hence the scientist has more information available to characterize his/her image. Furthermore, when detecting a particular region, the scientist can utilize texture which is difficult whenever one deals with edges [26]. In addition, region growing techniques usually give good image segmentation, which matches well with the observed edges. However, the disadvantage is that the output of region-growing methods is either too few regions (under-segmented), or too many regions (over-segmented) [25]. Objects such as quantum semiconductor dots, DNA micro-array elements, blood cells, toner spots on a printed page, or any other type of object that may span several disconnected regions cannot be found.



Also, region-based segmentation algorithms are generally more complex than edge-based approaches and multiple other image segmentation methods [26]. The other shortcoming is that the regions obtained in region-based segmentation strongly depend on the initial pixel chosen and the order in which the border pixels are examined. Furthermore, the results are susceptible to the threshold value.

Visualizing the watershed: the image on the left can be topographically represented as the image on the right.

#### D. Clustering-based Segmentation

Clustering is another powerful image segmentation technique. It is an unsupervised learning task that involves identifying a finite set of clusters to classify the pixels in a digital image. Cluster analysis entails partitioning an image data set into several disjoint clusters or groupings [29]. During the partitioning, two criteria must be maintained, namely low coupling property and high cohesive property. When processing an image, its features are first extracted and then put together into properly-separated clusters based on each class of an image [30]. Notably, the clustering algorithm aims at developing the partitioning decisions based upon the first set of clusters updated following every iteration [31]. The number of clusters in these clustering-based approaches is referred to as priors, and image pixels are classified into suitable clusters based upon the principle of inter-cluster similarity minimization or intra-cluster similarity maximization. There are two main categories of clustering-based segmentation algorithms, namely soft or fuzzy clustering and hard clustering.

#### E. Fuzzy C-Means

The Fuzzy C-Means (FCM) clustering algorithm was conceptualized in the year 1981 by Jim Bezdek. It is undoubtedly the most common soft clustering approach. It is a clustering method that allows one piece of data to belong to at least two clusters. It is an unsupervised clustering algorithm. Through FCM, an image is segmented by grouping pixels with identical or almost identical values into one cluster, in which every group of pixel's values belonging to one cluster are similar to each other and differ from pixel's values belonging to other clusters [32]. The clusters represent the segments of the image that has been segmented to indicate group membership. Notably, the FCM algorithm is an iterative method of clustering which yields an optimal  $c$  partition by reducing the weighted within-group sum of squared error objective function [33]. The algorithm is based upon minimization of the objective function shown below:

$$J = \sum_{i=1}^N \sum_{j=1}^C u_{ij}^m \|x_i - c_j\|^2 \text{ for } 1 \leq m < \infty \quad (10)$$

In equation 10,  $m$  is a real number greater than 1,  $u_{ij}$  is the member of the pixel value  $x_i$  in the cluster  $j$ . While  $c_j$  is the center of the cluster and  $x_i$  is the pixel intensity measured data. We use  $\| * \|_p$  to denote the  $p$ -th norm used to express the similarity between the pixel intensity and the center of the clusters [34]. The pixel intensity memberships  $u_{ij}$  are calculated as follows:

$$u_{ij} = \frac{1}{\sum_{k=1}^C \left( \frac{\|x_i - c_j\|}{\|x_i - c_k\|} \right)^{\frac{2}{m-1}}} \quad (11)$$

While the centers of cluster values are calculated as the following:

$$c_j = \frac{\sum_{i=1}^N u_{ij}^m \cdot x_i}{\sum_{i=1}^N u_{ij}^m} \quad (12)$$

In equation 11,  $k$  is the steps in the iteration. The procedure will converge when the stopping criteria  $\sigma$  is reached [33].

$$\sigma < \| U^{(k+1)} - U^{(k)} \| \quad (13)$$

To summarize, the FCM algorithm starts by initializing membership matrix  $U^{(0)}$ , then calculates the cluster centers vectors  $c_j$ . It then updates the values of the membership based on the new cluster centers using equation 11. The algorithm then makes the decision stop if the stopping criteria are met, otherwise calculate the new cluster centers, and begin the process again.

The main advantage of the FCM algorithm is that it is capable of preserving a lot more information than other clustering algorithms. Consequently, it also provides better results than other algorithms such as K-Means.

algorithm and k-nearest neighbors (KNN) algorithm [32]. In addition, the algorithm is renowned for giving the best result for overlapped data sets. Unlike the KM algorithm in which a data point has to belong only to a single cluster center, a data point in FCM clustering is allocated membership to every cluster center, and hence data point can belong to multiple cluster centers [33]. Finally, we mention that another major advantage of the FCM algorithm is computational efficiency. It is widely utilized in the medical field for soft segmentation, such as brain tissue models.

We end this section by mentioning a few shortcomings of the FCM method. First, the algorithm can be sensitive to image noise. It does not consider the pixels' spatial information and therefore can produce excessive output result variance in the presence of noise. The result is somewhat inaccurate image segmentation [34]. Another shortcoming is that the FCM algorithm is time-consuming due in large part to its iterative nature. Moreover, Euclidean distance measures with the Fuzzy c-means algorithm could unequally weigh underlying factors [35]. Besides, although better results can be obtained with lower values of  $\sigma$ , these are obtained to the detriment of more iterations [33]. A priori specification of the number of clusters is also listed as a limitation of the method, so we repeat it here to inform the reader.

#### F. Texture Based

A texture is broadly understood as the regular repetition of a particular pattern or element on a surface. It represents aspects of the surface pattern, including regularity, directionality, color, brightness, and coarseness[36]. It is utilized in identifying dissimilar non-textured and textured areas in an image, segmenting/classifying distinct texture areas in an image, and extracting boundaries between major texture

regions [37]. An image is partitioned into several regions with dissimilar textures containing a comparable group of pixels during texture segmentation. In essence, a textured image is segmented into various regions that have similar patterns. Segmentation of textures necessitates the choice of good texture-specific features with excellent discriminating power. In general, techniques for extracting texture features could be categorized into three main classifications: spectral, structural, and statistical. In spectral techniques, the textured image, as Madasu and Yarlagadda pointed out in [38], is changed into the frequency domain. After that, extract the texture features can be carried out by assessing the power spectrum. In structural-based feature extraction techniques, the fundamental facet of texture, known as texture primitive, is utilized in forming more intricate patterns of texture through the application of grammar rules that stipulate how texture patterns are generated. Lastly, in statistical techniques, texture statistics, for instance, the moments of the gray-level histogram, are founded upon gray-level co-occurrence matrix and are calculated for discriminating different textures [38]. Over the years, many different methods have been developed for texture-based segmentation. The main ones include Gabor filters, Markov random fields, and wavelets.

1) *Gabor Filter*: A Gabor filter essentially refers to a combination of a sinusoidal term and a Gaussian filter. Dennis Gabor conceptualized this method, and it is a linear filter. It is notable that frequency and orientation representations of Gabor filters are comparable to those of the human visual system and are suitable for texture discrimination and representation [39]. A two-dimensional (2D) Gabor filter in the spatial domain is a Gaussian kernel function modulated by a sinusoidal plane wave. In 2D, a Gabor filter is as illustrated in equation 14.

$$g_{\lambda, \theta, \psi, \sigma, \gamma}(x, y) = \exp\left(-\frac{x^2 + \gamma^2 y^2}{2\sigma^2}\right) \cos\left(2\pi \frac{x}{\lambda} + \psi\right) \quad (14)$$

In this equation,  $\lambda$  represents the wavelength of the cosine factor,  $\theta$  represents the orientation of the normal to the parallel stripes of a Gabor function in degrees,  $\psi$  is the phase offset in degrees, and  $\gamma$  is the spatial aspect ratio indicating the elliptical nature of the Gabor function support, and  $\sigma$  is the standard deviation of the Gaussian that determines the (linear) size of the receptive field.

While the sinusoidal component of the Gabor filter provides the directionality, the Gaussian provides the weights. The impulse response of the Gabor filter, as Haralick pointed out in [36], is defined by a harmonic function multiplied by a Gaussian function. A Gabor filter applies to a wide range of image-processing applications. Aside from texture segmentation, it can also be applied to image representation, retina identification, edge detection, and document analysis [36]. One of the advantages of Gabor filters is that they satisfy the minimum space-bandwidth product according to the uncertainty principle. As such, these filters provide simultaneous optimum resolution in both the spatial-frequency and space domains. They are utilized in solving problems that involve intricate images comprising textured regions [36]. Texture segmentation with the use of Gabor filters involves three steps. In the first step, a filter bank is used to decompose the input image, using the equation 14.

The second step is feature extraction. The following non-linear sigmoidal function that saturates the output of the filters is used in this step:

$$\tanh(\alpha t) = \left(\frac{1 - e^{-2\alpha t}}{1 + e^{-2\alpha t}}\right) \quad (15)$$

Where  $\sigma$  is the standard deviation that determines the receptive window size.

Lastly, the pixels in the Gabor responses are grouped together using a clustering algorithm such as K-Means.

2) *Markov Random Fields (MRF)*: Markov Random Fields (MRF) is a highly sophisticated texture-based segmentation method. It is a probabilistic model. Regions in natural images are usually homogeneous. Pixel homogeneity means that adjacent pixels often have similar properties. For instance, these properties include common characteristics such as texture, color, and intensity. MRF captures such contextual constraints. MRF-based segmentation approaches have been extensively utilized for classification and segmentation in remote sensing applications [40]. MRF is extensively studied and also has a solid theoretical background. According to [40], the MRF segmentation can only be applied to a Markovian image. A Markovian image is an image where the probability distribution of gray levels depends on the neighboring pixels' gray levels, and it is represented by Gibbs fields. The conditional probability for the pixel  $Z_i$  with a grey value of  $g_i$  belonging to a cluster of pixel values depends on the neighboring pixels  $Z^i$  with pixel values of  $g^i$ . It is denoted as the following:

$$P(Z_i = g_i | Z^i = g^i) = \frac{1}{S} e^{-H(g_i, G^i)} \quad (16)$$

and

$$S = \sum_{g=0}^G e^{-H(g_i, G^i)} \quad (17)$$

The partition sum  $S$  is calculated by summing the energy function of the Markov random fields for the partition. This characterization of the energy function is defined by the parameter vector  $\theta = [b_0, b_1, \dots]^T$ . The parameter vector  $\theta$  is used for the segmentation and characterization of texture.

### G. Deep Unsupervised Segmentation Models

In recent years, image segmentation has attracted interest in computer vision research. Object detection, texture recognition, and image compression are some applications of image segmentation. A set consisting of pairs of images and pixel-level semantic labels, such as street or car, is used to train supervised image segmentation. In contrast, unsupervised image segmentation is used to predict more general labels. However, there are no training images or ground truth labels for pixels in unsupervised image segmentation. Therefore, once a target image is input, the pixel labels and feature representations are jointly optimized, and the gradient descent updates their parameters. In [41], the proposed approach, label prediction

and network parameter learning are alternately iterated to meet the following criteria:

- 1) Pixels of similar features should be assigned the same label.
- 2) Spatially continuous pixels should be assigned the same label.
- 3) The number of unique cluster labels should be large.

In order to satisfy these criteria, Wonjik et al. present a CNN-based approach that optimizes both feature extraction and clustering functions at the same time [41]. They proposed a novel end-to-end differentiable network of unsupervised image segmentation, and in order to enable end-to-end learning of a CNN, an iterative approach to predict cluster labels using differentiable functions has been proposed. This study extends the previous research published (ICASSP) [42]. In the previous work, superpixel extraction using simple linear iterative clustering was employed for criterion (2) from the criteria mentioned above. However, the previous algorithm had a limitation that the boundaries of the segments were fixed in the superpixel extraction process. In this study, a spatial continuity loss is proposed as an alternative to mitigate the limitation mentioned above. Moreover, they presented an extension of the proposed method for segmentation with scribbles as user input, which showed better accuracy than existing methods while maintaining efficiency. In addition, they introduced another extension of the proposed method: unseen image segmentation by using networks pre-trained with a few reference images without re-training the networks.

1) *Differentiable Feature Clustering*: The following is a description of the picture segmentation problem that has been solved. For the sake of simplicity, let  $(\{\})$  denote  $(\{\}_n^N = 1)$  Unless otherwise stated, where  $N$  is the number of pixels in input color image  $I = V_n \in R^3$ . Consider  $(f : R^3 \rightarrow R_p)$  be a function for extracting features. And  $(X_n \in R_p)$  group of  $p$ -dimensional feature vectors of image pixels. By using  $C_n = G(X_n)$ , cluster labels  $C_n \in Z$  has been assigned to all of the pixels, where  $g : R_p \rightarrow Z$  is a mapping function.  $G$  can be an assignment function that returns the label of the cluster centroid that is closest to  $X_n$  in this case. The equation mentioned above is used to derive  $C_n$  in the scenario when  $f$  and  $g$  are fixed. In contrast, if  $f$  and  $g$  are trainable but  $C_n$  is fixed, the equation, as mentioned earlier, can be considered a conventional supervised classification issue. If  $f$  and  $g$  are differentiable, the parameters for  $f$  and  $g$  can be optimized using gradient descent. Unknown  $C_n$  are predicted in this work while training the parameters of  $f$  and  $g$  in an entirely unsupervised way. The following two sub-problems were addressed to put this into practice: prediction of the optimal  $C_n$  with fixed  $f$  and  $g$ , and training of the parameters of  $f$  and  $g$  with fixed  $C_n$ . In particular, the three criteria presented in Section I are mutually exclusive and can never be ultimately achieved. Applying K-means clustering to  $X_n$  for criterion (a), performing graph cut algorithm using distances to centroids for (b), and finding  $k$  in K-means clustering using a non-parametric technique for (c) is one feasible solution for tackling this problem utilizing a traditional method (c). However, because these traditional approaches are only applicable to fixed  $X_n$ , the solution may be suboptimal. As a result, a CNN-based algorithm is presented as a solution. All of the requirements above are satisfied by jointly optimizing the feature extraction functions for  $X_n$  and  $C_n$ . An

iterative strategy to forecast  $C_n$  using differentiable functions is suggested to enable end-to-end learning of a CNN. The input image  $I$  was fed into the CNN to extract deep features  $X_n$  using a feature-extraction module. The response vectors  $R_n$  of the features in  $q$ -dimensional cluster space were then calculated using a one-dimensional  $1D$  convolutional layer, where  $q = 3$  in this example. The three axes of the cluster space were represented by  $z_1$ ,  $z_2$ , and  $z_3$ . The response vectors were then standardized across the cluster space's axes using a batch normalization method. Furthermore, cluster labels  $C_n$  have been established by utilizing an *argmax* function to give cluster IDs to response vectors. The feature similarity loss was then computed using the cluster labels as pseudo targets. Finally, the spatial continuity loss and the feature similarity loss have been computed and backpropagated.

2) *Superpixel Learning*: Ilyas et al. propose a novel approach for unsupervised segmentation in using superpixels within a CNN framework in [43]. Superpixels are the outcome of perceptual pixel grouping, or, to put it another way, the effect of image over-segmentation. Superpixels contain more information than pixels and match with image borders better than rectangular image patches. The local contrast and distance between pixels in the image's RGB color space are used by superpixel extraction methods. In [43] the authors we extract  $P$  superpixels that are more detailed and unique in the input image. After that, each pixel in each superpixel is given the same semantic name. The fewer iterations the CNN must do to produce the final segmented image, the finer the pixels generated by the technique. Too many generated categories (superpixels) will cause the CNN to produce more iterations. To avoid similar situations, input images are pre-processed image by applying contrast enhancement and blurring. Many structures use the simple linear iterative clustering (SLIC) methodology to produce superpixels. However, Ilyas et al. chose the Felzenswalb algorithm because it utilizes a graph-based image segmentation method. In comparison to the other algorithms, this one does an excellent job with image details. Moreover, its time complexity is linear, and it is quicker than the other available methods.

In their approach, Ilyas et al. computed the  $n$ -dimensional feature vector from this RGB image through their network's  $N$  convolutional blocks. SE-ResNet (detailed later) is the first block, followed by batch normalization and ReLu activation. The dimensions with the highest value were then taken from the feature vector output of the last convolutional block. As a result, we were able to extract the labels from the resulting feature vector. To achieve feature recalibration, we used the bespoke squeeze and excitation networks (SE-Net) initially developed by Jie Hu et al. In order to obtain a SE-ResNet block. We chose to combine SE-Net with ResNet because of its increased representational power. Moreover, we name it SE-Block for simplicity of notation. CNN's extract hierarchical information from images using convolutional filters. Deeper layers detect more abstract features and geometry of the objects present in the images, whereas shallow layers find trivial features from contexts such as edges or high frequencies. Each phase extracts more and more critical information to complete the work at hand at each phase efficiently. In SE-Net, each output channel is weighted adaptively, which is the significant difference between SE-Net and Normal convolutional networks. We add a single parameter to each channel and shift it

linearly based on how relevant each channel is. This is done by obtaining a global understanding of each channel by squeezing the feature maps to a single numeric value using global average pooling (GAP). The results go through the neural network's two fully connected (FC) layers, which produce a vector of the same size as the input. Each original output channel may now be scaled based on its relevance using this n-dimensional vector. As the last step, we utilized K-means to eliminate noise from the final segmented image. In order to apply K-means, we have to find the number of K, which represents the number of clusters. Because of the unsupervised scenario, we do not know how many segmented areas will be in the final segmented image. So, in order to solve this issue, we count the number of disjointed segmented regions in the final segmented image and assign that value to K.

#### IV. PRE-EVALUATION

##### A. Dataset

For this study, we will be using the ADAS dataset provided by FLIR. This dataset contains 8-bit and 14-bit LWIR images and non-annotated RGB images of the same scenes for reference. The dataset was collected by mounting an infrared camera next to a true color camera with center lines approximately 2 inches apart [44]. The two cameras were mounted on a vehicle driving around, collecting synced segments of video and images in Santa Barbra, CA streets and highways. The image capture rate is two frames per second, and the rate of the video is at 30 fps. The infrared frames have a resolution of  $640 \times 512$  with a 45-degree horizontal field of view and a 37 vertical field of view. The RGB images have  $1280 \times 1024$  with a field of view set to match the infrared camera. The dataset contains 10,228 synced frames and includes a variety of categories/labels, such as, persons, cars, bicycles, dogs. The demonstrated test cases in the results table are selected by the dynamic pixel value range. for example, the road image has very low dynamic range i.e. all pixel values are limited to a very small number of bins in the histogram while other images have wider ranges. The FLIR dataset contains labels of bounding boxes of several object used for training object detection models. However, we do not employ any of the bounding box labels or details. the dataset is merely chosen since it provides pairs of RGB and thermal images with relatively high resolution. to that point there is also the KIAST dataset and several other face datasets.

##### B. Preprocessing

First, the image was sharpened to give each item in the image a clear border in order to make a higher-quality image. The image then applied to bilateral filter which reduced unnecessary noise while maintaining the sharpness of the object edges. The filter can be applied in a variety of sizes  $n \times n$ . We avoid using a values higher than  $n = 5$ , since this would result in extreme smoothing and leads to lose a lot of useful information.

##### C. Evaluation Methods

In the field of image processing, evaluating the performance of a segmentation algorithm is a crucial step. The primary key in evaluating segmentation algorithms is how each

method performs in a system or a specific application. For example, in some object detection and tracking applications, the evaluation of how well the segmentation algorithm performs is determined by how well the approach can distinguish the target object from the rest image being considered the background. After extracting the object from the image, the image is furtherly processed . In this case, the target is measured and compared with the ground truth, and the result is evaluated. In their paper, Zhang et al. classify and discuss assessment methods of image segmentation [45]. Additionally, the difference between supervised and unsupervised evaluation methods is examined in detail. In [46], a thorough study about the evaluation approaches in different applications is provided. In this paper, we will provide a qualitative evaluation of the segmentation results for each algorithm and visually compare the results. Furthermore, we will provide a quantitative and analytical evaluation of each algorithm using a semi-supervised approach.

The results reported in this study are calculated using the Dice index, Specificity, Sensitivity, and the Jaccard index as demonstrated in equations Equations (18) to (21).

$$Dice = 2 \times TP / (2 \times TP + FP + FN) \quad (18)$$

$$Specificity = TN / (TN + FP) \quad (19)$$

$$Sensitivity = TP / (TP + FN) \quad (20)$$

$$Jacc = TP / (TP + FN + FP) \quad (21)$$

The Dice index is the intersection between the generated segmentation and the ground truth given in 18. The specificity 19 is the correctly assigned pixels in the image. The sensitivity is the number of uniformly distributed pixels object pixels can be calculated as shown in equation 20. Equation 21 is the Jaccard index which is the relation between the two segmentations, the predicted and the ground truth.

#### V. EVALUATION

##### A. Threshold

Even though we already know that threshold or image "binarization" does not make sense for this application, we have implemented it as an essential step compared to the other segmentation techniques investigated in this study. The optimal number of thresholds for each image is determined by counting the number of peaks in the histogram. Here, we assumed that our objects have uniform temperatures and that this results in constant pixel values across a single object. This assumption means that the significant peaks will determine the optimal number of thresholds in the image. In order to standardize the peak finding process, a median filter was applied to the frames to provide a uniform range of pixel values. Since all the different techniques of locating the thresholds in the histogram returned close results, we will discuss and calculate the accuracy Otsu's approach since it is the commonly used approach and the most robust.

While determining the optimal number of thresholds, we assumed that objects with uniform temperatures create homogeneous regions or segments. Realistically, objects normally do not have consistent surface temperatures. This temperature discrepancy and environmental and sensor noise lead to the common characteristic of thermal images not containing well-defined regions. Therefore, it causes the thresholding process to often fail when dealing with a histogram with a small variance or a histogram with its peaks concentrated in a small portion. sample result is demonstrated in Fig. 1.

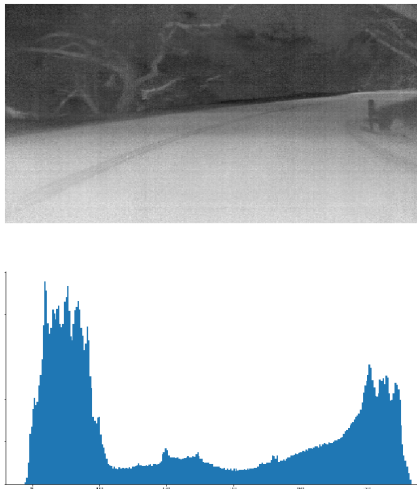


Fig. 1. This histogram has two major peaks and several local peaks which will cause the thresholding process to fail.

In Table I, we demonstrate more examples of the binarized images using Otsu's thresholds.

### B. Region and Edge-based Segmentation

When applying edge detectors to thermal images, we notice the overlapping objects, although not at the same depth, with the same pixel values are grouped and have no separating edges between them, as demonstrated in the Fig. 2.



Fig. 2. Over-lapping objects of different depths.

In the case of applying the Canny edge detector, in the active regions of the image, the detector returns many false

positives due to the variation in pixel intensities. In Fig. 3, the brick road forms multiple closed regions where it could be mistaken for multiple local regions when in reality, they belong to the same object.

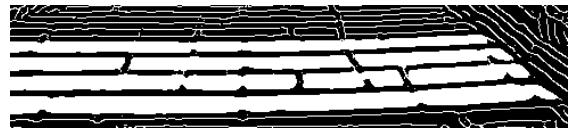


Fig. 3. Over-segmentation of the brick road due to visible gradient in the temperatures.

Watershed segmentation relies on finding the topographic elevation in the image intensities. We notice that watershed segmentation provides the best results when there is a significant disparity within a region that contains two objects of similar pixel intensities. But it also causes over-segmentation in other cases where the same object contains prominent edges. As shown in Table I, watershed generates qualitatively best results in terms of assigning a uniform labels to objects with respect to their edges and their local maxima.

### C. Clustering

Both  $K$ -means and Gaussian mixtures play an essential role in unsupervised machine learning. They offer simple and intuitive approaches to clustering and are straightforward to implement. Typically, they are included in any significant machine learning software package. When  $K$ -means was applied to the set of test images, it returned results similar to those achieved by multi-modal thresholds. When  $K$ -means fails, GMM comes in. Since  $K$ -means can do good enough on most images, we use GMM only for those cases where  $K$ -means cannot detect good boundaries. We use all the cluster centers calculated by  $K$ -means to initiate the GMM model for the same number of mixtures. Then for each given image, we calculate the probability. We then threshold and normalize them to create a black and white image similar to what we get from  $K$ -means. FCM has the disadvantages of sensitivity to initial cluster values, sensitivity to noise, and the solution provided does not consider any relevant spatial information from neighboring pixels. Applying fuzzy clustering on pixel values without any additional features will result in better segmentation when compared to the results from  $K$ -Means and multi-modal thresholds, as demonstrated in Fig. 4.

### D. Texture Analysis

The results shown provide some insight into how these texture-based feature extraction techniques are performed. The Gabor method performed decently in the given segmentation tasks, although more processing was required to achieve accuracy. Additionally, the Gabor method takes several parameters as initial input to the program, and these parameters require a lot of experimentation and errors. However, the Gabor parameters that have always made the most significant contribution to the method's output were the window sizes. Whether it was the size of the moment mask, the size of the Gabor filter, or the smoothing window after the activation function had been applied, these window sizes caused drastic changes in the results of the segmentation results.

TABLE I. SEGMENTATION RESULTS

Input image	Otsu's	Watershed	K-Means	FCM	Gabor	MRF	DFC	Superpixel

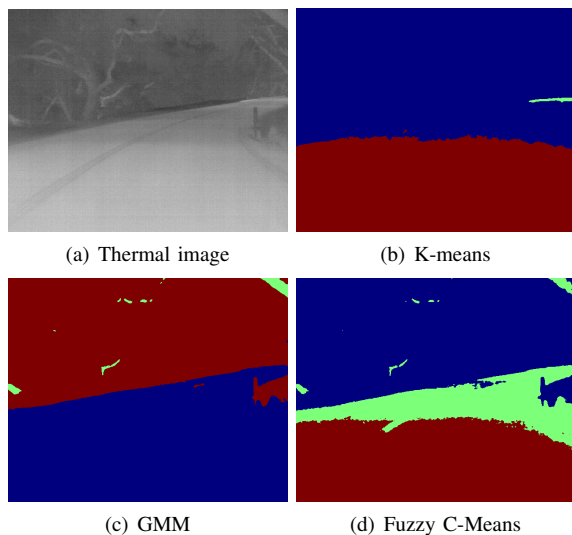


Fig. 4. Comparison between clustering methods K-means, GMM, and FCM.

The MRF model did not segment the image properly. Possibly, because exploiting only pixel values does not give enough segmentation power to the model. However, incorporating complex labels of each class's mean and variance provided more accurate segmentation for the labeled classes. Therefore, the aggregate four features: pixel intensity, mean, variance, and the sum of the log of the intensities of neighboring pixels, are used on the MRF model satisfying segmentation. Fig. 5 demonstrates the difference in the performance between the unsupervised segmentation and the hard-labeled segmentation.

### E. Unsupervised Deep Learning Models

As shown in the qualitative and quantitative results, unsupervised deep learning models provide similar results to the classical clustering algorithms. This poor performance can be due to the lack of feature representation in the images. If the feature representation is not well-suited to the task or

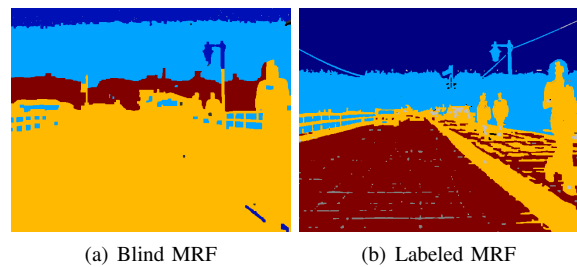


Fig. 5. The difference in the performance after providing hard labels for MRF segmentation. The left image is the blind segmentation result without providing labels while the right image is the result when providing sample segments for each label.

too limited in scope, the model may struggle to accurately segment the image. Another reason would be due to having these models need to be fine-tuned to the dataset used in this study. Also, the choice of hyperparameters would affect the overall performance of these models. There are several hyperparameters involved in unsupervised segmentation models, such as the learning rate, regularization, and optimization method. If the hyperparameters are not chosen correctly, the model's performance can suffer (Table II).

## VI. DISCUSSION

This paper reviewed the most common approaches for providing labels for training purposes using unsupervised segmentation algorithms. The first three sections covered the theory behind each approach. In the results section, we quantitatively and visually analyzed each approach and discussed cases where the method failed and the reasoning for the failure. The results indicated that we could not rely solely on pixel values for segmentation, even for such low-rank images as thermal images. Segmentation methods such as thresholds or clustering performed poorly in more complicated scenes with several objects of the same temperature in the scene. Therefore, extra information must be incorporated in the segmentation approach to producing a more accurate result. Approaches that rely on edges to separate different objects fail due to the



TABLE II. QUALITATIVE AND QUANTITATIVE RESULTS

	8-bit Images				16-bit Images				RGB Images			
	Dice	Spe	Sens	Jacc	Dice	Spec	Sens	Jacc	Dice	Spe	Sens	Jacc
Otsu's	0.33	0.80	0.79	0.20	0.68	0.43	0.24	0.63	0.61	0.52	0.55	0.41
Watershed	0.60	0.34	0.92	0.49	0.77	0.47	0.17	0.11	0.71	0.84	0.92	0.67
KM	0.37	0.32	0.14	0.23	0.37	0.32	0.14	0.23	0.40	0.61	9.14	0.33
GMM	0.37	0.32	0.14	0.23	0.71	0.12	0.31	0.78	0.42	0.67	9.14	0.31
FCM	0.34	0.93	0.98	0.21	0.34	0.93	0.98	0.21	0.49	0.54	0.98	0.30
Gabor	0.36	0.31	0.55	0.2	0.39	0.30	0.21	0.19	0.52	0.39	0.55	0.35
MRF	0.35	0.96	0.88	0.21	0.32	0.63	0.52	0.20	0.46	0.60	0.88	0.23
DFC	0.36	0.31	0.55	0.15	0.31	0.55	0.20	0.71	0.44	0.22	0.71	0.20
Superpixel	0.35	0.96	0.88	0.21	0.26	0.88	0.21	0.86	0.58	0.19	0.86	0.47

TABLE III. PERFORMANCE EVALUATION OF STUDIED METHODS FOR ALL THREE TYPES OF INPUT IMAGES

Approach	Time complexity
Otsus	$O(N + L^2)$
Watershed	$O(K \times N)$
K-Means	$O(K \times N \times T)$
FCM	$O(K \times N \times T)$
GMM	$O(N \times K \times D^3)$
Gabor	$O(M^2 \times N^2)$
MRF	$O(N \times M \times K \times T)$

lack of depth information. This issue comes in when there are several overlapping objects with the same temperature in the scene. Finally, we see that texture analysis often delivers the best performance since they consider the spatial relations between neighboring pixels. In the case of Gabor segmentation, this approach requires empirical determination of several parameters to return better results. It is worth mentioning that the enhanced results produced by these texture-based methods are not without significant increases in computational requirements, algorithmic complexity, and significant barriers to real-time implementation.

#### A. Time Complexity

Table III lists the time complexities for each of the studies algorithms. Where  $N$  is number of pixels in the image,  $L$  is histogram length,  $K$  number of clusters,  $T$  is the time to calculate the distance between two objects,  $D$  is the problem dimension, and  $M$  is the window size. We notice that texture analysis is more complex and require more analysis than thresholding or clustering. It is evident that in order to build a labeling GUI using any of those algorithms, it would need high computing capabilities to make the GUI easy to use and provide results quickly.

### VII. CONCLUSION AND FUTURE WORK

In conclusion, this paper has provided a comprehensive review of unsupervised segmentation techniques for long wave infrared (LWIR) images. Through the evaluation and analysis of various methods, several key findings have emerged. Firstly, it is evident that unsupervised segmentation techniques play a crucial role in extracting meaningful information from LWIR images, despite the challenges posed by noise, low contrast, and temperature variations. The reviewed techniques have shown varying degrees of effectiveness in segmenting LWIR images, with some demonstrating superior performance in specific scenarios.

Moving forward, there are several avenues for future research in this domain. Firstly, further investigation is needed to explore the combination of multiple unsupervised segmentation techniques to enhance the overall segmentation accuracy in LWIR images. Fusion methods that leverage the strengths of different algorithms could potentially yield superior results. Additionally, incorporating domain-specific knowledge and priors, such as thermal physics, object characteristics, and context information, may further improve segmentation accuracy and robustness. Furthermore, the evaluation of unsupervised segmentation techniques on LWIR video sequences warrants attention. Temporal consistency and motion information can be leveraged to improve the accuracy of segmentation results over time. Investigating the use of unsupervised segmentation techniques for real-time applications, such as tracking and object recognition, is another area of interest.

In conclusion, this review has shed light on the current landscape of unsupervised segmentation techniques for LWIR images. While notable progress has been made, there is ample room for further exploration and improvement. By addressing the identified research gaps and leveraging emerging technologies, we can advance the state-of-the-art in LWIR image segmentation, ultimately facilitating more effective and reliable analysis in LWIR applications such as surveillance, target detection, and autonomous systems.

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# The Application of Intelligent Evaluation Method with Deep Learning in Calligraphy Teaching

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**Abstract**—Scientific and effective teaching quality evaluation (QE) is helpful to improve teaching mode and improve teaching quality. At present, calligraphy teaching (CT) QE methods are few in number and have poor evaluation effect. Aiming at these problems, deep learning (DL) is introduced to realize intelligent evaluation of CT quality. First, based on relevant research, the CTQE indicator system is constructed. Secondly, rough set and the principal component analysis (PCA) are used to reduce the dimension of the CTQE index system and extract four common factors. Then, the corresponding index data is input into the BP neural network (BPNN) model optimized by the improved sparrow search algorithm for fitting. Finally, combining the above contents, the improved sparrow search algorithm (ISSA) BPNN model is built to realize the intelligent evaluation of CT quality. The experimental results show that the loss value of ISSA-BPNN model is 0.21, and the fitting degree of CT data is 0.953. The evaluation Accuracy is 95%, Precision is 0.945, Recall is 0.923, F1 is 0.942, and AUC is 0.967. These values are superior to the most advanced teaching QE model available. The SSA-BPNNCTQE model proposed in the study has excellent performance in CTQE. This is of positive significance to the improvement of teaching quality and students' calligraphy level.

**Keywords**—Deep learning; calligraphy teaching; BPNN; intelligent evaluation; sparrow search algorithm

## I. INTRODUCTION

In recent years, China has paid more and more attention to the inheritance and development of traditional culture. Chinese calligraphy has been handed down for a long time and is an important part of Chinese traditional culture [1]. In addition, calligraphy is also an art form that can fully display the meaning and beauty of Chinese characters, and can give people a beautiful feeling. In China, calligraphy is also known as wordless poetry and pictureless painting. It is an important way to cultivate sentiment, cultivate character and enhance aesthetic taste. Therefore, CT has received extensive attention in China, and relevant courses have been offered at different stages [2,3]. In this context, CTQE has also become a hot research topic. It provides theoretical support and implementation approaches for the improvement of CT mode and the improvement of students' calligraphy performance. At present, the main evaluation method of CTQE is based on expert opinions and student feedback, which has problems such as extremely low efficiency and objective evaluation results. Therefore, the problem of research is to find suitable CTQE methods to improve the efficiency and objectivity of CTQE. The reason for these problems is not only the ideal selection method, but also the unique characteristics of calligraphy Chinese characters, such as a large number of

Chinese characters and similar characters. The large number of Chinese characters makes the traditional CTQE method very effective, but due to the development of technology, the CTQE method has not been improved in a timely manner. Scientific and effective CTQE can promote the improvement of calligraphy teaching mode and improve the quality of calligraphy teaching. Therefore, research needs to design effective CTQE methods. DL is one of the important technologies to realize industry intelligence and automation, and has achieved remarkable results in data mining, machine learning, artificial intelligence and other fields [4,5]. Therefore, DL is introduced to realize the intelligent evaluation of CT quality, so as to help calligraphy teachers understand the defects in the teaching process more intuitively. Thus, the teaching quality and students' calligraphy level have been improved, which has positive significance for the inheritance and promotion of Chinese calligraphy culture.

The key components of the study include the construction of a CTQE indicator system, PCA based common factor extraction, improved BPNN based CTQE model, ISSA-BPNNCT quality intelligent evaluation model, and research results. The main research results are the comparison results between the ISSA-BPNN model and other models under different model evaluation values. There are two main innovations in the research. The first point is to use the improved sparrow search algorithm (ISSA) to optimize the BP neural network (BPNN), so as to build ISSA-BPNN and improve the performance of the model. The second point is to use ISSA-BPNN to realize intelligent evaluation of CT quality to improve the efficiency and objectivity of CT evaluation. Scientific and effective CTQE can help improve the quality of calligraphy teaching and also improve the efficiency of students' learning calligraphy. In order to find a suitable CTQE method, an improved sparrow search algorithm was introduced based on the BPNN algorithm.

## II. RELATED WORKS

China's traditional culture has a long history of inheritance and profound heritage, and is loved and yearned for by people all over the world. Calligraphy is an important part of China's traditional culture, which contains rich artistic aesthetic value. CT is an important course to carry forward our traditional culture, which can improve students' aesthetic taste, cultivate students' sentiment, and cultivate students' artistic aesthetics. Therefore, it has attracted the attention of many scholars. Fang et al. conducted a comprehensive discussion and analysis on the curriculum of calligraphy in Chinese universities. And they have studied the improvement and perfection of calligraphy curriculum, providing theoretical support for the

reform of calligraphy curriculum in China [6]. Under the background of journalism, Liu and others conducted a questionnaire survey on students and teachers of calligraphy in colleges and universities. Thus, the effect of CT reform is analyzed, and the reform strategy is given according to the results of the questionnaire [7]. Huda et al. analyzed the effect of students' calligraphy learning based on Bloom's revised classification to improve CT quality [8]. Sun takes Anhui University of Finance and Economics as an example to explore the auxiliary role of calligraphy learning in the training of environmental design talents. It provides ideas for the development of environmental design industry [9]. Liu discussed the frequency of calligraphic elements in classic films released in China in recent years, and the effects in films. It provides ideas for the inheritance and promotion of Chinese calligraphy aesthetics [10]. Huda S proposed a calligraphy learning assistant system based on projection mapping to improve students' calligraphy learning efficiency and improve their calligraphy level [11]. Kobayashi et al. based on DL, combined with image and human motion, then proposed a calligraphy generation method to realize automatic calligraphy writing [12]. Based on aesthetic psychology, Jin and others combined calligraphy and painting elements with cultural and creative products. It has achieved innovation in the design of cultural and creative products and contributed to the inheritance of calligraphy and painting culture [13].

Xi et al. evaluated the sorting capacity of urban domestic waste in China in combination with analytic hierarchy process (AHP) and BPNN to help cities improve their waste treatment level [14]. Liao et al. used genetic algorithm (GA) to optimize BPNN. Thus, the viscosity model of aluminum alloy is established, which provides a new method for the production and optimization of aluminum alloy [15]. Wen et al. combined random forest (RF) and particle swarm optimization (PSO) to optimize BPNN. Based on the optimized BPNN, the carbon dioxide emissions of China's commercial sector are predicted. It provides data support for China's environmental protection [16]. Chang et al. proposed a back-propagation neural network optimized by thought evolution algorithm to realize the prediction of the penetration quality of asymmetric fillet weld [17]. Li et al. used Levenberg-Marquardt algorithm to optimize BP neural network, and thus proposed a new approximate response model of quadrant detector. The model has good application prospects in beam position measurement [18]. Song et al. conducted mathematical modeling of solid oxide fuel cell (SOFC) through BPNN to evaluate and predict the performance of SOFC at different furnace temperatures. The error of the prediction method is less than 5%, and it is better than the traditional method [19]. In order to make up for the defects of BPNN, Han et al. selected Genetic Algorithm (GA) to obtain network parameters, optimize BPNN, and evaluate the effect of UAV shape product design scheme based on optimized BPNN. The relative error of this evaluation method is less than 4%, and it can evaluate the design scheme quickly and scientifically [20]. Li and others believe that the current motion management system has many defects, such as low accuracy of output results and poor efficiency. To solve these problems, they proposed an optimization method based on BPNN to optimize the motion management system. The effect of this optimization method is ideal and can

significantly improve the performance of the system [21].

In summary, CT accounts for a significant proportion in China's education system, while BPNN is also relatively mature and widely used in various fields. However, there is currently limited research on the combination of BPNN and CT, and the current CTQE method has significant shortcomings. Therefore, this study proposes an improved BPNN and utilizes it to achieve intelligent evaluation of CT, improving the accuracy and objectivity of CTQE. By introducing an improved BPNN into CT, the research has to some extent enriched the research results in this field and also made up for the shortcomings of weak objectivity in current CTQE methods. Therefore, it can provide data and theoretical support for CT reform.

### III. DL-BASED CTQE METHOD

#### A. Construction and Reduction of CTQE System

In CT, teaching QE can help teachers to more intuitively understand the problems in the teaching process, so as to urge teachers to take measures to improve the teaching mode and improve the teaching quality. Therefore, it is very necessary to evaluate the quality of CT. To conduct CTQE, first of all, we should select indicators and build a CTQE indicator system. Combined with the previous research results and the current situation of CT in China, the study evaluated the teaching quality from five dimensions. It includes CT content, teaching methods, teaching environment, teaching process and teaching effect. The research and construction of the CTQE indicator system is shown in Table I.

TABLE I. EVALUATION INDEX SYSTEM OF CALLIGRAPHY TEACHING QUALITY

First-Level Indicators	Code	Secondary Indicators	Code
Content of courses	X <sub>1</sub>	Professors' etymology	Y <sub>1</sub>
		Professor's font	Y <sub>2</sub>
		Calligraphy knowledge	Y <sub>3</sub>
		Calligraphy skills	Y <sub>4</sub>
		Cultural knowledge	Y <sub>5</sub>
		Related activities	Y <sub>6</sub>
Teaching method	X <sub>2</sub>	Teaching language	Y <sub>7</sub>
		Auxiliary teaching	Y <sub>8</sub>
Teaching environment	X <sub>3</sub>	Classroom layout	Y <sub>9</sub>
		Background music	Y <sub>10</sub>
Teaching process	X <sub>4</sub>	Classroom power	Y <sub>11</sub>
		Teacher role	Y <sub>12</sub>
		Student role	Y <sub>13</sub>
		Control of learning process	Y <sub>14</sub>
		Teacher's calligraphy ability	Y <sub>15</sub>
Teaching effectiveness	X <sub>5</sub>	Learner satisfaction	Y <sub>16</sub>
		Learner self-assessment	Y <sub>17</sub>
		Other comments of learners	Y <sub>18</sub>

CT content should be mainly from two aspects, namely, the teaching of calligraphy knowledge and calligraphy skills. To this end, in this dimension, the study includes the teaching of character sources, fonts, calligraphy knowledge, calligraphy skills, cultural knowledge, and related activities. In the dimension of teaching methods, the study includes two

indicators that can evaluate teaching innovation: teaching language and auxiliary teaching methods. In the dimension of teaching environment, the study selected two indicators: classroom layout and classroom background music. In the dimension of teaching process, the study selected five indicators. They include teacher's classroom power, whether the teacher's role is successfully played, whether the student's role is successfully played, whether the teacher has sufficient control in the process of student learning, and the teacher's calligraphy level and ability. In the dimension of teaching effect, the study selected three dimensions: student satisfaction, student self-evaluation score and others' score on students. The weight data corresponding to each index in Table I is input into the BPNN model for fitting learning. Then the intelligent evaluation of CT quality can be realized according to the predicted output results of the BPNN model. In Table I, KMO and Bartlett test are used to test various indicators, so as to analyze the correlation between indicators. Then the effectiveness of the CTQE indicator system built in the study is verified. KMO and Bartlett test results are shown in Table II.

TABLE II. KMO AND BARTLETT TEST

Project		P
KMO inspection		0.638
Bartlett sphericity test	Approximate chi-square	7604.358
	DF	0.74
	Significance	0.000

In Table II, KMP test and Bartlett test of all indicators have passed, and P value is less than 0.05. It means the indicators of the CTQE indicator system built in the study have significant correlation. The validity of the CTQE index system built in the study is further verified. However, KMO test is only 0.638, which indicates that in the CTQE indicator system shown in Table I, some indicators have weak correlation. But, the CTQE indicator system shown in Table I contains a large number of indicators, some of which cannot effectively reflect the CT quality. And the calculation amount in the subsequent calculation will be increased. Therefore, the reduction of rough sets is studied. Rough set has a good effect in dealing with uncertain data, so it is often used to deal with uncertain problems. The attribute reduction function of rough set is used to deal with the CTQE indicator system shown in Table I, so as to eliminate the invalid or weak correlation indicators. The index system was simplified to improve the accuracy of teaching quality evaluation. After reduction, a simplified CTQE indicator system is obtained, as shown in Table III.

In Table III, after rough set reduction, eight redundant indicators are deleted, so that the number of indicators included in the CTQE indicator system is reduced from 18 to 10. This method can effectively improve the efficiency and accuracy of CT quality evaluation.

**B. Common Factor Extraction based on PCA**

After using rough set to reduce the CTQE index system, a simplified CTQE index system containing 10 evaluation indicators is obtained. It reduces the amount of calculation for

subsequent teaching quality evaluation and improves the efficiency and accuracy of teaching quality evaluation. However, the simplified CTQE indicator system still contains a large number of indicators. If these indicator data are input into the BPNN model, 10 input layer nodes need to be constructed. This will cause the network structure of the model to be too complex, and the prediction performance of the model will also be significantly reduced. Therefore, the principal component analysis (PCA) is used to extract common factors to further reduce the dimension of indicators. First of all, the deviation standardization method is used to standardize all indicators. It can avoid the performance degradation of the model due to the inconsistency of the unit and magnitude between different indicators. The standardization process is shown in Equation (1).

$$X' = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \tag{1}$$

$X'$  is the index data value obtained after standardization;  $x_{ij}$  is the data value corresponding to the  $j$  index in the  $i$  calligraphy lesson;  $x_{\max}, x_{\min}$  represent the maximum and minimum values of  $x_{ij}$  in Equation (1). The maximum variance method is used for factor analysis of the indicator system to obtain the factor contribution rate in Table IV.

In Table IV, four common factors are extracted, and the cumulative variance of these four common factors exceeds 84%. This data can show that the four common factors extracted can effectively and objectively reflect the teaching situation of calligraphy class, so as to evaluate the teaching quality of calligraphy class. The factors in Table IV are descriptive statistics, and then the factor component matrix is obtained to analyze the correlation between each index and each common factor, so as to find the index of common factor mapping. The factor component matrix is shown in Table V.

From Table V, corresponding indicators that can reflect four common factors are extracted, namely  $Y_4, Y_8, Y_{15}$  and  $Y_{18}$ . This shows the four indicators of calligraphy skill teaching, auxiliary teaching methods, teachers' calligraphy level and others' evaluation of students. It can effectively and comprehensively reflect the effect of CT. Therefore, these four indicators are selected to evaluate CT quality.

TABLE III. SIMPLIFIED EVALUATION INDEX SYSTEM OF CALLIGRAPHY TEACHING QUALITY

First-Level Indicators	Code	Secondary Indicators	Code
Content of courses	$X_1$	Calligraphy knowledge	$Y_3$
		Calligraphy skills	$Y_4$
		Cultural knowledge	$Y_5$
Teaching method	$X_2$	Auxiliary teaching	$Y_8$
Teaching process	$X_4$	Classroom power	$Y_{11}$
		Teacher role	$Y_{12}$
		Student role	$Y_{13}$
		Teacher's calligraphy ability	$Y_{15}$
Teaching effectiveness	$X_5$	Learner self-assessment	$Y_{17}$
		Other comments of learners	$Y_{18}$

TABLE IV. FACTOR CONTRIBUTION RATE

Composition	Initial Characteristics			Extract The Sum of the Squares of the Load		
	Total	Percent Variance/%	Cumulative Contribution Rate/%	Total	Percent Variance/%	Cumulative Contribution Rate/%
1	8.785	37.140	37.140	8.785	37.140	37.140
2	4.833	22.054	59.194	4.833	22.054	59.194
3	3.575	15.438	74.432	3.575	15.438	74.432
4	2.038	10.053	84.685	2.038	10.053	84.685
5	.932	3.165	87.850	.932	3.165	87.850
6	.910	3.054	90.904	.910	3.054	90.904
7	.852	2.843	93.747	.852	2.843	93.747
8	.844	2.782	96.529	.844	2.782	96.529
9	.752	2.134	98.663	.752	2.134	98.663
10	.332	1.337	100.000	.332	1.337	100.000

TABLE V. FACTOR COMPONENT MATRIX

Indicator Code	1	2	3	4
Y <sub>3</sub>	0.083	0.032	0.167	0.073
Y <sub>4</sub>	0.854	0.072	0.302	0.147
Y <sub>5</sub>	0.157	0.135	0.134	0.025
Y <sub>8</sub>	0.086	0.758	0.135	0.308
Y <sub>11</sub>	0.149	0.062	0.226	0.094
Y <sub>12</sub>	0.203	0.234	0.309	0.413
Y <sub>13</sub>	0.342	0.130	0.184	0.078
Y <sub>15</sub>	0.325	0.083	0.882	0.024
Y <sub>17</sub>	0.053	0.344	0.006	0.056
Y <sub>18</sub>	0.144	0.098	0.178	0.769

C. CTQE Model based on Improved BPNN

Based on the CTQE index system constructed by the research, combined with AHP and expert evaluation method, the teaching quality of calligraphy can be analyzed and evaluated. However, this CT quality evaluation method is easily affected by subjective factors, so it lacks objectivity, scientificity and effectiveness. To solve this problem, DL is introduced to realize the intelligent evaluation of CT quality, so as to eliminate the negative impact of subjective factors on the evaluation results of teaching quality. The realization way is to determine the weight of Y<sub>4</sub>, Y<sub>8</sub>, Y<sub>15</sub> and Y<sub>18</sub> by using expert scoring method combined with AHP and fuzzy comprehensive evaluation. In the experiment, the data related to these four indicators are input into the BPNN model for fitting and learning, and the prediction score is obtained. CT quality was evaluated according to the predicted score. However, the traditional BPNN has some defects, and its performance is greatly affected by the initial parameter value. Therefore, SSA is studied to obtain the optimal parameters of BPNN model, so as to improve the performance of BPNN model. The algorithm of SSA is simple to implement and has good robustness and optimization effect, but it also has the defects of poor convergence performance and weak global optimization ability. To solve this problem, research and propose strategies to optimize it. First, the sparrow population in the algorithm is initialized using the idea of reverse learning. A sparrow population  $X_{i,j}$  is randomly generated, and the inverse solution  $X_{i,j}^*$  of  $X_{i,j}$  is calculated, as shown in Equation (2).

$$X_{i,j}^* = ub_{i,j} + lb_{i,j} - X_{i,j} \quad (2)$$

$ub_{i,j}, lb_{i,j}$  are the upper and lower limit of the  $j$  dimension of individual  $i$  in the initial sparrow population in Equation (1). The fitness value of the individual in the reverse population is calculated. If there is Equation (2), the individual is regarded as the initial population.

$$fit(X_{i,j}^*) < fit(X_{i,j}) \quad (3)$$

The strategy of Equation (1) and (2) can improve the population diversity of SSA, thus optimizing the global optimization ability of SSA. In SSA, the location update of the individual discoverer in the next iteration will refer to its current location information. This characteristic makes the convergence performance and search performance of SSA not ideal at the beginning of the iteration. The global search ability of SSA is poor at the end of the iteration, and it is easy to fall into local extremum. In view of this defect, a nonlinear weighting factor  $\lambda$  is proposed to improve the location update strategy of the individual discoverer in SSA, as shown in Equation (4).

$$\lambda = (t / T_{max})^2 \quad (4)$$

$t$  is the current iteration number;  $T_{max}$  is the maximum number of iterations in Equation (4). The strategy of Equation (5) is used to update the discoverer position.

$$X_{i,j}^{t+1} = \begin{cases} \lambda X_{i,j}^t & \text{if } R_2 < ST \\ X_{i,j}^t + Q & \text{if } R_2 \geq ST \end{cases} \quad (5)$$

$X_{i,j}^t$  is the position of the  $j$  dimension of individual  $i$  in the current iteration in Equation (5);  $Q$  is a normal distribution random number;  $R_2, ST$  are the early warning value and the early warning threshold. For the vigilance, the strategy of Equation (6) is used to update.

$$X_{i,j}^{t+1} = \begin{cases} X_{best}^t + \beta |X_{i,j}^t - X_{best}^t| & \text{if } f_i > f_g \\ X_{i,j}^t + \beta (X_{worst}^t - X_{best}^t) & \text{if } f_i = f_g \end{cases} \quad (6)$$

In Equation (6),  $X_{worst}^t, X_{best}^t$  are the worst individual and the best individual in the current iteration;  $\beta$  is a normal



distribution random number;  $f_i$  is the fitness value of individual  $i$ ;  $f_g$  is the fitness value of the worst individual in all iterations. Using Equation (4), (5) and (6) can effectively reduce the dependence of individual location updates on their current location information, thus improving the convergence and optimization performance of SSA. ISSA is used to optimize the parameters of BPNN, and the ISSA-BPNN model is constructed. Based on the ISSA-BPNN model, the intelligent evaluation of CT quality is realized. The ISSA-BPNNCT quality intelligent evaluation model is shown in Fig. 1.

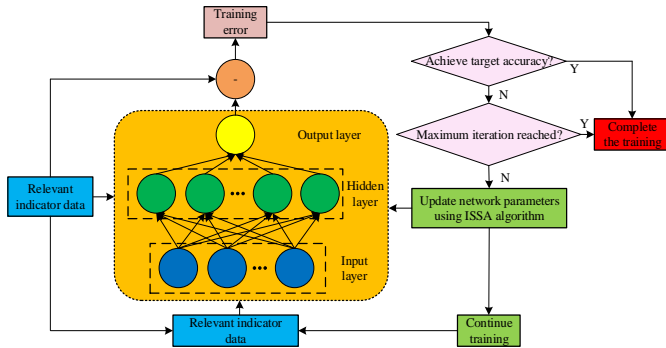


Fig. 1. ISSA-BPNN intelligent evaluation model of calligraphy teaching quality.

#### IV. ISSA-BPNNCT QUALITY INTELLIGENT EVALUATION MODEL

Calligraphy is an important part of China's traditional culture, which contains rich artistic aesthetic value. CT is to promote our traditional culture. It is an important course that can improve students' aesthetic taste, cultivate students' sentiment, and cultivate students' artistic aesthetics, so it has attracted the attention of many scholars. To realize the

intelligent and automatic evaluation of CT quality, the intelligent evaluation model of CT quality is built based on ISSA-BPNN. Relevant data were collected in the teaching system of calligraphy major in a university, and the experimental data set was constructed to test the performance of ISSA-BPNNCT quality intelligent evaluation model. 70% of the data in the experimental data set is randomly divided to train the model, which is recorded as the training sample set, and the other 30% of the data is used to test the model. At present, the common intelligent evaluation models of teaching quality include BPNN (GA-BPNN) model optimized by GA and radial basis function neural network (PSO-RBFNN) model optimized by PSO. The ISSA-BPNN model, GA-BPNN model and PSO-RBFNN model are trained by using the training sample set. During the training, the changes of the loss value and error value of the above models are shown in Fig. 2. In Fig. 2, when the minimum error and the minimum loss value are reached, the ISSA-BPNN model only needs 71 iterations, 42 and 71 times less than GA-BPNN model and PSO-RBFNN model, respectively. In Fig. 2(b), the loss value of ISSA-BPNN model is 0.21, which is 0.23 and 0.30 lower than GA-BPNN model and PSO-RBFNN model, respectively. In the above results, it is proved that the convergence of ISSA-BPNN model is better than GA-BPNN model and PSO-RBFNN model.

In the process of fitting the model to CT data, the fitting degree of several models and CT data is calculated and recorded in the experiment, as shown in Fig. 3. In Fig. 3(a), the fitting degree of ISSA-BPNN model reaches 0.953. In Fig. 3(b), the fitting degree of GA-BPNN model reaches 0.933, 0.020 lower than ISSA-BPNN model. In Fig. 3(c), the fitting degree of PSO-RBFNN model reaches 0.902, 0.051 lower than ISSA-BPNN model. The ISSA-BPNN model has a higher fitting degree with the data and better performance in CTQE.

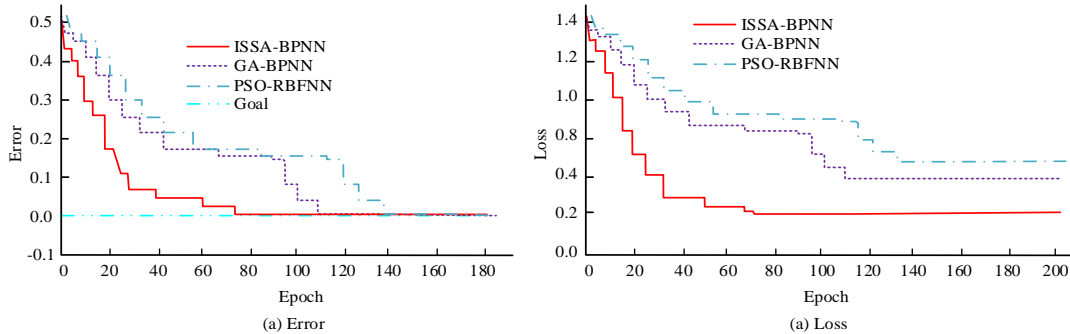


Fig. 2. Change of loss value and error value of the model.

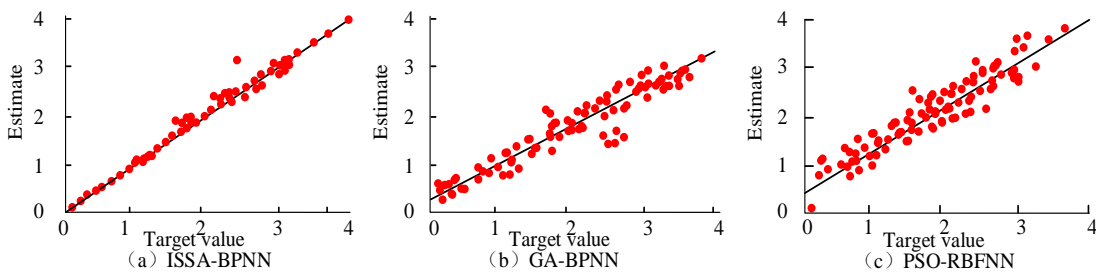


Fig. 3. Fitting degree of model and calligraphy teaching data.

20 samples were used to analyze the accuracy of ISSA-BPN model, GA-BPNN model and PSO-RBFNN model in CTQE. In the study, according to the evaluation score, the CT quality was divided into four grades, namely 4: excellent; 3: good; 2: general; 1: poor. Among the 20 samples, the difference between the predicted output of ISSA-BPN model, GA-BPNN model and PSO-RBFNN model and the actual sample value is shown in Fig. 4. In Fig. 4(a), in the evaluation of 20 samples, the ISSA-BPN model only evaluated the value of the sample with the number of 18, which was inconsistent with the actual value. However, the evaluation value is quite close to the actual value, and the evaluation accuracy rate reaches 95%. In Fig. 4(b), in the evaluation of 20 samples by GA-BPNN model, the evaluation values of samples numbered 12 and 17 are inconsistent with the actual values. Moreover, the evaluation value of the two samples is quite close to the actual value grade, and the evaluation accuracy rate is 90%, which is 5% lower than the ISSA-BPN model. In Fig. 4(c), PSO-RBFNN model evaluated 20 samples, and the evaluation values of samples numbered 4, 7 and 18 were inconsistent with the actual values. In the evaluation of the sample numbered 4, the evaluation value differs greatly from the actual value. In the evaluation of samples numbered 7 and 18, the difference between the evaluation value and the actual

value is small, and the evaluation accuracy is 85%, which is 10% lower than the ISSA-BPN model. The above results can show that the ISSA-BPN model is more accurate in the evaluation of CT quality, and even if there is an evaluation error, the evaluation error is also within the acceptable range.

The performance of ISSA-BPN, GA-BPNN and PSO-RBFNN are tested by using Precision and Recall indicators. The Precision and Recall of SSA-BPN, GA-BPNN and PSO-RBFNN are shown in Fig. 5. In Fig. 5(a), the precision value of ISSA-BPN is 0.945, 0.142 higher than GA-BPNN and 0.208 higher than PSO-RBFNN. In Fig. 5(b), the Recall value of ISSA-BPN is 0.923, 0.213 higher than GA-BPNN and 0.230 higher than PSO-RBFNN.

Fig. 6 shows the F1 value changes of ISSA-BPN, GA-BPNN and PSO-RBFNN during the iteration process. The F1 value of ISSA-BPN reaches 0.942. The F1 value of GA-BPNN is 0.908, 0.034 lower than ISSA-BPN. F1 value of PSO-RBFNN is 0.896, 0.048 lower than ISSA-BPN. The above data can show that the performance of ISSA-BPN proposed in the study is better than GA-BPNN and PSO-RBFNN in CTQE.

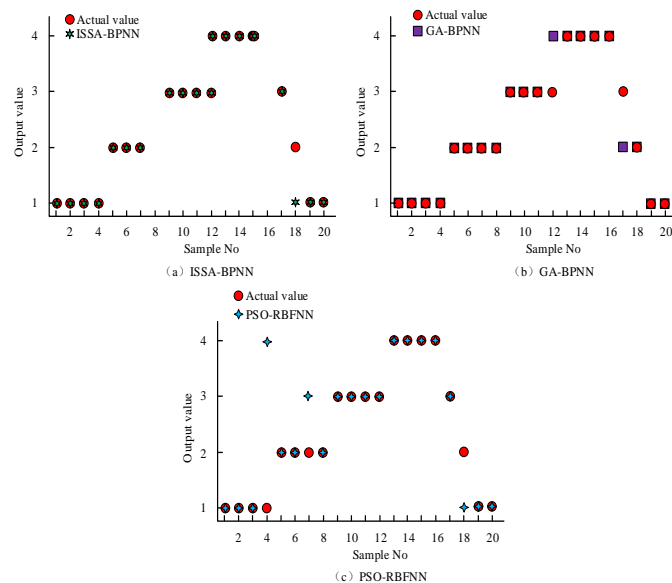


Fig. 4. Difference between model output forecast result and sample actual value.

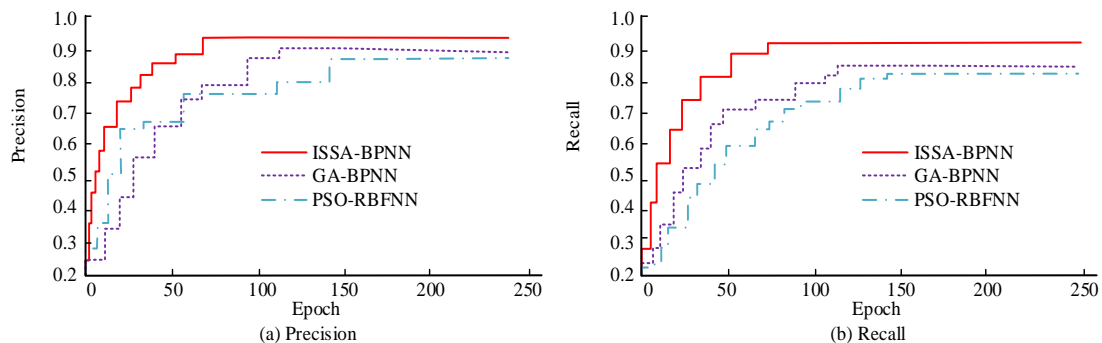


Fig. 5. Precision and recall of the model.

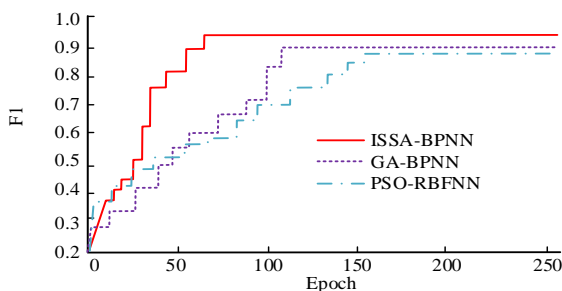


Fig. 6. F1 of the model.

The performance of ISSA-BPNN, GA-BPNN and PSO-RBFNN is evaluated by ROC curve. The AUC values of each are shown in Fig. 7. The AUC value of ISSA-BPNN is 0.967, 0.014 and 0.025 higher than GA-BPNN and PSO-RBFNN respectively. To sum up, the ISSA-BPNNCTQE proposed in the study has good performance and can achieve intelligent evaluation of CT quality with high efficiency and accuracy, thus providing a basis for CT improvement. It has positive significance for the improvement of students' calligraphy level and the inheritance and development of Chinese calligraphy culture.

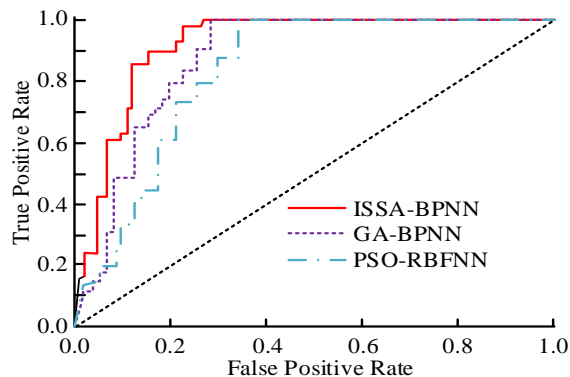


Fig. 7. AUC value of the model.

## V. DISCUSSION

Calligraphy teaching plays an important role in the development of traditional Chinese culture. In order to overcome the problems of low efficiency and non-objectivity in traditional CTQE methods, an optimized BPNN model was introduced based on the self-developed CTQE evaluation system, aiming to improve the quality of calligraphy teaching and learning efficiency. In order to verify the performance of the optimized BPNN model, the Rate of convergence, fitness, accuracy, recall, F1 value and AUG value of the model are compared and analyzed in the result analysis part. The application of research methods involves rough sets, principal component analysis, sparrow search algorithm, and BPNN algorithm. Research can be applied not only to the quality evaluation of calligraphy teaching, but also to the quality evaluation of teaching in other disciplines. The method chosen by the research institute can greatly improve the efficiency of evaluating the quality of calligraphy teaching and enhance the objectivity of the evaluation results. The author believes that the development of algorithm technology has brought convenience to people's daily work, and people should

effectively utilize it and continuously empower traditional work.

## VI. CONCLUSIONS

At present, the main method of CTQE is based on expert opinions and student feedback, which is extremely inefficient and the evaluation results are often not objective. To solve this problem, DL is introduced and an intelligent evaluation of CT quality based on ISSA-BPNN is constructed. The performance of ISSA-BPNN is tested using the relevant data of calligraphy major in a university. ISSA-BPNN only needs 71 iterations to achieve the best performance, 42 and 71 times less than GA-BPNN and PSO-RBFNN respectively. The loss value of ISSA-BPNN is 0.21, which is 0.23 and 0.30 lower than GA-BPNN and PSO-RBFNN respectively. The fitting degree of ISSA-BPNN reached 0.953, 0.020 higher than GA-BPNN and 0.051 higher than PSO-RBFNN. Its evaluation accuracy is 95%, 5% higher than GA-BPNN and 10% higher than PSO-RBFNN. Its Precision value is 0.945, 0.142 higher than GA-BPNN and 0.208 higher than PSO-RBFNN. The Recall value of ISSA-BPNN is 0.923, 0.213 higher than GA-BPNN and 0.230 higher than PSO-RBFNN. Its F1 value reaches 0.942, 0.034 higher than GA-BPNN and 0.048 higher than PSO-RBFNN. Its AUC value is 0.967, 0.014 and 0.025 higher than GA-BPNN and PSO-RBFNN respectively. To sum up, the ISSA-BPNNCTQE proposed in the study has good performance and can achieve intelligent evaluation of CT quality with high efficiency and accuracy, thus providing a basis for CT improvement. It has positive significance for the improvement of students' calligraphy level and the inheritance and development of Chinese calligraphy culture. However, there are also certain shortcomings in the research. During the experimental process, this study only used relevant calligraphy historical data from one university. This may lead to some randomness in the experimental results. Therefore, it is necessary to expand the research scope and include more universities in subsequent research to eliminate this randomness.

## ACKNOWLEDGMENT

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# Deep Learning-based Mobile Robot Target Object Localization and Pose Estimation Research

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**Abstract**—Two key technologies in robotic object grasping are target object localization and pose estimation (PE), respectively, and the addition of a robotic vision system can dramatically enhance the flexibility and accuracy of robotic object grasping. The study optimizes the classical convolutional structure in the target detection network considering the limited computing power and memory resources of the embedded platform, and replaces the original anchor frame mechanism using an adaptive anchor frame mechanism in combination with the fused depth map. For evaluating the target's pose, the smooth plane of its surface is identified using the semantic segmentation network, and the target's pose information is obtained by solving the normal vector of the plane, so that the robotic arm can absorb the object surface along the direction of the plane normal vector to achieve the target's grasping. The adaptive anchor frame can maintain an average accuracy of 85.75% even when the number of anchor frames is increased, which proves its anti-interference ability to the over fitting problem. The detection accuracy of the target localization algorithm is 98.8%; the accuracy of the PE algorithm is 74.32%; the operation speed could be 25 frames/s. It could satisfy the requirements of real-time physical grasping. In view of the vision algorithm in the study, physical grasping experiments were carried on. Then the success rate of object grasping in the experiments was above 75%, which effectively verified the practicability.

**Keywords**—Mobile robot; target object localization; pose estimation; YOLOv2 network; FCN semantic segmentation network

## I. INTRODUCTION

There are many high-intensity and dangerous delicate operations in the actual industrial production process, and with the significant increase of labor costs in recent years, the industrial production environment requires a lot of human capital to perform these operations. For enhancing the industrial productivity and control labor costs, a lot of industrial robots are introduced in industrial environments to perform daily industrial operations [1]. The ability of robots to perform a range of complex tasks in industrial production quickly and efficiently, and with lower input costs compared to manual labor, has made them the primary choice for real-world industrial operations [2]. However, mobile robots are still very difficult to fully automate in a real-world industrial production environment, and workers are often needed to assist in the process, resulting in limited efficiency gains for the entire industrial process [3-4]. To achieve fully automated robotic operations, vision systems need to be introduced on mobile robots equipped with robotic arms [5]. The introduction of

vision systems in robotics can on the one hand increase the reliability of robotic arms working in real complex industrial environments and on the other hand reduce the need for manual assistance in industrial operations [6-7]. Although a large number of mobile robots have been introduced into actual industrial production environments, they cannot fully automate actual industrial operations. Therefore, a mobile robot equipped with a robotic arm with visual feedback is needed to carry out transportation, sorting and other work in the industrial environment. To achieve this process, mobile robots first need to detect the target, locate the target position, estimate the object's posture, and determine the grasping point. The research mainly focuses on the vision algorithm of the sucking robot arm when grasping objects. The problems to be solved are target location and pose estimation. Research on combining depth information and image color information for pose estimation, and propose an adaptive anchor frame mechanism based on the characteristics of depth images. Then, the semantic segmentation network and principal component analysis are used to determine the surface normal vector of the object, in order to estimate the target pose. The purpose of the research is to make the Robotic arm adjust the pose direction of the robot arm and grasp the object more efficiently and accurately by determining the spatial position and pose of the target object.

## II. RELATED WORK

Target detection is the key and prerequisite for automated object grasping by robotic arms in industrial production environments, and is therefore a research focus in machine vision. Dai Y et al. present a discriminative network for infrared small target detection to address the problem of few features inherent in purely data-driven methods, which fully utilizes labeled data and domain knowledge, and validates its performance on the open SIRST dataset, verifying that the network has some enhancement performance [8]. Scholars Szemenyei M and Estivill-Castro V present two new neural network results for the target detection problem of rescue robots in soccer tournaments, both structures use environmental attributes for enhancing the semantic segmentation and target detection, and use synthetic transfer learning to complete the learning in a small number of manually labeled images, and finally validate the models in experiments low cost and advanced [9]. Three aspects of vision-based robot grasping were investigated by Du et al. A review of traditional methods based on RGB-D image input and new methods of deep learning (DL) was mainly conducted



to provide theoretical help for the challenges and solutions of robot grasping [10]. Ravindran et al. addressed the multi-target detection and multi-target tracking in vehicle driving and proposed the solution of combining sensing modalities with Deep Neural Network (DNN), which includes three sensors and fusion of sensor data with DNN, was proposed for multi-target detection and multi-target tracking problem in vehicle driving [11]. Afif et al. proposed a detection framework for specific indoor category, which is based on "RetinaNet" built and evaluated using ResNet, DenseNet and VGGNet, achieving up to 84.61% detection accuracy in the experiment [12].

After obtaining the target's position in the camera, in order to use the robotic arm to grasp the object, it is also necessary to obtain the object's pose information. Vision-based PE can be divided into two categories: learning-based PE and model-based PE. Wu et al. used linear complementary filters to deal with and depersonalize the multi-sensor PE problem in a device, specifically by obtaining a quadratic observation model through a gradient descent algorithm, and then building an additive measurement model based on the derived results, achieving a reduction in space without loss of estimation accuracy consumption and computational burden without loss of estimation accuracy [13]. Scholars Al-Sharman et al. train DNNs based on DL techniques for identifying related measurement models and filter them out, and use loss techniques to reduce computational sophistication [14]. Scholars Billings G and Johnson-Roberson M proposed SilhoNet, a new way for predicting 6D object pose in monocular camera data, which is to predict the intermediate contours of the objects with associated occlusion masks and 3D translation vectors, and then regress 3D orientation from the contours, obtaining better experimental performance than two networks Estimation performance [15]. Wang et al. presented a DL-based grasping pose estimation method for a SCARA loading and unloading robot, which fuses point clouds with category numbers into a point category vector and uses multi-point mesh networks for evaluating the robot's grasping pose, getting success rates of 98.89%, 98.89%, and 94.44% on three homemade sub-datasets [16]. Liu et al. proposed a grasping posture determination method related to shape analysis for target object shape analysis in robotic grasping, which reduces complicated objects to basic shapes and then simplifies the grasping of objects based on force closure [17].

Comprehensive domestic and international research on mobile robot target detection and PE reveals that most of the detection algorithms are related to DL, which is computationally intensive, while the learning-based PE

methods also rely heavily on the diversity of training data sets, which requires high data collection and calibration. Therefore, the study reduces the computational effort of target detection in the embedded platform by optimizing the original convolution process, and then performs PE by the Fully Convolution Network (FCN) semantic segmentation and (Principal Component Analysis (PCA) algorithm, aiming to provide a more concise and practical mobile robot vision algorithm.

### III. TARGET OBJECT LOCALIZATION ALGORITHM AND POSE ESTIMATION ALGORITHM FOR MOBILE ROBOT

#### A. Target Localization Algorithm and Optimization Based on YOLOv2 Network

Based on the progress of computer technology and artificial intelligence technology, the robotics industry has also developed rapidly, and robots have been applied to more fields, especially in tasks with harsh working conditions and strong repeatability. Using robots to perform these tasks can liberate workers from harsh working environments and also improve work efficiency. In many robot work scenarios, the most common action performed by robots is grasping. Robots perceive the surrounding environment through sensors and then perform grasping operations. When a mobile robot performs grasping of a target object, it must obtain the correct object position and pose to ensure that the robot arm accurately grasps the target from a suitable position and with the correct grasping pose. That is, there are two important problems to be solved in the whole grasping process: localization of the target object and estimation of the spatial pose of the target. The study uses computer vision algorithms to solve the problems faced by mobile robots performing industrial production operations, and the specific process is shown in Fig. 1.

Neural networks have powerful feature extraction capabilities, and with a sufficient number of training datasets with labels, the gradient back-propagation algorithm can be used to renew the weights of the neural network to achieve the coordinate position detection of different target objects. The YOLOv2 network is in view of the Darknet network. It has a powerful feature extraction capability and uses the anchor frame mechanism instead of the direct regression of the target frame coordinates in YOLOv1. However, although the YOLOv2 network has a relatively small model structure and fast localization detection speed, it is still difficult to be arranged in related platforms with very limited resources, so the network structure needs to be further optimized for decreasing the model's size. Fig. 2 indicates the structure of the convolutional layer.

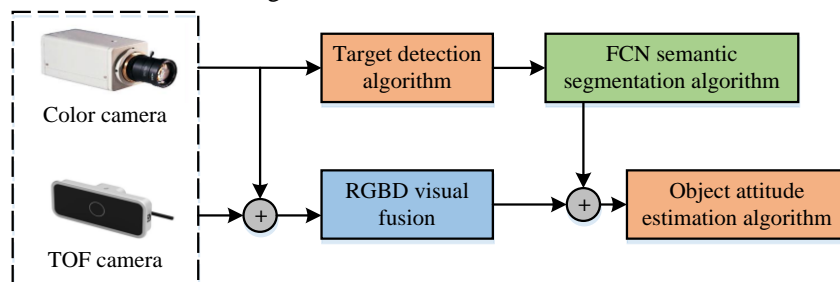


Fig. 1. Computer vision algorithm flowchart.



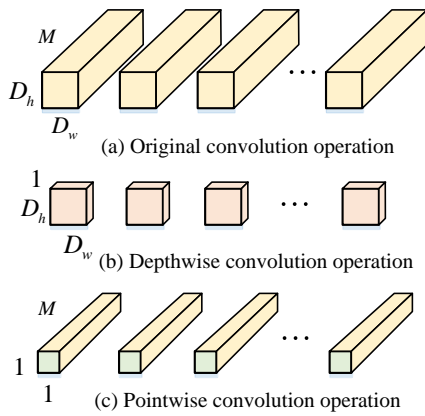


Fig. 2. Structure diagram of convolution layer.

It supposes that a feature map (FM) of  $D_w \times D_H \times M$  is input and a feature map of  $D_w \times D_H \times N$  is output in the standard convolution operation (CO) as in Fig. 2(a), where  $D_H$  and  $D_w$  are the length and width of the FM, respectively, and  $M$  serves as the channels' quantity of the input FM and  $N$  serves as the channels' quantity of the output FM. Assuming that the convolution kernel's (CK) size is  $D_k$  and the step size is 1, the parameters quantity of the CK is  $D_k \times D_k \times M \times N$ , then the amount of computation generated by one CO is shown in Equation (1).

$$D_k \times D_k \times M \times N \times D_w \times D_H \quad (1)$$

The standard CO is divided into two processes: filtering and combining. For decreasing the size of the network, the standard CO is split into depthwise convolution, which is only responsible for filtering, and pointwise convolution, which is only responsible for combining. The depth wise convolution in Fig. 2(b) uses a single-channel CK on each channel of the input FM to generate corresponding feature values at each position on each channel of the input FM. Then the point wise CO is used, i.e., a  $1 \times 1$  CK is used to combine the feature values on different channels at the same position to produce the corresponding feature vectors. Compared with the standard CO, the parameters quantity for depth wise convolution is  $D_w \times D_H \times M$  and the parameters quantity for point wise

convolution is  $1 \times 1 \times M \times N$ . Equation (2) demonstrates the parameters quantity for the two-step CO.

$$D_k \times D_k \times M + M \times N \quad (2)$$

And the two-step CO produces the computation as shown in Equation (3).

$$D_k \times D_k \times M \times D_w \times D_H + M \times N \times D_w \times D_H \quad (3)$$

Compare the transport arithmetic before and after splitting the standard CO into two parts, depth wise CK and point wise convolution, as shown in Equation (4).

$$\frac{D_k \times D_k \times M \times D_w \times D_H + M \times N \times D_w \times D_H}{D_k \times D_k \times M \times N \times D_w \times D_H} = \frac{1}{N} + \frac{1}{D_k^2} \quad (4)$$

The size of CK is usually assumed to be 3, so the former term in Equation (4) can be neglected, i.e., by splitting the standard CO, the number of CK parameters can be reduced while the computation is reduced to one-ninth of the standard CO. In order to facilitate more accurate target detection and localization by the machine, an adaptive anchor frame mechanism is presented to obtain the 3D position of the object by using additional depth pictures to complement the information of the color pictures. The adaptive anchor frame mechanism only requires pre-setting  $n$  anchor frames with different aspect ratios of 1. The width and height of the anchor frames are multiplied by the scale factor calculated from the depth image to obtain the effect of the original anchor frame. The YOLOv2 network framework after adding the adaptive anchor frames is shown in Fig. 3.

Fig. 3 illustrates that the input image is subjected to the YOLOv2 network to generate the prediction parameter, which is used to improve the shape of the anchor frame and produce the normalized prediction frame. The depth image is processed to obtain the scale factor map, and the final detection result is obtained by multiplying the scale factor corresponding to each pixel to the prediction frame. When the camera captures an object, the same object has different distances from the camera and has different sizes in the computer's field of view, thus the object size can be obtained by combining the depth fusion map. The correspondence between depth distance and object size is shown in Fig. 4.

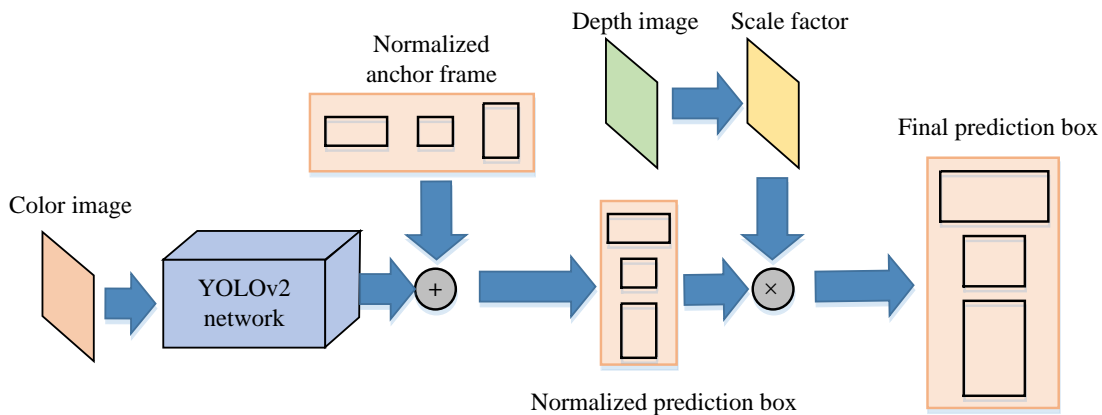


Fig. 3. YOLOv2 network combined with adaptive anchor frame mechanism network block diagram.

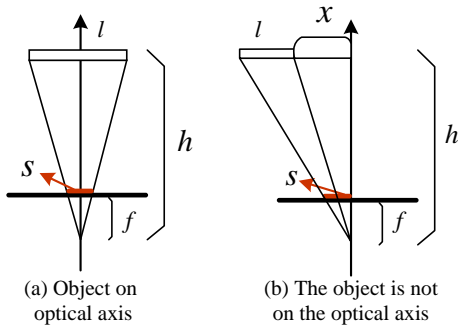


Fig. 4. Correspondence between depth distance and object size.

Fig. 4(a) indicates that the size of the object imaged on the imaging plane of the camera is  $s$  can be calculated based on the principle of similar triangles, as shown in Equation (5).

$$s = \frac{f \times l}{h} \quad (5)$$

In Equation (5),  $l$  is the actual length of the object,  $h$  serves as the distance between the object and the camera, and  $f$  serves as the focal length of the camera. In Fig. 4(b), the image size can also be calculated as shown in Equation (6).

$$s = \frac{f \times (l + x)}{h} - \frac{f \times x}{h} = \frac{f \times l}{h} \quad (6)$$

The size factor can be approximated based on this model of the relationship between the object-to-camera distance and the imaging size on the imaging plane, and multiplied by the normalized anchor frame to achieve the original anchor frame effect and get a relatively accurate prediction frame. For fully utilizing the information of all the prediction frames generated on the same object, a soft NMS is used in the study specifically by doing a weighted average of the coordinate information of all the frames to get the final prediction frame  $Box_i$ , as shown in Equation (7).

$$Box_i = \frac{\sum_j conf_{ij} \times box_{ij}}{\sum_i conf_{ij}} \quad (7)$$

In Equation (7),  $box_{ij}$  is the  $j$  th predictor box output on the  $i$  th object, and  $conf_{ij}$  is the confidence score of the predictor box. Finally, the overfitting phenomenon caused by limited training samples is solved by training the anchor frame parameters in steps. When training the anchor frames individually, the training data assigned to each anchor frame almost doubles, thus overcoming the over fitting phenomenon of a single anchor frame due to insufficient training samples.

### B. Target Object Pose Estimation Algorithm

In actual industry and life, mobile robots often need to grasp objects with various shapes, uncertain postures, and possible occlusion between objects. Therefore, it is necessary to obtain the position and attitude information of the target object through appropriate methods, and then use a robotic arm

to grasp the target object. After the position of the object in the camera is determined by the target detection and localization algorithm, the spatial coordinate values of the object can be obtained by using the camera's internal reference and related fused depth maps. However, the robotic arm also needs to know whether there is a plane on the object surface that can be absorbed when it grasps the object. This process can be done by semantic segmentation network to do pixel-level classification of the pixel points on the object surface and extract the points on the object surface that can be grasped, and the maximum connected domain (CD) consisting of these points is the absorbable plane (AP). The plane normal vector (PNV) of the plane equation in the 3D space established by these points is the pose direction of the target object, while the center on the CD is chosen as the target's 3D spatial location. The flow of the PE algorithm in the study is shown in Fig. 5.

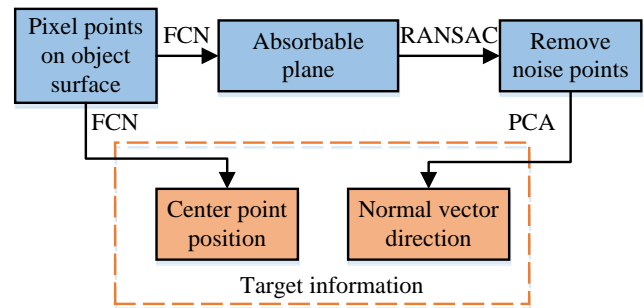


Fig. 5. Flow chart of attitude estimation algorithm.

In Fig. 5, the PE first extracts its AP using the FCN neural network algorithm, then removes the noisy points of the plane using the Random Sampling Consensus (RANDOM Sample Consensus, RANSAC), and finally solves the parameters of the object surface model using PCA for getting the target's pose message. Since there is noise in the depth map by the camera, after using FCN to determine the joint area on the AP of the target, RANSAC is used for removing the noise with large errors before getting a more accurate plane model. The processing flow is shown in Fig. 6.

The planar model used in the study has four parameters. Therefore, four data points (DP) are required for addressing the model. In Fig. 6, the RANSAC algorithm randomly selects four DP in the data set generated from the FCN results for solving the model parameters. All DP are included in the solved model, and the statistical error is less than the internal points' quantity. The model is considered accurate only when the internal points' quantity exceeds the set threshold, and then the PCA algorithm is used for addressing the related model parameters, and if the error of the current optimal model is greater than that of the obtained model, the optimal model is renewed.

The PCA algorithm is used to compress the data in the original feature space into a lower dimensional space. A schematic diagram of the PCA algorithm and its solution to the PNV is shown in Fig. 7.

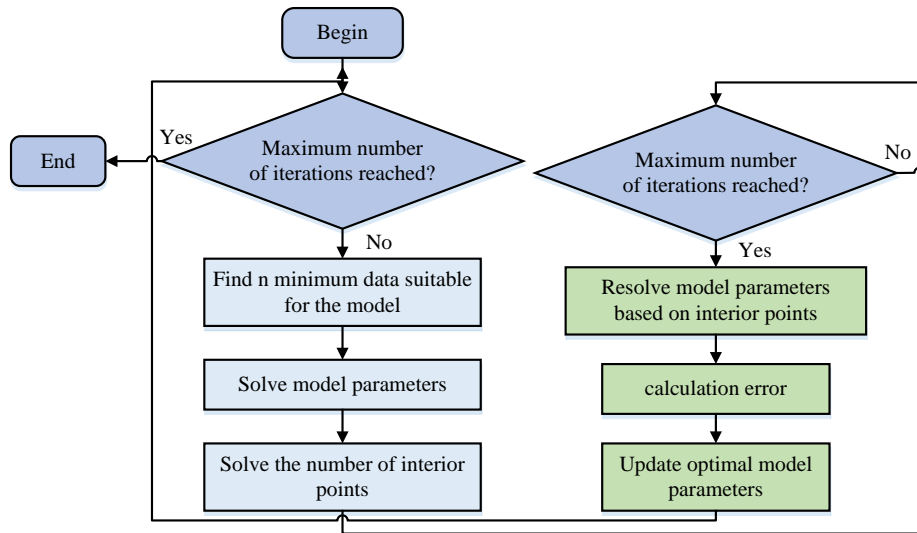
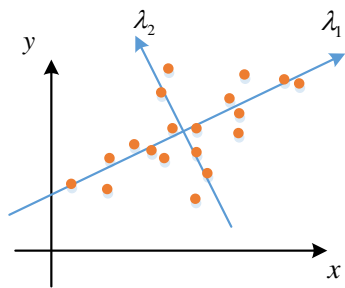
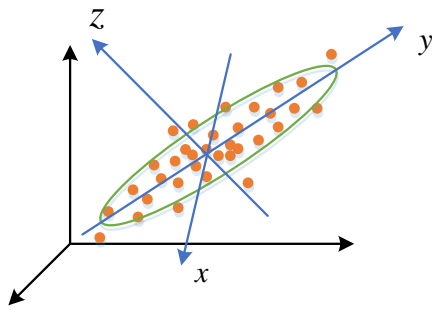


Fig. 6. Flow chart of RANSAC algorithm.



(a) Schematic diagram of PCA algorithm principle



(b) Schematic Diagram of PCA Algorithm for Solving Plane Normal Vector

Fig. 7. PCA algorithm and its schematic diagram for solving plane normal vector.

In Fig. 7(a), PCA transforms the data in the original feature space into the new orthogonal feature space by linear transformation, and then removes the dimensional information that is less informative, leaving a number of dimensions with more informative information to express the original data. The amount of information in a dimension can be expressed by the variance of the data in that dimension; the larger the variance, the greater the amount of information. The projection transformation is shown in Equation (8).

$$\begin{cases} \delta = A^T x \\ A = [\alpha_1, \alpha_2, \dots, \alpha_n] \end{cases} \quad (8)$$

In Equation (8),  $x$  is the data in the dataset,  $A$  is the change transformation matrix, the projected data is  $\delta$ , and the feature space formed by  $\alpha$  as the feature vector is the projected space where the vectors have the relationship shown in Equation (9).

$$\begin{cases} \alpha_i \alpha_i = 1 \\ \alpha_i \alpha_j = 0, i \neq j \end{cases} \quad (9)$$

The data in the original feature space is projected into the feature space consisting of  $\alpha$  as the feature vector by the projection transformation, and the projection value of the vector  $x$  in  $\alpha_i$   $\delta_i$  is shown in Equation (10).

$$\delta_i = \alpha_i^T x \quad (10)$$

The principle of PCA is to let the information in the dataset fall into the feature space as much as possible, so the variance of the projection on the new feature vector should also be as large as possible. The data variance of the projected data in one dimension is shown in Equation (11).

$$\begin{aligned} D(\delta_i^2) &= E(\delta_i^2) - E^2(\delta_i) \\ &= E(\alpha_i^T x x^T \alpha_i) - E(\alpha_i^T x) E(x^T \alpha_i) \\ &= \alpha_i^T \sum \alpha_i \end{aligned} \quad (11)$$

In Equation (11),  $D(\delta_i^2)$  is the variance after projection. To maximize it and to satisfy the relation, it is solved using the Lagrange multiplier method as shown in Equation (12).

$$f(x) = \alpha_i^T \sum \alpha_i - \lambda (\alpha_i^T \alpha_i - 1) \quad (12)$$

In Equation (12),  $\lambda$  serves as the eigenvalue of the matrix  $\Sigma$  and  $\alpha_i$  serves as the corresponding eigenvector. The derivative of  $\alpha_i$  is obtained when the derivative is 0. The maximum value of  $D(\delta_i^2)$  is obtained when the derivative is 0, as shown in Equation (13).

$$\begin{cases} \frac{\partial f(x)}{\partial \alpha_i} = \Sigma \alpha_i - \lambda \alpha_i \\ \Sigma \alpha_i = \lambda \alpha_i \end{cases} \quad (13)$$

Since the points on the AP of the target object are distributed in the whole plane space, the two eigenvectors along the plane direction have the largest variance, and the eigenvector normal to the plane direction corresponds to the smallest eigenvalue, so the eigenvector corresponding to the smallest eigenvalue found by PCA is the normal vector of the AP. With the obtained PNV as the target's pose direction, the grasping of the robot arm for the target can be realized. As shown in Fig. 6(b), PCA first determines the two feature vectors with the largest variance  $x$  and  $y$ , and determines the  $z$  axis direction in view of certain premises. Due to the small impact of sensor noise on the  $z$  axis direction, a portion of the sensor noise is successfully filtered out using the PCA method. The evaluation metric for the target PE is the 2D projection metric, and the PE is considered accurate if the average distance between the projection of the predicted corner point and the real labeled corner point  $e_{REF}$  is less than 5 pixels. 2D projection metric is defined as shown in Equation (14).

$$e_{REF} = \|P_i - TM\mu\|_2 \quad (14)$$

In Equation (14),  $M_c$  is the camera matrix,  $G$  is the target pose to be estimated,  $P_i$  is the position of the  $i$  th pixel, and  $\mu$  is the average of the pixel distribution with the maximum blending weight.

#### IV. ANALYSIS OF THE EFFECT OF TARGET OBJECT LOCALIZATION AND POSE ESTIMATION FOR MOBILE ROBOTS

##### A. Performance of Target Object Localization Algorithm for Mobile Robots

The study is based on a mobile robot platform to test the visual perception algorithm, including the performance analysis of target localization algorithm, PE algorithm and the effect analysis of the robot arm's grasping for the target. The mobile robot platform is equipped with a robot arm system, a color depth binocular vision system, a TX2 DL IPC and an image acquisition IPC for completing the grasping process of the target. The initial Learning rate of network training is 0.001, and the Learning rate of every 100 epochs is divided by 10. The configuration parameters of the experimental hardware are shown in Table I.

The public dataset used in the object detection and positioning experiment is from LineMod, which is a standard dataset for attitude estimation. There are 1200 instances of 13 objects, and the data includes color maps, depth maps, and corresponding camera coordinate information from different

perspectives. In order to improve operational efficiency, the study selected 200 images of each of the four types of objects for comparative analysis of different anchor box mechanisms and to compare the performance of the algorithms before and after the improvement. The mean Average Precision (mAP) results of the original anchor frame mechanism and the adaptive anchor frame mechanism in YOLOv2 are shown in Fig. 8.

In Fig. 8, the accuracy of the adaptive anchor frame mechanism improves by 1.55% when there are only 1 or 2 anchor frames, and the improvement is more obvious. When the number of anchor frames is three or more, the original anchor frame mechanism shows a serious over fitting phenomenon, and the detection accuracy decreases by 3.65%~3.77%. The adaptive anchor frame mechanism can still maintain a high detection accuracy when the number of anchor frames is three and four, which indicates that it has some improvement effect on the over fitting problem. The detection accuracies of different target detection and localization algorithms are shown in Fig. 9.

TABLE I. CONFIGURATION OF EXPERIMENTAL HARDWARE PARAMETERS

Configuration	TX2 Deep Learning Industrial Control Board	Image acquisition industrial control board
CPU	ARM Contex-A57	Intel Bay Trail J1900
Memory	8GB LPDDR4	8G DDR3L 1333MHz
Hard disk	32GB eMMC5.1	64GB Solid-state drive
interface	Wireless, Bluetooth, Ethernet	Network interface, serial port, USB

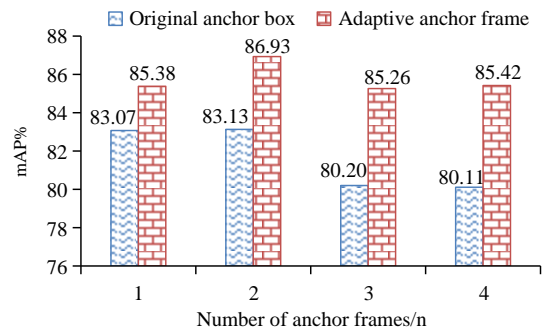


Fig. 8. Comparison of mAP results between the original anchor frame mechanism and the adaptive anchor frame mechanism under different number of anchor frames frames.

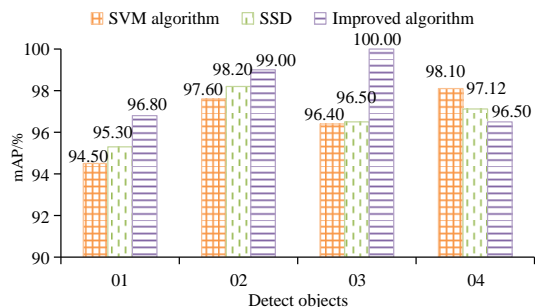


Fig. 9. Detection accuracy of target detection and location algorithm before and after improvement.

In Fig. 9, the improved algorithm detects objects 01, 02, and 03 significantly better than the Support Vector Machine (SVM) algorithm and the Single Shot multiBox Detector (SSD) algorithm, and the detection accuracy for object 04 is lower than the other two algorithms, but still above 95%. The SSD algorithm has good detection speed and accuracy compared to the SVM algorithm, but it is still weak in detecting small object 02. The average detection accuracies of the improved algorithm, SVM algorithm and SSD algorithm for objects are 98.8%, 96.65% and 96.78%, respectively. Taken together, the YOLOv2 network used in the study has high detection accuracy, good small object detection ability, and the optimized model size can be applied to embedded platforms, which is the optimal choice.

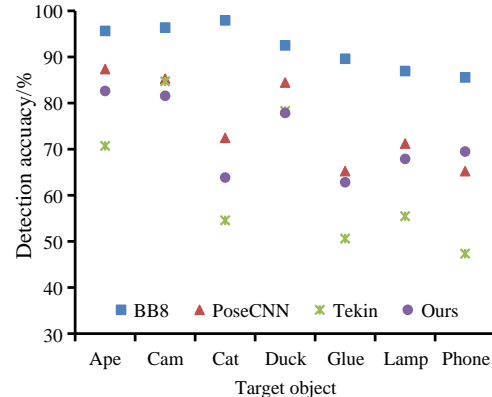
**B. Performance of Target Object Pose Estimation Algorithm for Mobile Robots**

The training samples for the pose estimation network model for mobile robots are taken from the LineMod dataset. In order to better simulate the real work environment and verify the stability of the algorithm, the dataset used during the testing was the Occlusion LineMod dataset, which was reannotated and generated from the LineMod dataset, was used during testing. This dataset contains 1435 images of eight objects with complex backgrounds and occlusions. For testing the PE algorithm in the study, it is compared with several commonly used PE algorithms for experiments. The PE results of different algorithms for seven target objects are shown in Fig. 10.

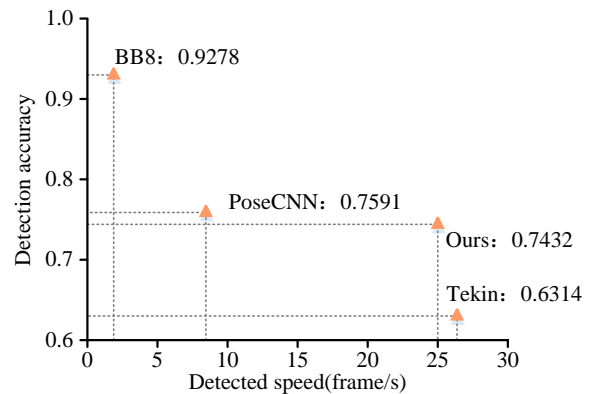
In Fig. 10(a), the BB8 algorithm has the highest PE accuracy for seven types of targets, followed by the PoseCNN algorithm, and the detection accuracy of the proposed PE algorithm is close to that of PoseCNN. However, according to the average detection accuracy and detection speed in Fig. 10(b), although the detection accuracy of BB8 is 92.78%, its detection speed is only 2 frames/s.

The detection accuracy of PoseCNN is 75.91% and the detection speed is 7 frames/s, which is slightly higher than that of BB8. The detection accuracy of PoseCNN is 75.91% and the detection speed is 7 frames/s, which is slightly higher than that

of BB8. The Tekin algorithm runs the fastest at 26 frames/s, but its estimation accuracy is only 63.14%. The accuracy of the PE algorithm is 74.32%, which is a big improvement over Tekin's algorithm, and it runs at 25 fps, which seems to satisfy the needs of real-time operation. Table II depicts the experimental results of the visual perception algorithm for different objects in the real object grasping experiments.



(a) Comparison results of detection accuracy for different target objects



(b) Comparison results of detection accuracy and speed of different algorithms

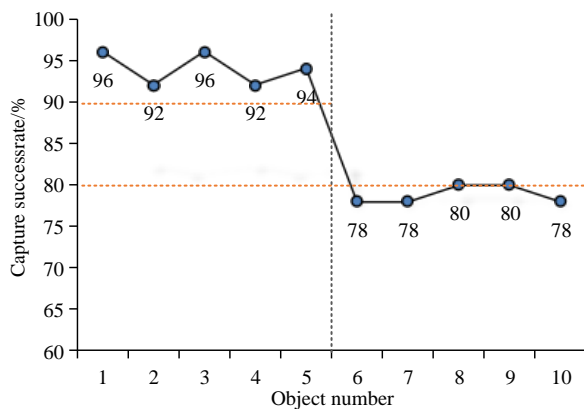
Fig. 10. Comparison of results of common object attitude estimation algorithms.

TABLE II. RESULTS OF VISUAL PERCEPTION ALGORITHM ON DIFFERENT OBJECTS

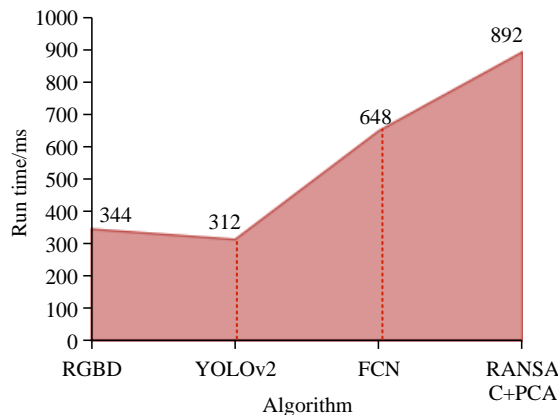
Object number	Surface center coordinate point	Coordinate point directly above	Surface normal vector	Center pixel coordinates	Pixel coordinates directly above
1	(0.09,0.24,1.84)	(0.12,0.24,1.64)	(-0.17,0.00,0.99)	(710,665)	(751,688)
2	(-0.06,0.11,1.36)	(-0.07,0.15,1.39)	(0.03,0.87,0.25)	(621,537)	(614,385)
3	(-0.10,0.07,1.54)	(-0.11,0.12,1.51)	(0.04,1.00,0.14)	(556,548)	(543,367)
4	(0.00,0.14, 1.50)	(0.06,-0.05,1.45)	(-0.28,0.95,0.17)	(646,608)	(708,434)
5	(0.05,0.21,1.18)	(0.05,0.31,1.01)	(-0.04,0.50,0.87)	(699,727)	(722,906)
6	(0.07,0.06,1.27)	(0.08,-0.12,1.19)	(-0.03,0.91,0.42)	(721,546)	(734,337)
7	(0.08,0.05,1.37)	(0.09,-0.13,1.28)	(-0.03,0.89,0.45)	(728,532)	(740,340)
8	(0.06,0.16,1.35)	(0.07,0.27,1.18)	(-0.04,-0.52,0.86)	(710, 649)	(728,796)
9	(0.07,0.04,1.28)	(0.08,-0.11,1.37)	(-0.03,0.82,0.49)	(725,518)	(746,322)
10	(-0.08,0.06,1.14)	(-0.09,0.08,1.46)	(0.05,1.01,0.15)	(558,543)	(547,361)



In the physical object grasping experiments, a total of 10 unknown objects were grasped, with object numbers 1 to 5 for normal-sized objects and 6 to 10 for smaller-sized objects. In Table I, the surface center coordinate point indicates the three-dimensional spatial point of the absorbable point on the object's surface in the corresponding coordinate system, and the coordinate point directly above indicates the three-dimensional spatial point at 20 cm directly above the center coordinate point. The robot arm system controls the end of the robot arm to move to the upper coordinate point, and adjusts the direction of the end nozzle to be consistent with the PNV, and then makes it move to the surface center coordinate point along the normal direction for completing the grasping of the target. The pixel coordinates projected to the color camera coordinate system are the center pixel point and the upper pixel point. The results of the grasping success rate and the each algorithm's time are shown in Fig. 11 for 50 grasps of each object.



(a) Success rate result of grasping target object



(b) Running time of each algorithm in the process

Fig. 11. The success rate of grasping objects and the running time of each algorithm in the process.

In Fig. 11(a), the success rates of physical grasping for objects 1~5 of normal size are all over 90%, while the success rates of physical grasping for objects 6~10 of smaller size are reduced but still maintain around 80%. The average success rate of physical object grasping reaches 86.4%, which tests the practicality of the physical object grasping algorithm proposed in the study. The study also tested the running time of the

vision algorithm for each stage. In Fig. 11(b), although the neural network algorithm is computationally intensive, it does not account for a large percentage of the total algorithm running time because the target detection algorithm runs on the GPU and the optimization of the DL framework substantially increases the neural network's speed. The RANSAC algorithm takes up the largest percentage of the time because it requires multiple iterations and the iterative process also uses PCA to calculate the interior point error.

## V. CONCLUSION

As robots are used to replace tedious manual labor in more and more industries, the use of mobile robots to complete the handling of goods in the logistics industry has gradually become a hot research topic nowadays. The study designs a set of vision algorithms for a mobile robot platform for the vision system of fully automated handling, mainly including a target object detection and localization algorithm based on the embedded platform with improved convolutional structure and an object PE algorithm based on FCN semantic segmentation network. While the detection accuracy of the original anchor frame mechanism decreases by 3.65%~3.77% due to the overfitting phenomenon, the proposed adaptive anchor frame mechanism can still maintain a high detection accuracy with good resistance to overfitting when the number of anchor frames is 3 and 4. In the experiments of detection and localization of different objects, the target localization algorithm proposed in the study improves the detection accuracy by 2.22% and 2.09% compared with the SVM algorithm and the SSD algorithm, respectively, with better localization results. The average success rate of grasping physical objects also reaches 86.4%, which effectively tests the algorithm's practicality proposed in the study for physical object grasping. However, although the study has optimized the convolutional structure and reduced the network's model parameters, the computational burden is still too large for the embedded platform, and the base convolutional layers can be considered to be combined together in subsequent studies to further reduce the model size of the network.

## VI. DISCUSSION AND PROSPECTS

The study used object detection networks to determine the three-dimensional position information of objects and semantic segmentation networks to assist in estimating the pose of objects. Although the research has optimized the convolution structure of the network, reduced the model parameters of the network, and improved the operation efficiency of the feedforward network, for the embedded platform, the computational burden of using two convolutional neural networks is still too large, resulting in the overall operation efficiency of the system is not very ideal. Jiang D et al. used an improved Fast RCNN to achieve tasks such as semantic segmentation, object classification, and detection in indoor scenes, resulting in a model with good performance and high efficiency [18]. Scholar Feng T used Mask RCNN combined with a single multi box detector algorithm to achieve gesture detection and recognition in human-computer interaction, which has high detection accuracy and speed [19]. Therefore, in future research, it can be considered to draw on the solutions of these two networks and merge the basic convolutional layers



together to reduce repetitive operations in the network. The results of the target detection network can also be projected onto the intermediate feature map, and the FCN head network can be run on the extracted feature image pixels to further improve the running speed of the feed forward network.

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# Character Representation and Application Analysis of English Language and Literature Based on Neural Network

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**Abstract**—The development of computer technology has promoted the continuous progress of Natural language processing technology and the great development of ideology and culture, and also prompted literary workers to create a large number of literary works. This poses a new challenge to the application of Natural language processing technology. Text analysis and processing is realized by Natural language processing technology. In the information society, the amount of data is increasing exponentially, and the number of literary works produced is also rapidly increasing. In order to gain a comprehensive understanding of domestic and foreign history and culture, some Chinese readers are not only satisfied with reading Chinese works from ancient and modern times, but also hope to read and understand foreign literary works. Current mainstream methods for literary character analysis are manual, making the results highly subjective and inefficient for large-scale literary works. To address this problem, this study proposes a character representation and analysis method based on neural networks using English novels as an example. By preprocessing data and utilizing the word dependency relationship to represent character vectors and calculate similarity, the study uses the Skip-gram model to train character vectors and K-means for clustering. An AGA-BPNN model is proposed for character and gender prediction and classification, with a 95.42% accuracy rate achieved in character prediction classification, and an average accuracy, recall, and F1 score of 0.953, 0.962, and 0.962, respectively, in gender prediction and classification. The results demonstrate the effectiveness of the method and propose a new approach for novel character analysis.

**Keywords**—Neural network; English; literary image; character vector; similarity calculation

## I. INTRODUCTION

In literary works, fiction is one of its important forms of expression. In novel analysis, the analysis of novel characters, including gender, personality, etc., is the basic work to help readers understand novels [1]. Analyzing and researching the characters in novels can help readers understand the characteristics of characters, social environment and the author's thought expression in literary works from the aspects of society, history and literary value [2-3]. In the traditional analysis of characters in novels, the mainstream method is mainly manual. As a result, the analysis results are highly subjective. In addition, the efficiency is low and it takes a long

time to analyze large literary works [4]. In China, due to the fact that most modern Chinese literary works are protected by copyright, it is relatively difficult to obtain a large number of Chinese literary texts and conduct analysis and research on them. However, some English literary works are no longer within the copyright protection period. In order to facilitate the processing, analysis, and research of these works, English novels are used as a novel corpus for study and analysis. With the help of Natural language processing technology, analyzing literary works and extracting useful information from them can help readers better read literary works. Using computer to analyze characters in novels requires the use of Natural language processing related technologies to transform the expression of characters in novels into data that can be understood by computers. Neural network (NNs) is an algorithm model that imitates the structure of the human brain and realizes high-precision, high-efficiency distributed parallel information processing. The advantage of NNs is that it can process large-scale data in parallel, and the accuracy and operation speed of the model will not be greatly affected. In classification problems, NNs has important and wide applications [5]. To this end, the study takes English literary works as an example, and builds a model based on the Skip-gram model, K-means and neural network to analyze the characters in the novel. The main purpose of the research is to apply NLP technology and NNs technology to large-scale novel character analysis, so as to improve the efficiency of novel character analysis, strengthen readers' understanding of the work, and help readers better understand the connotation and history of the novel's heritage.

## II. RELATED WORKS

In a literary work, characters are one of the three elements of a novel, the core part of a literary work, and an important content that embodies the literary value of a novel. Analyzing and researching the characters in novels can help readers understand the characteristics of characters, social environment and the author's thought expression in literary works from the aspects of society, history and literary value. Therefore, the research on the analysis of literary characters is very common. Shutan MI took the literary characters that appeared in the tenth grade Russian literature class as examples, such as Andrei Bolkonsky and Nikolai Rostov, to reveal the parallelism among literary characters, so as to ensure the effective cognition of student's sex [6]. Ravela took

“White Boys Shuffle” as an example to analyze the experience and growth of the protagonist in the novel, and discussed the racial ideology in the novel, believing that the novel has to some extent promoted the global conceptualization of race [7]. Rebel analyzed the works of three famous writers, and compared the content including the structure, theme, genre and ideology of the works, so as to dynamically analyze the development process of nineteenth-century literature. The analysis results show that ideological disputes have a greater impact on the fate of characters in Turgenev’s novels [8]. From a narrative perspective, Bai and others analyzed the protagonist’s image and character in the work of Nobel Prize winner William Faulkner - A Rose for Emily, to help readers better understand the thoughts expressed in “A Rose for Emily” [9]. Nischik took the novel "Penelope Piad" as an example to compare the mythical characters in Canadian mythology and Greek mythology, and reimagined the characters in "Odyssey" to reveal the genders contained in the concept of ancient mythology [10]. In a study by Ni, the language, use of behavior, and descriptions of the characters in Miracle are analyzed, and the techniques, intentions, and types used by literary characters to convey between words are explored. After summarizing, the researchers believe that their types include assertiveness, empathy, instruction, and expression [11]. Starkowski believes that in the study of literary works, more energy and attention should be devoted to the study of secondary characters. And taking Dickens' "Still There" as an example, he discusses the inadequacy of the traditional interpretation of secondary characters and the reflection of secondary characters in the novel on the society in the work [12]. In a study by Indrasari et al., taking Bronte’s novel Wuthering Heights as an example, they used sociological methods and qualitative description methods to conduct an in-depth analysis of the middle-class female roles in the novel in the 19th century, thereby deepening the understanding of these roles [13].

NNs is an algorithm model that imitates the structure of the human brain and realizes high-precision, high-efficiency distributed parallel information processing. The advantage of NNs is that it can process large-scale data in parallel, and the accuracy and operation speed of the model will not be greatly affected. Therefore, NNs has important and wide applications in classification problems. For example, CNN, which performs well in image recognition and classification, and BPNN, which appears frequently in automatic data classification research, etc. In recent years, scholars have made more and more in-depth research on neural networks. Plonka et al. analyzed the structure of one-dimensional ReLU DNN, and proposed a recursive algorithm to remove parameter redundancy in the deep ReLU neural network (ReLU DNN), thereby optimizing the network structure of ReLU DNN and improving its performance [14]. Raghu et al. discussed the similarity between CNN and visual transformer, and based on this similarity, discussed the possibility and operability of complementary fusion between the two [15]. Jiang designed a photonic device evaluation model based on an improved DNN, and discussed the model’s learning of device geometric features in the context of photonics, and the robustness of the model under large-scale data [16]. In order to better understand the problem solving ability and

interpretability of problem solving strategies of deep neural networks, Samek et al. conducted a comprehensive discussion and analysis of relevant research literature in recent years. And its application fields, application effects, and application prospects were analyzed and discussed [17]. Chung et al. proposed a neural population geometry method, and used this method to explain and analyze the structure and function of ANN. The actual application effect of the method was tested. The test results verified the effectiveness of the method [18]. Based on the latest research contents, Zhou et al. reviewed the construction, optimization and application of graph neural network (GNN), and discussed the application and performance of GNN variants, pointing out the direction for the development of GNN [19]. Wright et al. designed a deep physical neural network (DPNN) trained by backpropagation, which can effectively reduce the energy consumption required in scientific and engineering applications [20]. Ghosh et al. provided a comprehensive description of the basic structure, foundation, research progress, and main application fields of CNN, and pointed out the important contributions of CNN in the field of artificial intelligence [21]. Kong et al. proposed an Audio Neural Network (PANN) for audio recognition in large-scale data. Tests show that the model outperforms recent state-of-the-art audio recognition models [22].

In summary, CNN can perform image recognition and classification, and has excellent performance in automatic data classification research. In Computer language, ReLU DNN carries out vector training for fictional characters through Natural language processing, and uses mathematical methods to express characters, so that people can be counted and analyzed. The above content indicates that character analysis in literary works is very important, as it is the foundation for readers to understand the novel. However, the existing analysis of characters in literary works is based on a small number of novel characters, which is inefficient, and the analyzed literary works are also extremely limited. Therefore, this study applies neural networks to the analysis of characters in English literary works, and efficiently analyzes a large number of characters in novels through Big data technology and NLP technology. Thus, it can help readers of different novels more conveniently understand the content of the novel, as well as the corresponding characters' history and culture in the novel.

### III. REPRESENTATION AND APPLICATION OF LITERARY CHARACTERS BASED ON NEURAL NETWORK

Neural network technology is the foundation of all subsequent research in this paper. The main content of this chapter is to construct a corpus and preprocess the data using the corpus. At the same time, the Skip gram model is used to train character and feature word vectors, thereby calculating the training of novel character vectors and character similarity. Then, K-means is used to cluster and analyze feature vectors, and an adaptive mutation improved genetic algorithm (AGA) is proposed to obtain the optimal parameters of BPNN and improve model performance. Finally, the feature vectors are input into AGA-BPNN to achieve prediction and classification of feature features and gender.

#### A. Corpus Construction and Data Preprocessing

In literary works, fiction is one of its important forms of expression. In novel analysis, analyzing the characters in the novel, including gender, personality, etc., is the fundamental work to help readers understand the novel. In recent years, with the rise and development of AI, it is very feasible to use NLP technology to perform automatic, intelligent, and efficient clustering, classification, and analysis of novel characters, which has aroused the interest of some researchers. To this end, the paper takes English literary works as an example, and builds a model based on a neural network to analyze the characters in the novel. The first is to collect data in Project Gutenberg (PG) and build a corpus. PG is a text database that contains a large number of novels of different genres and authors. After the corpus is constructed, the corpus data is preprocessed to facilitate subsequent natural language processing (NLP). The preprocessing of literary works includes lexical and syntactic analysis, clustering of names, etc., as shown in Fig. 1.

The part of speech tagging and Named-entity recognition in Fig. 1 are implemented in this study using conditional random field model (CRF). If there are two groups of random variables  $x$  and  $y$ , when input  $x$ , the conditional

probability distribution of the  $p(y|x)$  output is expressed as  $y \cdot y$  can be regarded as a Markov random field at this time, but  $p(y|x)$  is a conditional random field. At this time, the conditional probability is obtained by formula (1).

$$p(y|x, \theta) = \frac{1}{Z(x, \theta)} \exp\left(\sum_{c \in C} \theta_c^T f_c(x, y_c)\right) \quad (1)$$

In formula (1),  $\theta_c$  is a weight vector.  $\theta$  is the weight vector in any potential energy function.  $f(\cdot)$  is the activation function.  $c$  is the largest set of conditional random fields, and  $Z(x, \theta)$  is the normalization term, which can be expressed as formula (2).

$$Z(x, \theta) = \sum_y \exp\left(\sum f_c(x, y_c)^T \theta_c\right) \quad (2)$$

In the vocabulary tagging process of the English novel corpus, if the structure of  $x$  and  $y$  is the same, a linear chain CRF will be formed, as shown in Fig. 2.

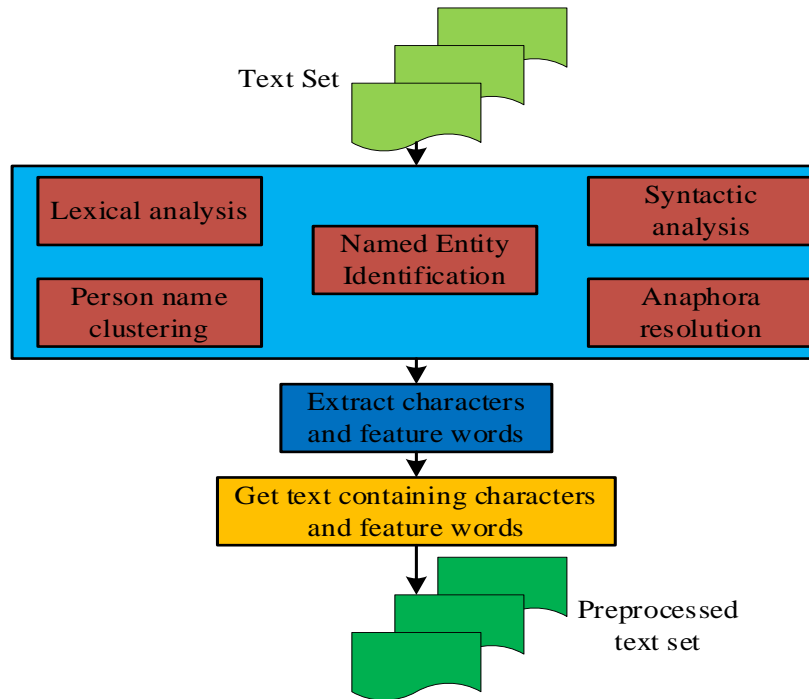


Fig. 1. Pretreatment of literary works.

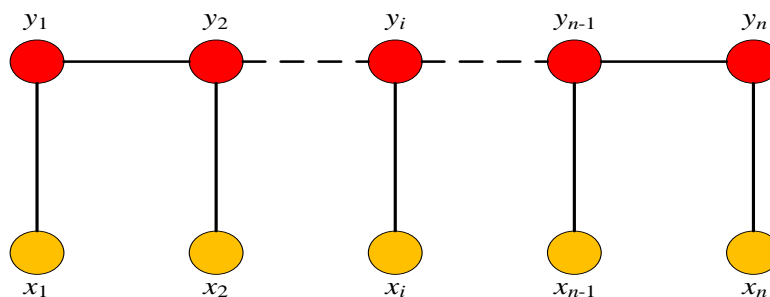


Fig. 2. Linear chain CRF.

The conditional probability at this time is obtained by formula (3).

$$p(y|x, \theta) = \frac{1}{Z(x, \theta)} \exp \left( \sum_{t=1}^{T-1} \theta_1^t f_1(x, y_t) + \sum_{t=1}^{T-1} \theta_2^t f_2(x, y_t, y_{t+1}) \right) \quad (3)$$

In formula (3),  $f_1(x, y_t)$  is a position  $t$ -related state feature, and  $f_2(x, y_t, y_{t+1})$  is a state transition feature that can be represented by a state transition matrix. In Natural language processing, specific words are divided into five categories according to the dependency grammar relationship between specific words and Chinese characters, namely possessive case (poss), direct object (doobj), noun subject (nsubj), adjective subject (amod) and passive noun subject (nsubjpass). The character words and feature words in the corpus are extracted and expressed as binary phrases (characters and feature words). According to the dependency grammar relationship between feature words and Chinese characters, the top 4 words in each category are selected. The extraction results are shown in Table I. It can be seen that the feature words in Table I are closely related to the behavior or attributes of the characters.

A word, the basic unit of a language, with its own sound, meaning, and syntactic function, expresses ideas and information that are universally and intuitively understood by its native speakers. In terms of novel, a word plays an essential part in composing an outstanding masterpiece, portraying striking characters, and sculpturing a unique style.

The scope of English vocabulary is wide and has different types. For example, from formal to informal, simple to complex, standard to non-standard, common to rare, written to colloquial, general to specific, conceptual to associative, elegant to rough, monosyllabic to polysyllabic, Anglo Saxon to Latin. The artful and skillful choice of words is crucial for achieving special effect and getting desired texture in novels. However, the author does not randomly choose vocabulary, but deliberately chooses vocabulary after carefully considering the purpose, theme, and readers.

Word frequency refers to the times of words appeared in literary works. From Table I, it can be clearly observed that most of the top 4 word in each category are from Anglo-Saxon.

English vocabulary mainly comes from Anglo Saxon, French, Latin, and Greek. The vocabulary derived from Anglo Saxon forms the basic vocabulary of English speakers, who have known these words since childhood and frequently use them in daily life. These words are short, simple, basic daily words --- monosyllables and disyllables, indicating that authors tend to use common words to portray characters, create a brisk rhythm and convey the theme to readers.

Verbs occur as part of the predicate of a sentence and carry markers of grammatical categories, such as person, number, tense, aspect, and mood. Verbs can be stative ones, referring to state of affairs; as well as dynamic ones, referring to actions and events. Table I shows that the most commonly used verbs are simple but dynamic, and many of them refer to characters' movements. The frequently used verbs add rhythmic value to novels and make the characters in novels full of vivid energy.

Nouns are commonly divided into two categories --- the concrete nouns and the abstract nouns. The former refers to a real, physical thing with a definite indication vividly and clearly; while the latter mostly refers to a quality, state, action, perception or any other implicit concepts. It is eye-catching that top 4 words in poss (possessive case) are all concrete nouns, which transmit specific and accurate meaning and thought to readers and produce vivid impressions.

Adjective can be used to express psychological, physical, auditory, visual, color, evaluative, and emotive attributes. Moreover, they can be used to portray characters and convey the thematic meaning of novels. The abundant adoption of adjective can assist in the vivid portrayal of the characters, enrich the setting of novels, as well as push forward the development of the story. Frequently used adjectives present the beauty of language and charm of novels before readers.

### B. Character Vector Training and Character Similarity Calculation in Novels

After preprocessing the corpus, feature words with dependent syntactic relationships can be obtained. At this point, the Skip-gram model is used to train character word vectors and feature word vectors. In a text data set  $D$ , the probability distribution model is expressed as formula (4).

$$p(D = 1|w, c) = \frac{1}{1 + e^{-v_w \cdot v_c}} \quad (4)$$

TABLE I. TOP 4 WORDS IN EACH CATEGORY

Category	Terms	Word frequency	Category	Terms	Word frequency
poss	hand	323364	a mod	old	89334
	the face	225147		young	54381
	life	119574		major	46453
	mind	101435		great	33680
doobj	tell	183454	nsubjpass	call	19405
	take	80144		bear	19241
	meet	58442		make	15403
	reply	50554		know	14428
nsubj	say	2122164	-	-	-
	be	754572		-	-
	go	469388		-	-
	come	369643		-	-

In the formula (4),  $w$  and  $c$  represent character words and feature words, respectively, and the word pairs formed by the two are  $(w, c)$ .  $v_w$  and  $v_c$  represent the vectors of character words and feature words, respectively.  $p(D=1|w, c)$  represents the probability of word pairs in  $D$ . In Equation (4),  $v_w$  and  $v_c$  are the main learning parameters of the model. In order to maximize the target word pair in  $D$ , using the objective function of formula (5) to constrain it.

$$\arg \max_{v_w, v_c} \sum_{(w, c) \in D} \log \frac{1}{1 + e^{-v_w \cdot v_c}} \quad (5)$$

In formula (5), by adjusting the value in the data set  $w, c$ , the value of  $v_w = v_c$  and  $v_w \cdot v_c$  is large enough. To use the Skip-gram model to train character word vectors. The process is shown in Fig. 3(a), where  $n$  represents the number of character words in the data set.

According to the parts of speech of the five specific words mentioned above, they are divided into five categories. Among them, the first group combines the above characteristic words to represent a vector, where the vector is denoted as  $c\_Pdnan\_Vec$ , using this method to represent character vectors; The second group uses  $nsubj$  and  $nsubjpass$ , with the vector recorded as  $c\_Nn\_Vec$ ; The third group is through  $dobj$ , and

the vector at this time is recorded as  $c\_d\_vec$ ; The fourth group is through  $poss$ , and the vector at this time is recorded as  $c\_p\_vec$ ; The fifth group is through  $amod$  to represent the characters in the novel, and the vector at this time is recorded as  $c\_a\_vec$ . Fig. 3(b) shows the representation and classification of five groups of character vectors in the process of training character word vectors by the Skip-gram model. In Fig. 3, the trained character vectors all have 200 dimensions. After extracting all characters and related feature words, the character vector is represented by the word heat method, denoted as  $c\_Pdnan\_Hot$ . In this method, the characteristic words of any novel character only have one chance to appear.

After the character vector is generated, to calculate the character similarity of the characters in the novel. The principle of character similarity calculation is that in the two novels A and B, if the context of the characters in A is similar to that of the characters in B, it is considered that these two characters are similar, and their vectors in multidimensional space are also similar. The paper adopts the cosine similarity method to calculate the similarity between person vectors. Assuming that the vectors of each dimension of a character in a novel  $P$  are expressed as  $[P_1, P_2, \dots, P_{200}]$ , and the vectors of each dimension of another character in a novel  $Q$  are expressed as  $[Q_1, Q_2, \dots, Q_{200}]$ , the cosine similarity value between the two is calculated by formula (6).

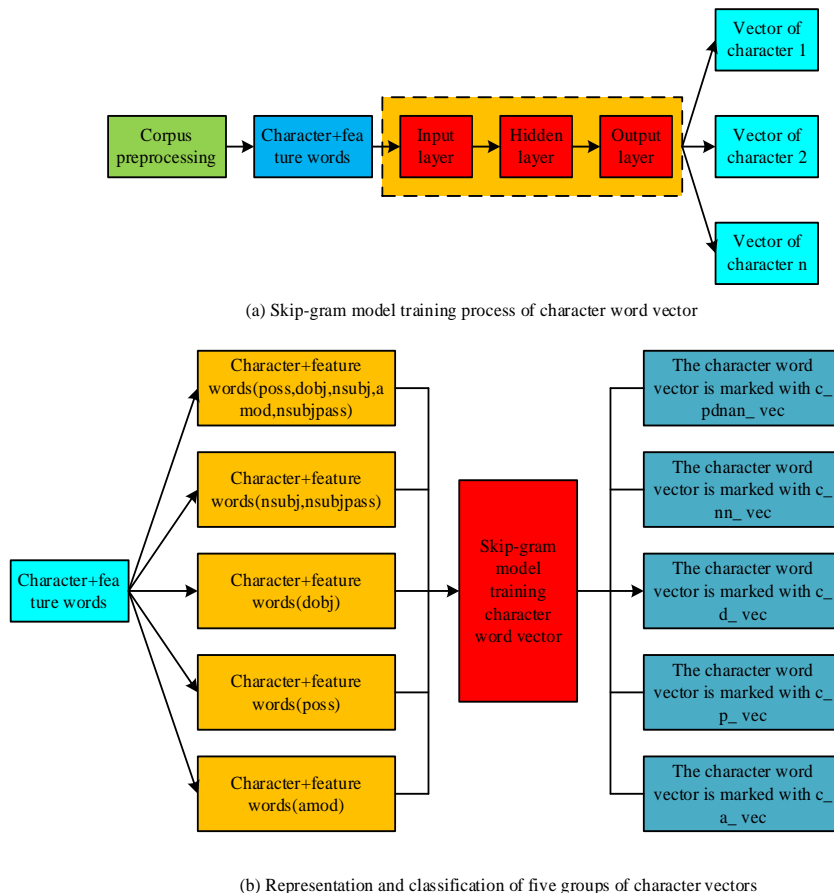


Fig. 3. Word vector training.



$$Sim(P, Q) = \cos(\theta) = \frac{P \cdot Q}{\|P\| \|Q\|} \quad (6)$$

In formula (6),  $\theta$  represents the angle between the vectors of the two novel characters  $Q$  and  $P$  in the vector space. Based on the above content, the extraction of novel character vectors and the calculation of novel character similarity are completed.

### C. Clustering and Classification of Novel Characters Based on Neural Network

In order to obtain the relationship between the characters in the novel more clearly, the study uses K-means to perform cluster analysis on the character vectors. The clustering steps of K-means are shown in Fig. 4.

In the clustering of K-means, the  $k$  samples in the data set are divided into  $k$  clusters by selecting an initial cluster center; and then iteratively optimizes the cluster center and refines the grouping. If the division of clusters is expressed as  $(B_1, B_2, \dots, B_k)$ , then the iterative goal of K-means is to minimize the value of formula (7).

$$E = \sum_{i=1}^k \sum_{x \in B_i} \|x - \mu_i\|_2^2 \quad (7)$$

In formula (7),  $\mu_i$  represents the centroid of the  $i$ -th cluster, that is, the  $B_i$  is the mean vector of all sample data in the  $i$ -th cluster, which can be calculated by formula (8).

$$\mu_i = \frac{1}{\|B_i\|} \sum_{x \in B_i} x \quad (8)$$

If the input data sample in K-means is expressed as  $A = \{A_1, A_2, \dots, A_m\}$ , a sample  $k$  is randomly selected in the data set  $A$  as the initial  $k$  centroid, expressed as  $\{\mu_1, \mu_2, \dots, \mu_k\}$ . At this time, the distance between a  $i$ -th sample  $x_i$  and the  $j$ -th centroid  $\mu_j$  is shown in formula (9).

$$d_{ij} = \|x_i - \mu_j\|^2 \quad (9)$$

$d_{ij}$  is the distance between all centroids and the sum  $x_i$  according to formula (9). Selecting the smallest centroid of  $d_{ij}$  as the new cluster center, and updating the cluster, such as in formula (10).

$$B_{\lambda i} = B_{\lambda i} \cup \{x_i\} \quad (10)$$

In formula (10), it represents the  $B_{\lambda i}$  th cluster after updating in the data set.  $i$  At this time, the centroid is recalculated. When the vectors of all centroids in the data set are no longer changing, it indicates that the clustering effect at this time is optimal, and the cluster division result is output at this time, see formula (11).

$$B = \{B_1, B_2, \dots, B_k\} \quad (11)$$

After the character clustering is completed, a model needs to be built to automatically classify novel characters, including character classification and gender classification. Among them, character traits are an important content for readers to understand the characters in novels, and also an important entry point for readers to analyze characters in novels. In psychology, there are many ways to analyze the character of a character. The paper selects the most authoritative and commonly used Myers-Briggs type index to analyze the character of the characters in the novel. The gender prediction is classified according to the characteristics of the characters, such as titles, actions, language, and emotions. The classification model is constructed using a neural network. In the work of automatic data classification, commonly used neural networks include perceptrons, BPNNs, and RBFNNs. This paper builds a classification model based on BPNN, and optimizes BPNN to improve classification performance. Firstly, an improved genetic algorithm with adaptive mutation (AGA) is proposed to obtain the optimal parameters of BPNN. The adaptive mutation probability of AGA is calculated by formula (12).

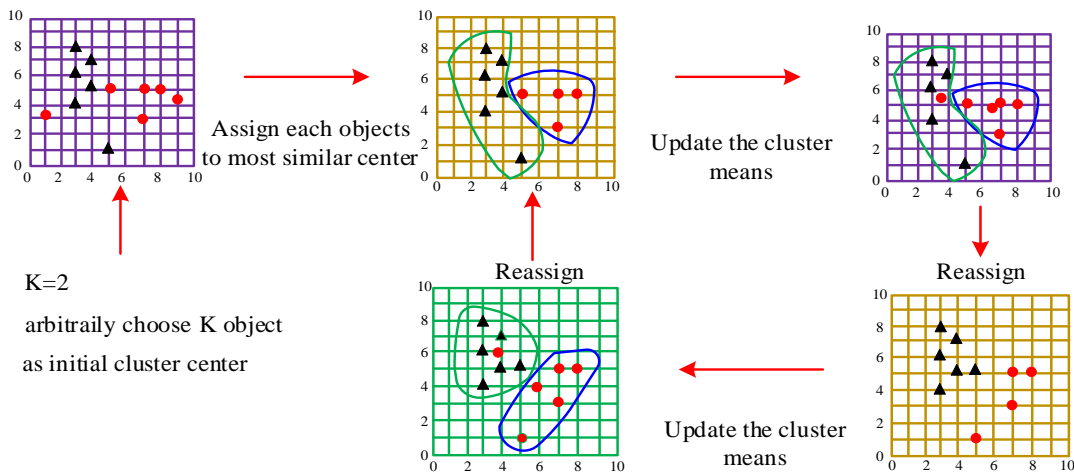


Fig. 4. Clustering steps of K-means.

$$P = \frac{P_1 + P_2}{2} = \frac{[P_0 - (P_0 - P_{\min}) \cdot m]}{M} + \frac{[P_0 \cdot \max_{X_k \in \Omega} F(X_k) / \bar{F}]}{2} \quad (12)$$

In formula (12),  $M$  is the total number of the updates of the algorithm.  $m$  is the current iterative update number of the algorithm.  $P_0$  is the initial variation probability.  $P_{\min}$  is the minimum mutation rate.  $\bar{F}$  is the average fitness value  $\max_{X_k \in \Omega} F(X_k)$  of the current population of the algorithm. In any update iteration of the algorithm, the probability of any individual in the population  $a_j$  being selected for mutation in this iteration can be calculated by formula (13).

$$z(a_j) = \frac{f(a_j)}{\sum_{j=1}^d f(a_j)} \quad (13)$$

In formula (13) of  $f(a_j)$ ,  $a_j$  is the fitness value, and  $d$  is the number of all individuals in the current population in AGA. Through the formula (13), the mutation probability of all individuals in the current population is calculated, and according to the accumulated probability value, it is judged which individuals can be inherited to the next generation. By this method, the prematureness of the algorithm can be avoided, and the deficiency of the weak global optimization ability of GA can be made up. Compared with the fixed mutation probability strategy adopted by traditional genetic algorithms, the adaptive mutation probability of genetic algorithms can adjust the mutation probability of the population according to the situation. This can enable the algorithm to better jump out of local optimization and enhance its global optimization ability. Therefore, using AGA to optimize BPNN can find the best parameters of BPNN better and faster and improve the performance of the model. Input the character vector into AGA-BPNN to realize the prediction and classification of character and gender. Based on the above content, the representation of novel characters based on neural network is realized, and then the intelligent and automatic analysis of novel characters is realized.

#### IV. EFFECTIVENESS ANALYSIS OF CHARACTER REPRESENTATION METHOD BASED ON AGA-BPNN

##### A. Effectiveness of $c\_pdnan\_vec$ Vector Representation

Based on the Skip-gram model, the study extracts and classifies novel character vectors, uses cosine similarity to calculate the similarity between different novel characters, and then uses K-means to cluster the extracted novel character vectors. In addition, the novel character vector is input into AGA-BPNN for training and learning, and the gender and

personality of the novel characters are predicted and classified through AGA-BPNN. Based on the above strategies, the intelligent and automatic analysis and representation of novel characters is realized. The English novels in PG are collected as experimental data to test the effectiveness of the proposed method. First, the validity of  $c\_pdnan\_vec$  character vector representation is verified. Four assumptions commonly used by literature researchers are used to verify  $c\_pdnan\_vec$ ,  $c\_nn\_vec$ ,  $c\_d\_vec$ ,  $c\_p\_vec$ ,  $c\_a\_vec$ ,  $c\_pdnan\_hot$ . The above six kinds of character vectors are used to represent the similarity between people in the four categories of hypotheses, and the similarity evaluation accuracy of each vector in the four categories of hypotheses is compared. The results are shown in Table II. It can be seen that on the four major assumptions, the average accuracy of the  $c\_pdnan\_vec$  vector representation is 1.00, 0.85, 0.76, and 0.62, and it performs best among the six vector representations. The  $c\_a\_vec$  vector representation has the worst performance. In the first type of hypothesis, the performance of the  $c\_pdnan\_hot$  vector representation is close to that of the  $c\_pdnan\_vec$  vector representation, but on the second to fourth types of hypotheses, the performance of the  $c\_pdnan\_vec$  vector representation is significantly better than that of the  $c\_pdnan\_hot$  vector. This is because  $c\_pdnan\_vec$  vector representation is more comprehensive and can reflect the character characteristics from many aspects. The test results verify the correctness of the  $c\_pdnan\_vec$  vector representation.

##### B. K-means-based Novel Character Cluster Analysis Effect

The paper uses the K-means algorithm to cluster novel characters. In order to verify the application effect of K-means in novel character clustering, it is compared with K-MEDOIDS, fuzzy C-means algorithm (FCM) and density-based clustering algorithm (DBSCN). Purity and clustering accuracy (ACC) are used to compare the performance of several methods on novel character clustering. See Table III for the Purity values of several methods. It can be seen that in the five experiments, the average value of K-means Purity is 0.75, which is 0.12, 0.11, and 0.13 exceed that of K-MEDOIDS, FCM, and DBSCN, respectively. These data show that the clustering effect of K-means is better. The distance between the readers and the characters in the novels can be shortened, and the distance between the readers and the author can also be shortened. Readers are more likely to feel that they are invited to experience the whole story.

The ACC are shown in Table IV. In the five experiments, the average ACC of K-means is 0.86, which is 0.05, 0.05 and 0.08 exceed that of K-MEDOIDS, FCM and DBSCN respectively. The above results indicate that K-means has a better application effect in novel character clustering and is more suitable for clustering analysis of novel characters, verifying the correctness of the K-means algorithm. This can achieve the goal of vividly portraying characters and creating a certain rhetorical effect.

TABLE II. SIMILARITY EVALUATION ACCURACY OF EACH VECTOR IN THE FOUR CATEGORIES OF ASSUMPTIONS

Vector representation	Number of experiments	Four categories of assumptions			
		1	2	3	4
c_pdnan_vec	1	1.00	0.86	0.76	0.68
	2	1.00	0.83	0.77	0.65
	3	1.00	0.87	0.75	0.62
	Average	1.00	0.85	0.76	0.65
c_nn_vec	1	0.80	0.68	0.18	0.25
	2	0.82	0.66	0.20	0.21
	3	0.75	0.64	0.17	0.25
	Average	0.79	0.66	0.18	0.24
c_d_vec	1	0.25	0.25	0.17	0.27
	2	0.20	0.26	0.19	0.29
	3	0.23	0.28	0.18	0.25
	Average	0.23	0.26	0.18	0.27
c_p_vec	1	0.50	0.50	0.48	0.14
	2	0.54	0.51	0.52	0.12
	3	0.45	0.53	0.53	0.11
	Average	0.50	0.51	0.51	0.12
c_a_vec	1	0.00	0.00	0.32	0.00
	2	0.00	0.00	0.30	0.00
	3	0.00	0.00	0.31	0.00
	Average	0.00	0.00	0.31	0.00
c_pdnan_hot	1	1.00	0.45	0.50	0.53
	2	1.00	0.43	0.49	0.52
	3	1.00	0.42	0.54	0.53
	Average	1.00	0.43	0.51	0.53

TABLE III. PURITY VALUE OF SEVERAL METHODS

Number of experiments	Purity value			
	K-means	K-MEDOIDS	FCM	DBSCN
1	0.75	0.63	0.64	0.55
2	0.73	0.66	0.52	0.54
3	0.75	0.58	0.68	0.63
4	0.78	0.69	0.70	0.71
5	0.74	0.59	0.65	0.65
Average	0.75	0.63	0.64	0.62

TABLE IV. ACC VALUE OF SEVERAL METHODS

Number of experiments	Purity value			
	K-means	K-MEDOIDS	FCM	DBSCN
1	0.85	0.80	0.76	0.76
2	0.91	0.82	0.85	0.75
3	0.87	0.84	0.82	0.72
4	0.82	0.83	0.77	0.84
5	0.86	0.78	0.86	0.82
Average	0.86	0.81	0.81	0.78

C. Effect Analysis of AGA-BPNN Classification Model

To verify the application effect of AGA-BPNN model in novel character gender prediction classification, this paper borrowed the Myers Briggs type index to analyze the personality characteristics of novel characters in personality prediction classification. Recording several personalities of the characters as 1~5. Compare the AGA-BPNN, GA-BPNN, and BPNN models to classify character personalities under different sample sizes, and verify the optimization effect of AGA on BPNN, as shown in Fig 5. In Fig. 5, when the number of samples ranges from 0 to 80, the prediction accuracy of the three models for character personality is high. When the number of samples exceeds 80, the prediction accuracy of BPNN drops significantly, the accuracy of

GA-BPNN model decreases to a certain extent, while the accuracy of AGA-BPNN model hardly changes. Overall, the accuracy of the AGA-BPNN model reaches 95.42% when performing character prediction and classification of novel characters; while the accuracy of the GA-BPNN model reaches 90.66%, which is 4.76% lower than the AGA-BPNN model; the accuracy of the BPNN model reaches 86.53% %, 8.89% lower than the AGA-BPNN model. It can be seen that in the prediction and classification of characters in novels, the accuracy of the AGA-BPNN model is significantly better than the other two models.

The same data is used to evaluate the gender prediction and classification ability of the above three models. Accuracy, Recall and F1 are selected as evaluation indicators. Fig. 6

shows the gender prediction and classification performance of the three models. It can be seen that the average accuracy, average recall and average F1 values of AGA-BPNN are 0.953, 0.962 and 0.929, respectively, which exceed GA-BPNN and BPNN models. The above results show that the model proposed in the study has better performance in gender prediction. This is because after the optimization of the AGA algorithm, the accuracy and convergence of the BPNN model have been improved, thus improving the accuracy of the

BPNN model for novel character classification. The average accuracy of the BPNN model reached 0.929, which has higher accuracy compared to the ReLU DNN network structure proposed by Plonka G et al. and the DPNN network proposed by Wright L G et al. To sum up, the methods proposed in the paper can accurately realize intelligent novel character representation and analysis, thus helping readers better understand the novel.

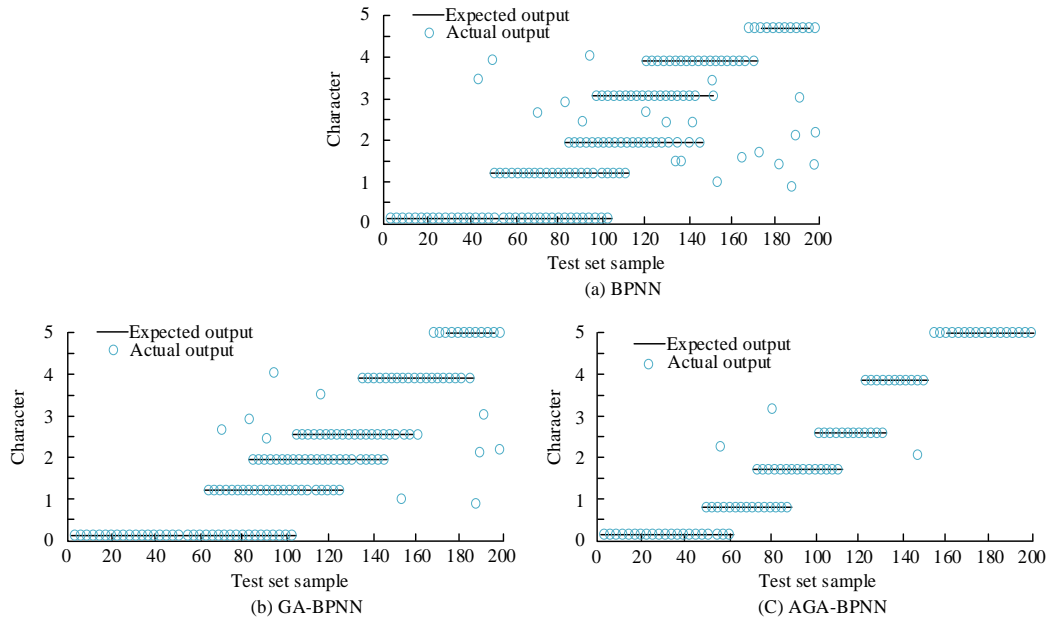


Fig. 5. Accuracy of AGA-BPNN classification of character.

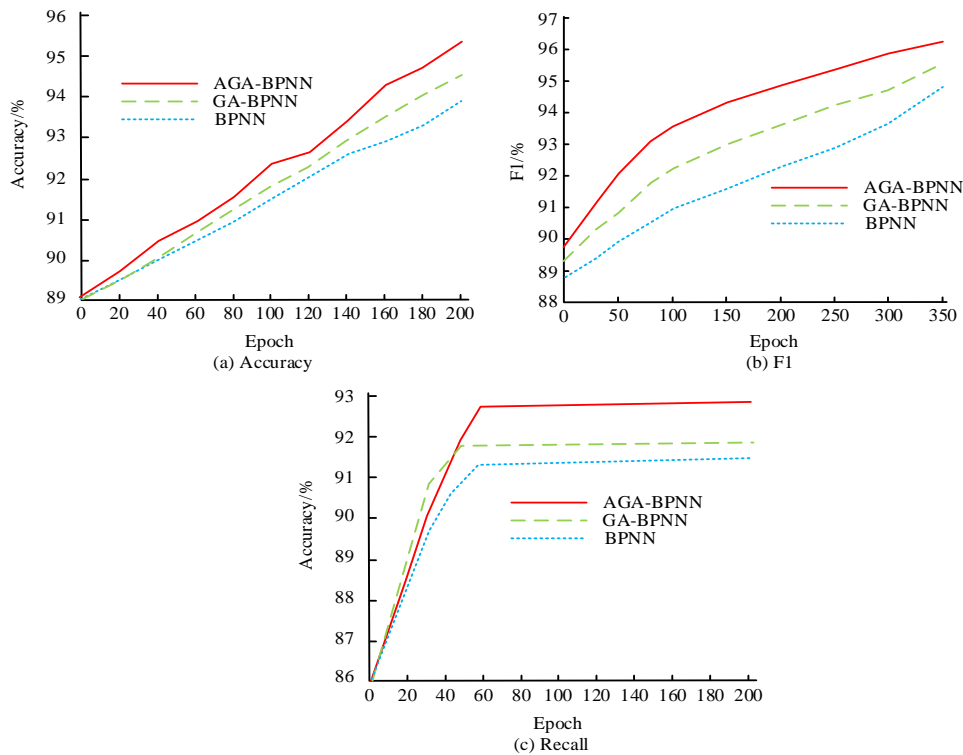


Fig. 6. Gender prediction and classification ability of three models.

## V. CONCLUSION

Character analysis in literary works is very important, and it is the basis for readers to understand novels. However, the existing analysis of characters in literary works is based on a single or a small number of novel characters, which is inefficient. Aiming at this problem, the paper is based on the Skip-gram model and the AGA-BPNN model to realize the vector representation. In the experiment, on the four assumptions, the average accuracy of c\_pdnan\_vec vector representation is 1.00, 0.85, 0.76, 0.62. Therefore, c\_Pdnan\_Vec vectors perform the best in terms of comprehensiveness among the six vector representations. The performance of VEC vector representation is the worst, which verifies the validity of c\_pdnan\_vec vector representation. The average value of K-means Purity is 0.75, 0.12, 0.11, and 0.13 exceed K-MEDOIDS, FCM, and DBSCN, respectively. The average value of ACC is 0.86, which is 0.05, 0.05, and 0.08 exceed K-MEDOIDS, FCM, and DBSCN, respectively. This confirms the effectiveness of K-means in novel character clustering work. When predicting and classifying characters in novels, the accuracy of the AGA-BPNN model reaches 95.42%, which is 4.76% exceed that of the GA-BPNN model and 8.89% exceed that of the BPNN model. When the sample size is between 0 and 80, the three models have higher prediction accuracy for character traits. When the number of samples exceeds 80, the prediction accuracy of BPNN decreases significantly, and the accuracy of GA-BPNN model decreases to a certain extent, while the accuracy of AGA-BPNN model remains almost unchanged. The accuracy of the AGA-BPNN model is significantly better than the other two models in predicting and classifying the personalities of novel characters. In the gender prediction classification of novel characters, the average accuracy rate, average recall and average F1 value of AGA-BPNN are 0.953, 0.962 and 0.929, respectively, which are exceed those of GA-BPNN and BPNN. The average accuracy of the BPNN model reached 0.929, which has higher accuracy compared to the ReLU DNN network structure proposed by Plonka G et al. and the DPNN network proposed by Wright L G et al. Compared to Bai X et al.'s approach of analyzing novel characters from a narrative perspective, research based on the Skip gram model and AGA-BPNN model provides a better understanding of character characteristics and article ideas. Therefore, the method proposed in the paper can accurately realize intelligent novel character representation and analysis, thereby helping readers to better understand the novel. However, the novel text data used in the experiment are all English novels, so the experiment only verifies the effect of the proposed method in the analysis of characters in English novels. In-depth research is needed in the future to verify the application effect of the proposed method in the analysis of characters in novels in other languages.

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# NLPashto: NLP Toolkit for Low-resource Pashto Language

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**Abstract**—In recent years, natural language processing (NLP) has transformed numerous domains, becoming a vital area of research. However, the focus of NLP studies has predominantly centered on major languages like English, inadvertently neglecting low-resource languages like Pashto. Pashto, spoken by a population of over 50 million worldwide, remains largely unexplored in NLP research, lacking off-the-shelf resources and tools even for fundamental text-processing tasks. To bridge this gap, this study presents NLPashto, an open-source and publicly accessible NLP toolkit specifically designed for Pashto. The initial version of NLPashto introduces four state-of-the-art models for Spelling Correction, Word Segmentation, Part-of-Speech (POS) Tagging, and Offensive Language Detection. The toolkit also includes essential NLP resources like pre-trained static word embeddings, Word2Vec, fastText, and GloVe. Furthermore, we have pre-trained a monolingual language model for Pashto from scratch, using the Bidirectional Encoder Representations from Transformers (BERT) architecture. For the training and evaluation of all the models, we have developed several benchmark datasets and also included them in the toolkit. Experimental results demonstrate that the models exhibit satisfactory performance in their respective tasks. This study can be a significant milestone and will hopefully support and speed-up future research in the field of Pashto NLP.

**Keywords**—NLP; text processing; word segmentation; POS tagging; BERT, LLMs; Pashto; low-resource languages; CRF; CNNs; RNNs

## I. INTRODUCTION

Pashto is an Indo-European language primarily spoken in Afghanistan and Pakistan. Written in the Perso-Arabic script, Pashto is also cursive, written right-to-left (RTL), and the letters take on different forms depending on their position in the word. Despite being the native language of a large population, NLP research in Pashto is still very rare, and sophisticated tools can hardly be found even for basic text-processing tasks, such as word segmentation and spelling correction. Additionally, the tools developed for other languages are not sufficient for Pashto text processing due to the complex and unique morphology of the language. Pashto is not a standardized language, lacking any golden rules to impose a uniform way of writing. For instance, it is a good practice to add space after each word in typing (writing with a keyboard), but in some cases, space omission is acceptable for human readers, which creates an issue for NLP applications. Without space between words, a naive NLP algorithm will consider the whole string as a single word. Due to this inconsistency in writing, any arbitrary Pashto text, whether on social media, news websites, or even books, is noisier compared to any other language.

This study aims to address the challenges in Pashto text processing and develop essential resources and state-of-the-art (SOTA) models for preliminary NLP tasks. All these resources and models, along with the benchmark datasets, are packaged in a toolkit named NLPashto, publicly available on GitHub and PyPi hub. The objective of toolkit is to enhance re-usability, avoid reinventing the wheel, and provide a single point of entry for further research in Pashto NLP. The initial prototype of NLPashto includes static word embeddings (Word2Vec, fastText and GloVe) and the first monolingual Pashto BERT, pre-trained on our custom-developed Pashto text corpus of 15 million words. The toolkit includes four SOTA models, three of which are general-purpose tools for basic text processing: spelling correction, word segmentation, and POS tagging, while the fourth model is for offensive language detection.

Most NLP algorithms require the input text split into individual units before processing. Two baseline techniques commonly used for converting text into tokens/words: whitespace tokenization and lexicon-based word segmentation. In whitespace tokenization, words are separated by whitespaces (spaces, tabs, or line breaks), commonly used in Western languages like English. On the other hand, languages that do not have spaces between words, such as Chinese and Japanese, use word segmentation, which is typically more complex because it involves identifying the boundaries between words and deciding which character belongs to which word. However, none of these techniques is perfect for the Pashto language. In Pashto, unlike English, the "space" is not consistently used for word separation and is not a reliable word delimiter, and unlike Chinese, space is a part of writing and cannot be completely ignored. To handle these limitations, we have developed two specialized machine learning models, one for spelling correction and the other for word segmentation. The spelling correction model can be used to identify the proper position of spaces in the text, remove extra spaces, or insert spaces where required. Once the spaces are corrected, we can use the baseline whitespace tokenizer to convert the text into tokens. The word segmentation model can be used in applications that need to split the text into "full" words rather than space-delimited tokens. For example, a NER application may need to extract "whole" words from text like "New York" rather than "New" and "York". Therefore, we have developed a specialized word segmenter for the Pashto language that will not break the compound words, such as *واره خواره* (dispersed) or *چيان مظاهره* (protesters).

POS tagging is also a fundamental text pre-processing task that involves assigning a grammatical category to each word



in a sentence, such as a noun, verb, adjective, or adverb. POS information is very helpful for AI models better understand the language, as they can learn more about the grammatical structure of the text, which could improve models' ability to generate coherent and grammatically correct text. It is one of the earliest types of annotation performed on corpora and is still used, for example, BNC [1], Brown Corpus and LCMC. POS tagging is not intuitive, as a particular word can have different tags based on the context. For example, in the sentence *وريکي واوره غرونو په* (it is snowfall on the mountain), the word *واوره* is a noun, while in the sentence *واوره خبره زما* (listen to me), *واوره* means "listen," which is an imperative verb. For automatic POS tagging, we have developed a machine learning-based POS tagger and included it in the toolkit.

The rise of social media has led to an increase in the dissemination of offensive language, which has a profound negative impact on the targeted individuals and the community. The sheer volume of content posted everyday, makes the manual removal of offensive content by human moderators unfeasible. Therefore, automated NLP systems for detecting offensive content have become essential. Significant research has been dedicated to this area in other languages, such as English [2], Chinese [3], Arabic [4], [5], [6], [7], Hindi [8], and German [9], to name a few. However, for the Pashto language there is no such research work available. In this study, we have developed a SOTA AI model for Pashto offensive language detection, trained on a dataset of tweets manually categorized as "offensive" and "not-offensive."

Toolkit development is an ongoing process, and we are actively working on NLPashto to make it more inclusive, though the progress we have already achieved can be summarized as follows:

We developed a *Pashto text corpus* of around 15 million words and used it to pre-train the *Static Word Embeddings* for Pashto. We developed the first monolingual *Pashto BERT* from scratch. We developed benchmark datasets and used them to develop four SOTA models for *Spelling Correction*, *Word Segmentation*, *POS Tagging*, and *Offensive Language Detection*. Finally, we packaged all the resources, benchmark dataset, and pre-trained models in a *Toolkit* and distributed them publicly on GitHub and PyPi hub to facilitate and speed up future research in this domain.

## II. RELATED WORK

Natural language toolkits have been utilized in the research and development of various NLP applications. One of the most widely known NLP toolkits is the Natural Language Toolkit (NLTK) [10], which is a Python library providing a comprehensive suite of tools and resources for NLP tasks, including tokenization, POS tagging, NER, sentiment analysis, and more. Another popular NLP toolkit is CoreNLP [11], which offers a set of core NLP tools similar to NLTK, such as tokenization, POS tagging, parsing, and NER. It also encompasses advanced tools like coreference resolution, relation extraction, and sentiment analysis.

In recent years, language-specific NLP toolkits have gained prominence, offering SOTA tools, datasets, and pre-trained models for specific languages. An example of such toolkits

is FudanNLP [12] for the Chinese language. FudanNLP employs statistics-based and rule-based methods to tackle various NLP tasks, including word segmentation, POS tagging, NER, dependency parsing, anaphora resolution, and time-phrase recognition. For Urdu, a sister language of Pashto, [13] developed the UNLT toolkit, which includes three preliminary NLP tools: word tokenizer, sentence tokenizer, and part-of-speech tagger. The word tokenizer utilizes a morpheme-matching algorithm combined with a stochastic n-gram model. The toolkit addresses space-omission through back-off and smoothing characteristics, and space-insertion is handled using a lexicon-based look-up technique. The POS tagger is based on HMM entropy-based stochastic and lexicon-based look-up techniques. InaNLP [14] is a natural language toolkit for the Indonesian language, which integrates several NLP modules, such as tokenization, sentence splitter, POS tagger, NER, syntactic parser, and semantic analyzer, with most of the models being rule-based. [15] developed a toolkit named CAMEL for the Arabic language. CAMEL provides tools for preliminary NLP tasks, including morphological analysis, dialect identification, and NER, with support for various Arabic dialects. DaNLP [16] is another toolkit for low-resource languages, specifically designed for Danish. It contains pre-trained models for NER, POS tagging, coreference resolution, and sentiment analysis and also includes benchmark datasets and static word embeddings. IceNLP, developed by [17], is an NLP toolkit for the morphologically complex Icelandic language. It encompasses essential pre-processing tools, such as tokenizer, sentence segmenter, rule-based taggers, finite-state parser, and morphological analyzer. For Vietnamese, [18] have developed VnCoreNLP, a toolkit that provides solutions for preliminary NLP tasks such as word segmentation, POS tagging, NER, and dependency parsing. Lastly, [19] developed an NLP toolkit for the Bengali language, which includes supervised machine learning models for tokenization, POS tagging, and NER, as well as other resources like word embeddings.

## III. CHALLENGES IN PASHTO TEXT PROCESSING

Pashto is not a standardized language, and there are no golden rules for the proper usage of space in the writing system, which leads to two typical spelling errors, space omission, and space insertion error. Besides that other challenges in Pashto text processing include non-standardized transliteration and homograph ambiguity.

### A. Space-omission Errors

A space-omission error occurs when the space between two words is ignored, causing the words to merge into a single string. For example, the phrase *داميز* (this table) has two words, *دا* (this) and *ميز* (table), but the space between the words is omitted, which is perfectly readable to a human reader and thus it is not considered to be a typo in Pashto; however, an NLP system will interpret and process the phrase as a single word.

### B. Space-insertion Errors

A space-insertion error occurs when a "useless" space is inserted within a word, splitting it into two or more (possibly meaningless) parts. For example, the words *خبريال* (reporter) and *يال خبر* look very similar, but the latter one has an extra

space between the two ligatures *خير* and *يال*. A human reader may consider it correct, but an NLP application treat each ligature as a separate word. An example sentence in Fig. 1, highlights the issues of both the space-omission and space-insertion errors.

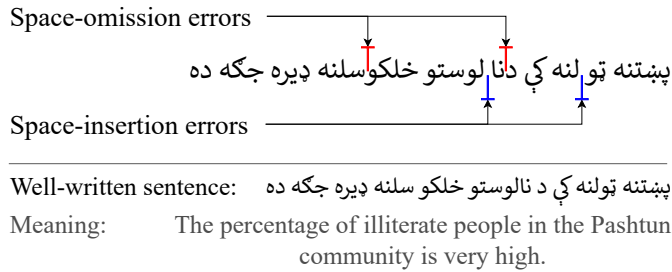


Figure 1. Example of space-omission and space-insertion errors.

### C. Non-standardized Transliteration

Transliteration is the process of converting the characters of one writing system into another, preserving the pronunciation of original words. Transliteration is very common in Pashto, but there are no standard rules to enforce one common spelling for foreign words transliterated into Pashto. The spelling of transliterated words usually depends on the choice of the writer (translator or transliterator), resulting in several variants of spellings for one word. For instance, the word "Coronavirus" has more than ten variants in our Pashto text corpus, e.g., *کرونا*, *کرونا وائرس* and *وائرس کورونا وائرس*.

### D. Homograph Ambiguity

Homograph ambiguity is a common issue, not only in Pashto but in many languages, which occurs when a word has more than one meaning. It can create ambiguity in the language, as the meaning of a homograph may be unclear based solely on its spelling. For example, the word "tear" in English can refer to a "liquid from the eyes" or "to rip apart forcefully". Similarly, in the Pashto sentence, *تور هغه* (he is wearing a black jacket), the word *تور* is an adjective, means "black", while in the sentence *تور دې د هغوي لکوي هیواد گاونډي په* (they blame the neighboring country for it), the word *تور* refers to "blame", which is a Common Singular Masculine Noun.

## IV. TEXT CORPUS AND BENCHMARK DATASETS

This project involves the development of word embeddings and a BERT model. Training these models requires a substantial corpus of text that should be diverse and representative of the entire language. However, Pashto is a low-resource language, where electronic textual content, large-scale corpora, and well-organized datasets are hard to find. Therefore, we developed a Pashto text corpus, for which we collected text from four primary sources: news websites, Wikipedia articles, books, and Twitter tweets. The corpus size is over 15 million tokens, with an average token length of 3.6 characters.

### A. Dataset for Spelling Correction and Word Segmentation Models

To develop the dataset for spelling correction, the first step was to obtain raw sentences. We used our Pashto text corpus, which consisting around 400K sentences. Our goal was to annotate each sentence for explicit word-boundary information. However, manually annotating such a large dataset was not feasible. So, we initially employed a lexicon-based approach to mark word boundaries.

Lexicon-based segmentation is an intuitive technique often used to divide text into words [20], [21]. It involves scanning a sequence of input characters and matching them against a lexicon of words. If the sequence is found in the lexicon, it is considered a word. To ensure matching the longest possible sequence, a variant of the lexicon-based approach called the Longest Matching (LM) algorithm is used. The LM is a greedy algorithm that strives to find the longest sequence. Since the LM algorithm starts the search from the beginning and moves forward, it is also called Forward Longest Matching (FLM). Another variant of the LM algorithm performs the search in the backward direction, known as Reverse Longest Matching (RLM). Sometimes, both FLM and RLM are combined to form Bidirectional Longest Matching (BMM).

To annotate our corpus, we incorporated the BLM technique with a small modification. Instead of looking up sequences of characters, we looked up sequences of tokens obtained from whitespace tokenization. A space in Pashto can either be a word delimiter or part of the word, where the purpose of annotation was to discriminate these spaces and mark them with explicit labels. We used the label "B" for word delimiters and "S" for the spaces that were part of the words. In the first round, after passing all 400K sentences through the lexicon-based model, 95K sentences were "fully" annotated, where no out-of-vocabulary (OOV) tokens were found. The "partially" annotated sentences, where at least one token was OOV, were further processed. The OOV tokens were extracted, manually inspected, and added to the lexicon if they were valid Pashto words. These partially annotated sentences once again passed through the lexicon-based segmenter, where some more sentences were fully annotated. This process was repeated several times with an updated lexicon each time. Finally, the size of the dataset reached 150K sentences (nearly 4 million words). It is worth mentioning that we used the same dataset for training both the spelling correction and word segmentation models.

### B. Part-of-Speech Dataset

To develop the POS dataset, we annotated the spelling correction and word segmentation dataset with POS information. For POS annotation, we initially employed the lexicon-based approach, in which the words in the sentences are looked up one by one in the lexicon and labeled with the corresponding POS tags. It is a context-free approach in which the surrounding information of the taken are not taken into consideration. In the first round, after passing all 150K sentences through the lexicon-based model, 80K sentences were fully annotated, with every word assigned a POS tag. Two example sentences are given in Fig. 2, annotated using this approach. In both sentences, the word *تور* has been assigned

the Singular Masculine Noun tag, though, in the first sentence تور means (black), which is an Adjective.

غوستی_NNM	كوت_NNM	تور_NNM	هغه_PRPIii
wearing	jacket	black	he

Meaning ≈ He is wearing a black jacket

لگوي_VBP	ولسمشر_NNM	په_IN	تور_NNM	دي_VBPC	د_IN	هغوي_PRPIii
...ing	president	on	blame	of the		they

Meaning ≈ They blame president for that

Figure 2. Example sentences, annotated using the lexicon-based technique.

After the lexicon-based annotation, we randomly selected 10K of the sentences for manual correction. Using a specialized web application we developed, sentences from the database were presented one by one to the annotators (human experts), with each word already assigned a static tag (by the lexicon-based tagger), and the job of the annotators was to verify or change the tags. This way, all 10K sentences were annotated for POS information with 100% (theoretical) accuracy. By analyzing the results of manual correction, we found that changes were made to around 7% of the tags by human annotators. It shows that the lexicon-based POS tagger can achieve an accuracy of 93%.

### C. Pashto Offensive Language Dataset

The Pashto Offensive Language Dataset (POLD) is a collection of tweets manually categorized into two classes: "offensive" and "not-offensive" (Fig. 3). The first step in creating the POLD dataset was to collect raw tweets in Pashto from Twitter. However, offensive tweets only make up a small portion of overall tweets, therefore, annotating random tweets was inefficient. To increase the size of the offensive class, we used a seed list of offensive words to filter tweets. To minimize bias and maintain diversity in the dataset, firstly, we made the seed list large and inclusive, and secondly, we analyzed many tweets and observed common patterns in offensive tweets, such as the use of second-person pronouns, i.e., ت (you: singular) or تاسو (you: plural), and included these patterns in the seed list. Using the Twitter Search API, we searched for each word and pattern in the seed list and collected nearly 300K raw tweets between January 10 and February 10, 2023.

The tweets corpus underwent several pre-processing steps, which involved removing HTML tags, URLs, usernames, and other special characters. Digits in non-Pashto format were normalized to the Pashto format, i.e., 1234 became . Duplicate tweets were deleted, and tweets with less than 10 characters or more than 150 characters were also discarded. The final corpus size dropped to 70K tweets, from that we randomly selected 35K (50%) for manual annotation.

The manual annotation was carried out by a total of five participants, including one of the authors and four paid professionals. Tweets containing any type of offensive language, such as hate speech, cyberbullying, aggression, abuse, or profanity, were assigned the label "1" (offensive), and the rest (normal or positive tweets) were assigned the label "0" (non-offensive). Each annotator individually tagged the complete

corpus without knowing the decisions of other annotators. The decision regarding the final status of the tweets made by a majority vote. The final POLD dataset consists of 34,400 tweets, with 12,400 labeled as offensive and 22,000 labeled as non-offensive.

## V. WORD EMBEDDINGS

Word embedding is a process that involves mapping words from a vocabulary to vectors of real numbers. The basic idea behind word embeddings is to learn a distributed representation of words based on their co-occurrence in a large corpus of text. A neural network is trained to capture the syntactic and semantic meaning of the words in the text. The network learns to associate words that appear in similar contexts with similar vector representations. The resulting vector representations can then be used as input for other machine learning models. NLP researchers generally prefer to utilize pre-trained word embeddings, typically trained on extensive corpora. However, for Pashto, no pre-trained word embeddings are currently available except fastText. Nevertheless, we pre-trained static word embeddings and a BERT model for the Pashto language and included them in NLPashto.

### A. Static Word Embeddings

We used the Pashto text corpus and trained the three popular types of static word embeddings: Word2Vec, fastText, and GloVe, and included them in the toolkit. For all three models, most of the hyper-parameters were kept uniform. The vector size was fixed at 100, the window size at 5, and the minimum count at 2, which is the minimum frequency needed for a word to be included in the final vocabulary. We chose the skip-gram architecture for Word2Vec and fastText and trained each model for 5 epochs. The GloVe model was trained using the GloVe package, while Word2Vec and fastText were trained using the Gensim and fastText Python libraries.

### B. Pashto BERT

The recent progress in Large Language Models (LLMs) has revolutionized the field of NLP. Some of the most popular LLMs in use today include BERT [22], GPT [23], XLM-R [24], and RoBERTa [25], to name a few. LLM takes into account the context in which a word appears in a sentence when generating the embeddings, which allows the model

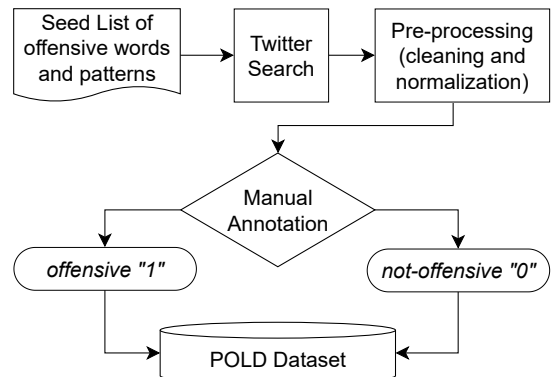


Figure 3. Procedure of POLD dataset development.

to capture the meaning and nuances of words in different contexts. These models are usually trained on multilingual data and can understand and generate text in several languages. However, for language-specific tasks, monolingual models generally outperform the multilingual models. In this study, we have trained a Pashto monolingual language model and included it in the NLPashto toolkit as well as publicly uploaded it to the Huggingface hub.

The model we utilized for training Pashto BERT is the BERT<sub>Base</sub>, which has 12 layers, 768 hidden states, 12 attention heads, and 110M parameters. Training data is our Pashto text corpus of 15 million tokens. To tokenize the input sequences, we used WordPiece tokenizer [26], which is the recommended tokenizer for BERT<sub>Base</sub>. We fixed the vocabulary size at 30K words and used special [CLS] and [SEP] tokens at the beginning and end of the sequences, respectively. To enable the model to differentiate between original and padded tokens, we employed an attention mask to generate a vector of 1s and 0s for each input sequence, where 0s indicate the padded tokens and 1s indicate the original ones. The hyper-parameters setup for pre-training is shown in Table I. We implemented the model architecture and training pipeline using PyTorch and the Huggingface transformers library, where training of the model performed on a cloud GPU – NVIDIA Tesla P100 that took nearly 2 hours to complete.

TABLE I. HYPER-PARAMETERS SETUP FOR PRE-TRAINING THE PASHTO BERT MODEL

Hyper-parameters	Values
Batch Size	32
Sequence Length	128
Padding	Post-padded
Learning Rate	1e-4
Linear Warmup Schedule	10K steps
$\beta_1$ and $\beta_2$	0.9, 0.999
L2 Weight Decay	0.01
Epsilon	1e-8

## VI. MODELS

The initial prototype of the NLPashto toolkit includes four SOTA AI models for (i) Spelling Correction, (ii) Word Segmentation, (iii) POS tagging, and (iv) Offensive Language Detection. The first three are essentially sequence tagging models that involve assigning a label or tag to each element in the sequence of input data. For sequence tagging tasks, NLP researchers use several supervised machine learning algorithms, such as HMM (Hidden Markov Model) [27], [28], RNN (Recurrent Neural Networks) [29], [30], [31], [32], [33], and CRF (Conditional Random Fields) [34], [35], [36], [37]. For various sequence tagging tasks, such as Word Segmentation and POS tagging, the CRF usually outperforms the other models. We have also incorporated CRF for training the three sequence tagging models. On the other hand, the model for offensive language detection is essentially a (binary) sequence classifier, which discriminates the input sequences into two categories, offensive and not-offensive. For that, we fine-tuned our pre-trained Pashto BERT model.

### A. Spelling Correction Model

The spelling correction module is aimed to remove the two typical spelling errors, the space-omission, and space-insertion. This model will predict the correct position of space in the text, insert a space where necessary, remove extra spaces from the sequence, and will return the noise-free text with the minimum required spaces.

1) *Features for Spelling Correction Model:* For modeling the spelling correction task, the “character” was considered as the basic text unit (like Chinese), and Pashto text was formalized as a series of characters and intervals as shown in Eq 1.

$$C_1I.C_2I.C_3I...IC_n \quad \text{for } I \in \{J, S\} \quad (1)$$

where  $C$  means a character, and  $I$  means an interval between the two characters, where the interval can be a space or “none”. Each character in the dataset was assigned with one of the two tags: an “S” if the character is followed by a space or a “J” otherwise, where “J” stands for “Joined”. Features for training the spelling correction model are the target character itself and n-grams of characters before and after the target character, based on which the CRF algorithm predicts whether the character is followed by a space or not. A summary of the features for the spelling correction model is as follows:

- The target character  $C$
- Check if  $C$  is the first character in the sentence, last on neither
- n-grams of characters before and after  $C$ , where the value of  $n$  ranges between 1 and 4

2) *Experimental Results:* For the experiment, we used the sklearn-crfsuite library in Python. Hyper-parameters were tweaked for optimal results, where both  $c_1$  and  $c_2$  were set to 0.1, representing  $L_1$  and  $L_2$  regularization, respectively. The L-BFGS method was selected as the training algorithm. The dataset of labeled characters was converted into a CRF-friendly dataset of features. 80% of the dataset was used for training, and the remaining portion was used to test the model.

The spelling correction model achieved an F1-score of 99.16% with an accuracy of 99.35%. The contribution of different pairs of n-grams and their combined effect is given in Table II. The model performed its best for n-gram in the range between 1 and 4, which is very logical considering the average token length of 3.6 characters. By utilizing 4-grams before and after the target character, the model captures information from a total of 9 characters. Overall the model’s performance is quite satisfactory, making it useful in practical applications.

TABLE II. CONTRIBUTION OF THE PREVIOUS AND NEXT N-GRAMS AND THEIR COMBINED EFFECT IN MODEL’S PERFORMANCE, IN TERMS OF F1-SCORE (%)

n-grams	Previous	Next	Combined
1	82.42	88.18	91.22
2	88.25	93.78	96.99
3	92.86	96.61	98.87
4	94.61	97.44	<b>99.16</b>

## B. Word Segmenter

Similar to the spelling correction model, the word segmenter is also a sequence tagging model based on the CRF algorithm. However, the word segmenter considers the token-level information instead of character-level information. A token is the basic unit for feature extraction, which can be the character in Chinese [31] and Javanese [34], syllable in Burmese [38], or character cluster (KCC) in Khmer [39]. In the proposed Pashto word segmenter, a token is a space-delimited “string” of characters, which can be a single character, such as د (of), or a string of any arbitrary length like افغانستان (Afghanistan), which has nine characters.

1) *Features for Word Segmenter*: For modeling the word segmentation task, the token was considered as the basic unit, and Pashto text was formalized as a series of tokens and intervals as shown in Eq. 2.

$$T_1 I T_2 I T_3 I \dots I T_n \quad \text{for } T \in \{S, B\} \quad (2)$$

where  $T$  means a token, and  $I$  means Interval (or space) between two tokens. The space can be a word-delimiter or a separator between two ligatures of a compound word. All the tokens in the dataset were assigned one of the two tags, an “S” if the token is followed by a “simple” space or a “B” if the token is followed by a word-breaker (word boundary). Pashto is a language with a rich morphology, and words are inflected to express various grammatical and syntactic information. These inflections are mostly exhibited in the form of prefixes and suffixes of the words, which are very informative and, in most cases, enough for locating the word boundary. The features for the word segmenter include these morphological attributes and context information of the token. Following is the list of features, finalized after trial and error:

- The *token*
- Length of the *token*
- One and two characters prefixes and suffixes of the *token*
- All the above features for previous and next token
- Three-characters prefix and suffix of the *token*
- Is *token* first in the sentence, last or neither
- Is *token* numeric
- Previous and next tokens up to two places

2) *Experimental Results*: The contribution of various features and their combined effect on the model’s performance is presented in Table III. The results show that without context information (Previous and Next tokens), the model achieves an F1-score of 79.87%. However, combining the features of surrounding tokens increases the F1-score to 96.81%. It demonstrates the model’s ability to predict the boundary of the word, even if it has not been encountered before, thereby overcoming OOV errors that occur in the baseline lexicon-based segmentation approach.

## C. Part-of-Speech Tagger

Similar to the previous two models, the POS tagger is also modeled as a sequence tagger based on the CRF algorithm. However, the dataset for the POS tagger has 10K sentences, which is comparatively smaller. Unlike the lexicon-based word segmenter, the lexicon-based POS tagger yields a very high error rate (around 5%), leads to a laborious and time-consuming manual correction phase. To extend the size of the dataset with reasonable speed, we adapted an iterative approach where the model training and dataset development were carried out in parallel in several rounds, as shown in Fig. 4.

In the first round, we used the POS dataset of 10K sentences to train the initial prototype of the model. This model was then used to annotate another chunk of 10K sentences, followed by a manual correction phase add then added to the dataset. This process was repeated for several rounds, where each round has basically two phases, an automatic POS assignment, and manual correction. In each round, the amount of training data was increased by an amount of 10K sentences, and consequently, the accuracy of the model increased as well. With the reduction in the error-rate of the model, the burden on human annotators reduced as well, and the manual correction phase became less time-consuming.

1) *Tagset*: A Tagset is a list of POS labels/tags used to indicate the part-of-speech of each word in a text corpus. In this study, we used the tagset proposed in [40], which follows the naming convention similar to the Penn Treebank [41] that is one of the commonly adopted conventions by various corpora. Our tagset has a total of 38 tags, which is very concise and pragmatic and enough to encompass all the words. The disagreement of the researchers is respected, and a non-tagged version of the corpus is also included in the toolkit, which can be tagged using any preferred tagset.

2) *Features for Part-of-Speech Tagger*: The contexts used to predict the POS tag in Pashto are roughly similar to that used for English. These are the surrounding words and word components. Pashto has a similar or maybe richer morphology than English, where words are enriched by various affixes that

TABLE III. CONTRIBUTION OF VARIOUS FEATURE SETS AND THEIR COMBINED EFFECT ON MODEL’S PERFORMANCE

Feature set	Accuracy (%)	F1-score (%)
Token	98.12	79.87
Previous	98.31	81.24
Next	98.61	86.34
Combined	99.65	<b>96.81</b>

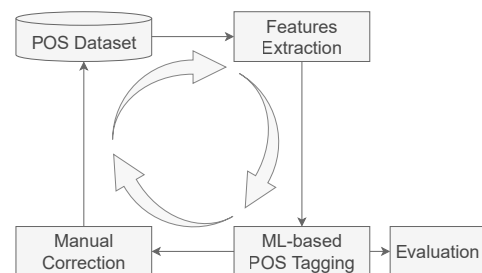


Figure 4. Iterative training of the POS tagger.



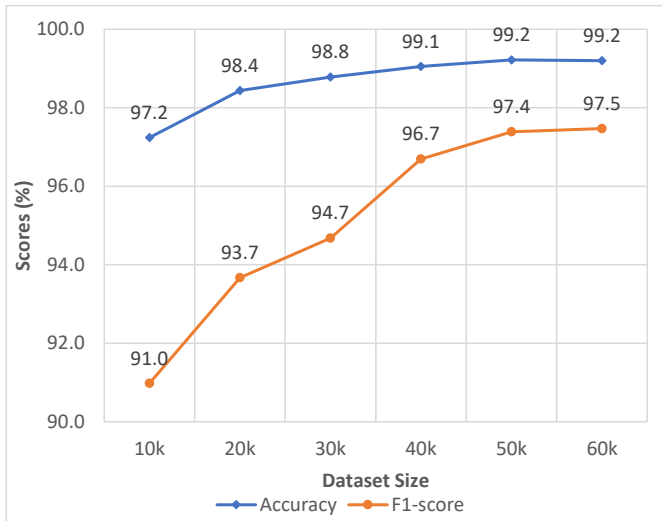


Figure 5. Improvement in performance of the POS tagger with the increasing dataset size. Lx.B represents the lexicon-based segmentation.

can be exploited for feature extraction. For training the POS tagger, we considered the same features as the word segmenter model, which are the morphological components of the token and the neighboring tokens.

3) *Experimental Results:* For the implementation and training of the POS tagger, we followed the same experimental setup as the previous two models, including the hyper-parameters and ratio of the dataset train and test splits. However, we trained the POS tagger in several rounds, starting from a dataset of 10K sentences and gradually increasing the dataset size until the model achieved significant performance. The model's performance was evaluated after each round, as plotted in the graph in Fig. 5. In the first round, the model secured an accuracy of 97.2% with an F1-score of 91.0%, which was an improvement of 4.2% in terms of accuracy in comparison to the baseline lexicon-based approach, which achieves an accuracy of 93.0%. After six rounds of training, the dataset size reached 60K sentences (nearly 1.5 million words), and consequently, the accuracy of the model reached 99.2% with an F1-score of 97.5%. This performance is significantly better than the baseline.

#### D. Offensive Language Detection Model

The model for Offensive language detection is based on the transfer learning approach. Conventional machine learning generally involves training a model from scratch using a large dataset, whereas transfer learning uses a pre-trained model as a starting point to solve a new task, called fine-tuning. The pre-trained model we fine-tuned is our Pashto BERT model, which is pre-trained on a generic text corpus; where the purpose of fine-tuning is to adapt it to the specific task of offensive language detection by fine-tuning its parameters on the labeled dataset, POLD.

To our knowledge, no previous research work is available on Pashto offensive language detection. Hence, for the evaluation, we also fine-tuned a multilingual language model, XLM-R [24]. Several other multilingual models are also available,

TABLE IV. PARAMETERS FOR FINE-TUNING THE TRANSFORMER MODELS

Parameters	XLM-R	Ps-BERT
Learning Rate	2e-5	5e-5
Batch Size	16	16
Sequence Length	100	100
$\beta_1, \beta_2$	(0.9, 0.999)	(0.9, 0.999)

though most of these are missing Pashto, while XLM-R can understand text in 100 languages, including Pashto. Besides transfer learning, we also investigated the classic neural network-based models, such as CNNs and various types of RNNs, using the static word embeddings, Word2Vec, GloVe, and fastText as features.

1) *Fine-tuning BERT models:* Fine-tuning a BERT model involves adding a classification layer on top of the model and training it on a specific dataset. For sequence classification, BERT takes the final hidden state of the classification token, identified by [CLS], as the representation of the whole sequence of text. We fine-tuned both the multilingual XLM-R and monolingual Pashto BERT on the task-specific POLD dataset. We tokenized the tweets and added special tokens [CLS] and [SEP] to mark the beginning and end of the sequence, respectively. However, the tokenizers used by the XLM-R and vanilla BERT are different, where XLM-R uses SentencePiece [42] tokenizer, while BERT expects the text to be tokenized by the WordPiece tokenizer. We implemented the models in PyTorch and Huggingface transformers library and used a GPU-facilitated Kaggle platform to conduct the experiments. We used the hyper-parameters given in Table IV and trained each model for 3 epochs.

2) *Neural Network-based Models:* As the baseline classifiers, we examined the performance of five neural networks, the CNNs, and four types of RNNs (LSTM, Bi-LSTM, GRU, and Bi-GRU), across three types of word embeddings: Word2Vec, fastText, and GloVe, as features. The primary components of our neural network models are the embedding layer, hidden layer, and output layer. The Embedding layer is the first hidden layer, which is a matrix of size  $pq$ , where  $p$  is the vocabulary size, and  $q$  is the sequence length, fixed at 64 tokens. To prevent overfitting, We used a dropout of 0.2. The output layer employs the Sigmoid activation function and Adam optimizer and uses cross-entropy loss to predict the tweet's category.

Besides the upper-mentioned common components, each model has its own adaptation and hyper-parameters setup. For CNNs, we constructed a 1D convolutional layer with 100 filters and a kernel size of 4. The next layer is max-pooling, followed by a dropout layer, and finally the output layer. The LSTM model has one LSTM layer with 100 units and a dropout layer, followed by a classification layer. The same architecture is used for the GRU model also, with the LSTM layer replaced by GRU. To build the Bidirectional LSTM, we construct one Bi-LSTM layer with 100 hidden units. The output vectors are flattened and fed to the classification layer. The Bi-GRU is using the same configuration of Bi-LSTM, except for the first layer which is replaced by the Bi-GRU. We used the batch size of 32 and trained each model for 5 epochs.

3) *Experimental Results:* We performed a series of experiments investigating various models for the task of Pashto



TABLE V. COMPARISON OF ALL THE MODELS FOR OFFENSIVE LANGUAGE DETECTION

Model		Accuracy (%)	F1-score (%)
Features	Classifier		
Word2Vec	BiGRU	92.33	91.50
	BiLSTM	92.85	92.09
	CNN	90.29	89.08
	GRU	92.94	92.18
	LSTM	93.23	92.52
GloVe	BiGRU	93.40	92.74
	BiLSTM	93.40	92.76
	CNN	92.97	92.24
	GRU	93.43	92.75
	LSTM	93.40	92.78
fastText	BiGRU	93.46	92.82
	BiLSTM	93.49	92.81
	CNN	92.24	91.44
	GRU	93.49	92.82
	LSTM	93.72	93.08
XLM-R		94.48	94.01
Ps-BERT		94.77	94.34

offensive language detection. A performance evaluation is presented in Table V. The results exhibit that the transformer models achieve comparatively better performance than the classic neural networks. Among all the models we examined, the fine-tuned monolingual Pashto BERT demonstrates the best performance which yields an F1-score of 94.34% with an accuracy of 94.77%. The XLM-R performed poorly compared to the Pashto BERT, yet better than the neural networks. Concerning the neural network models, the results indicate that the RNNs performed better than CNNs, where the LSTM classifier with fastText embeddings outperforms the other models and achieve an F1-score of 93.08% with an accuracy of 93.72%. In bidirectional RNNs, BiGRU performs the best with fastText features and achieves an F1-score of 92.82% with an accuracy of 93.46%. On the downside, the CNN model with Word2Vec embeddings exhibits the lowest performance.

### E. Comparison of Static Word Embeddings

Fig. 6 illustrates the performance comparison of the static word embeddings, using the LSTM classifier. The results show that the fastText achieves the highest F1-score of 93.08% with an accuracy of 93.72%. One reason is that the fastText model uses sub-word tokenization, which is particularly useful for the task of offensive language detection, as the OSN users commonly write half words instead of the full form, or use alteration. For example, on English social media, words like “f\*ck”, “b!tch”, “c#ck”, etc., are commonly used, where the same convention is used in Pashto also. This way of writing often leads to OOV errors in Word2Vec and GloVe, while in fastText, if a word is not present in the vocabulary the sub-words might be, which is useful in obtaining representations for altered, misspelled, or half-words.

## VII. CONCLUSIONS

Pashto is a low-resource language and lacks the basic tools and resources required for NLP. This study aimed to develop SOTA models, benchmark datasets, and other preliminary resources necessary for the research in Pashto NLP. To facilitate the reuse of our findings, we packaged everything

in a toolkit called NLPashto and distributed it publicly on GitHub<sup>1</sup> and PyPi<sup>2</sup> hub. The initial prototype of NLPashto consists of three general-purpose models for basic text pre-processing, a spelling correction model, a word segmenter and a POS tagger, and a special-purpose model for detecting offensive language (particularly on social media). Additionally, the toolkit includes three pre-trained static word embeddings: Word2Vec, fastText, and GloVe, as well as a pre-trained monolingual Pashto BERT for dynamic word embeddings. All the SOTA AI models we developed are based on the supervised learning approach, trained on labeled datasets. The toolkit also includes the benchmark datasets we developed for training and evaluating the models. The evaluation results show that our Pashto BERT model outperforms the multilingual XLM-R, even though the corpus used for training the Pashto BERT is much smaller in comparison to the XLM-R corpus. Similarly, all the other models included in the NLPashto toolkit perform quite satisfactorily on their respective tasks and can be used in practical applications. In summary, this is a pioneering study on Pashto NLP, and we hope that our findings and the resources and tools we developed will facilitate and speed up future research in this domain.

Toolkit development is an ongoing process, and we are continuously working to add more modules in the upcoming prototypes of NLPashto, such as NER and Constituency and Dependency Parsing. Apart from that, there are several research areas yet to be explored in Pashto NLP, such as stemming, lemmatization, machine translation, text-to-speech, and speech-to-text.

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<sup>1</sup>NLPashto on GitHub: <https://github.com/ijazul-haq/nlpashto>

<sup>2</sup>NLPashto on PyPi Hub: <https://pypi.org/project/nlpashto/>

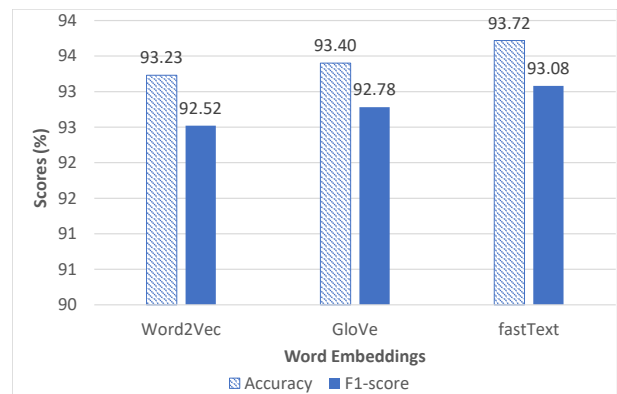


Figure 6. Comparison of the static word embeddings using LSTM classifier.

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# Intelligent Traffic Video Retrieval Model based on Image Processing and Feature Extraction Algorithm

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**Abstract**—Intelligent transportation is a system that combines data-driven information with traffic management to achieve intelligent monitoring and retrieval functions. In order to further improve the retrieval accuracy of the system model, a new retrieval model was designed. The functional requirements of the system were summarized, and the three stages of data preprocessing, feature matching, and feature extraction were analyzed in detail. The study adopted preprocessing measures such as equalization and normalization to minimize the negative effects of noise and brightness. Based on the performance of various algorithms, the distance method was selected as the feature matching method, which has a wider applicability and is better at processing bulk data. Next, the study utilizes Euclidean distance method to extract keyframes and divides the feature extraction into three parts: color, shape, and texture. The methods of color moment, canny operator, and grayscale co-occurrence matrix are used to extract them, and ultimately achieve relevant image retrieval. The research conducted multiple experiments on the retrieval performance of the model, and analyzed the results of retrieving single and mixed features. The experimental results showed that the algorithm performed better in the face of mixed feature extraction. Compared with the average value of a single feature, the recall and precision of the three mixed features increased by 13.78% and 15.64%, respectively. Moreover, in the case of a large number of concurrent features, the algorithm also met the basic requirements. When the concurrent number was 100, the average response time of the algorithm is 4.46 seconds. Therefore, the algorithm proposed by the research institute effectively improves the ability of video retrieval and can meet the requirements of timeliness, which can be widely applied in practical applications.

**Keywords**—Matching extraction; feature fusion; image retrieval; intelligent transportation

## I. INTRODUCTION

As the economy continues to grow, the basic needs of the people continue to develop, which is reflected in the field of transportation by the large increase in the number of private cars, which not only causes serious environmental pollution, but also provides greater pressure on traffic management. Therefore, China vigorously promotes the intelligent transportation, combining data-based information with traffic management to achieve automated detection and retrieval of surveillance images, which greatly improves the efficiency of transportation and reduces the burden of manpower, and is an effective way to retrieve target images [1]. Today's video image retrieval systems have been able to achieve real-time extraction functions, while providing appropriate processing

methods. First of all, it is necessary to install surveillance at different intersections or streets, and the intelligent transportation system is divided and displayed according to the area. The supervisory equipment of the video can help the relevant staff to realize the real-time processing of effective information, and also has five functions of list classification, live video, quick screenshot, remote lens control and setting up display image parameters. Among them, the list display can make the video classification more efficient. The system automates the display of list data through a tree diagram format, with the installation location as the title and the boundaries according to each area, and can usually view 1 to 16 surveillance screens simultaneously. It can also be further assisted by features such as quick screenshots and remote control of footage. Human adjustment of each parameter can also be utilized during live video streaming to assist in completing the work efficiently. Administrator-centric maintenance of organizational units, devices, i.e., surveillance points, and electronic maps can be implemented at [2, 3]. Image retrieval can be applied to areas such as traffic flow statistics, i.e., the use of image features to count the flow of people and vehicles. These informational functions greatly reduce the pressure of traffic management, because the traditional manual detection methods are not only time-consuming and laborious, but also have a very limited scope of work. The new digital management can help traffic management to be smoother and more accurate [4]. The video image retrieval system can provide great value to the traffic field, so the study explores the intelligent traffic system based on image processing and feature extraction algorithm, and designs three stages of data pre-analysis of traffic, feature matching of video and image, and feature extraction, and the study aims to further enhance the development of intelligent traffic. The main contribution of the research is to design and build the architecture of video surveillance systems, complete the collection and monitoring of image data, and then utilize video stream keyframe extraction technology to integrate various image analysis and processing sub-functional modules, forming effective algorithms for analyzing and identifying surveillance objects.

The research content is mainly divided into four parts. The first part is a summary and analysis of domestic and foreign scholars' research on image retrieval technology and image processing technology. The second part is to study and construct a smart transportation model, which describes the extraction of image color and texture features. The third part is to conduct performance experiments on the proposed method

through experiments, and verify the feasibility of the research method through scientific control. The fourth part summarizes the research and analyzes the shortcomings in the current research, while proposing future research directions.

## II. RELATED WORKS

The image retrieval function of video has been studied by many scholars in various fields. Yan et al. [5] concluded that video image retrieval also has some security privacy issues. Based on this, they proposed a new class of secure video retrieval method to maintain user privacy based on cryptographic type vector expansion approach, and experimentally verified that this cryptographic retrieval yielded the same results as ordinary retrieval. Radenović et al. [6] proposed a convolutional neural network based image retrieval method; This method is highly compact as well as extremely efficient in extraction, at the same time it also requires a large amount of data support for the training of the model; The study used the method of adjusting cellular neural networks, using automated retrieval of random images, introducing concepts such as hard positives. This is to further improve the efficiency of the algorithm and achieve efficient operation of image retrieval. Veres and Moussa [7] considered that the transportation system is a more complex. This system requires the modules to operate in cooperation with each other, which contains a large number of temporal and spatial features, so building a model for this system is difficult. The study then proposes a deep learning theory, gives a detailed overview of its development in transportation systems, and provides solutions for its development and other problems. Chen et al. [8] argued that traditional transportation systems should have been overturned long ago. Consequently, the study applies a deep learning theory based on edge nodes to traffic flow data, introduces a detection algorithm for YOLOV3 and a deep simple online tracking algorithm for vehicle detection purpose. Gohar and Nencioni [9] combined smart transportation with 5G technology. Then they provide an overview of the background as well as the prospect of 5G technology and describe its application in smart transportation system in detail and also analyze its application in other fields. The study uses image processing based as well as feature extraction algorithms to design traffic systems. Rovithakis et al. [10] used hybrid neural networks as well as genetic algorithms for feature

extraction and apply it to medicine. This is to identify normal and cancerous cells whose features generate highly dispersed classes in space while using spectral classification to achieve further testing. Xu et al. [11] considered the use of the study discussed the temporal characteristics of the data and proposed a nonlinear data feature extraction technique, i.e., kernel principal component analysis. This technique first maps the low-dimensional data into a high-dimensional space and completes the feature extraction in that control. Then the study compared this method with the linear PCA method experimentally, and obtained that the kernel principal component analysis method has better. The key to more efficient feature extraction is to compress the data, which can achieve the purpose of discarding irrelevant signals, excluding noise and various redundant feature data. Zebari et al. [12] used a combination of FS and FE method for feature extraction and verified the reliability performance of the method through comparative experiments.

In the above analysis, scholars have used various algorithms to retrieve videos or images, etc., in order to achieve intelligent transportation. Their research used combinatorial algorithms to construct models and obtained relatively reliable results. However, the results basically only meet the minimum requirements for practical applications, and in the face of complex video environments, its performance is difficult to achieve the same effect. Therefore, research suggests that in smart transportation, algorithms still need to have better performance. Inspired by the above literature, the study combines image processing technology, feature extraction technology, and other technologies to form a composite model. This model is applied to the field of transportation.

## III. INTELLIGENT TRAFFIC SYSTEM BASED ON VIDEO IMAGE RETRIEVAL

### A. Intelligent Transportation System Data Pre-processing

The study adopts a video retrieval system based on image processing technology and feature extraction algorithm. The system contains five main aspects, which are: image processing, data storage, monitoring and management, and traffic flow statistics. The flow chart of the whole system is shown in Fig. 1.

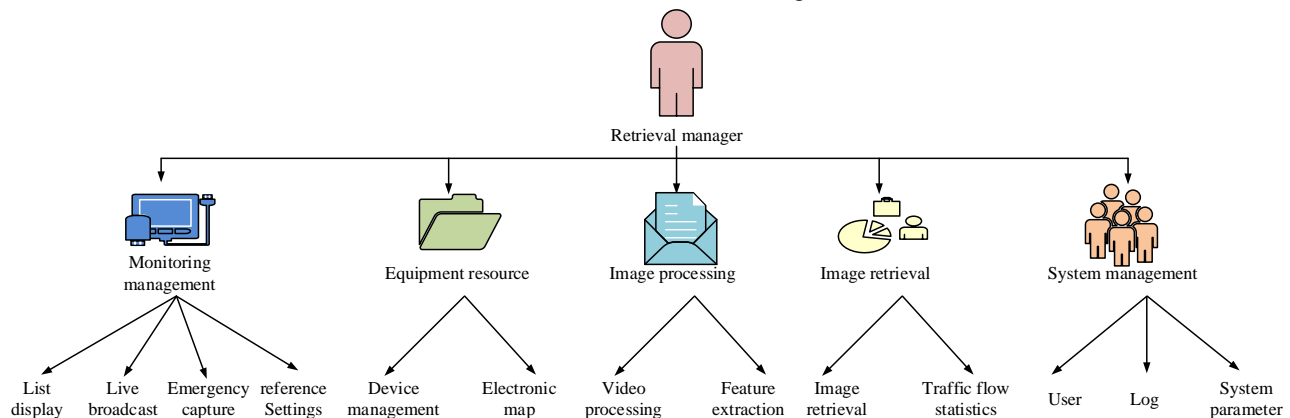


Fig. 1. Intelligent transportation system.

Data preprocessing is performed in order to eliminate as many extraneous signals as possible and to make the subsequent image processing steps more efficient. Data preprocessing includes data normalization, noise exclusion, and attenuated luminance [13]. The formula is shown in Equation (1):

$$f(D) = \frac{D_m}{A_0} \int_0^D H(u) du = D_m \int_0^D \frac{H(u)}{A_0} = D_m P(D) \quad (1)$$

In Equation (1),  $D_m$  denotes the maximum gray value in the image set;  $A_0$  denotes the total pixel value in the image set;  $H(u)$  denotes the total number of all pixels in the image set whose gray value is not equal to 0;  $P$  represents the probability of the occurrence of grayscale values in an image. This equalization method is based on the mutual difference relationship of pixel gray values for feature recognition. The difference between the gray value of a pixel and its neighboring pixels within a certain range is used as the judgment criterion. When it exceeds a certain threshold value, it means that the point is an irrelevant signal, i.e., it has a correlation crossover with other points and should be discarded; on the contrary, the point can be regarded as a valid signal to be retained, and the expression of the whole process is shown in Equation (2):

$$y_{ij} = \begin{cases} med(W[x_{ij}]), x_{ij} = \min \text{ or } \max \\ x_{ij}, x_{ij} = \text{other} \end{cases} \quad (2)$$

In the above Equation (2),  $y_{ij}$  represents the pixel value of the output point  $(i, j)$  after equalization;  $x_{ij}$  represents the initial pixel value of the input;  $W$  represents the weighting operation; and  $med$  represents the intermediate value function of the solution. In summary, the pre-processing of video, i.e., screening key frames and eliminating noisy signals, finally constructs an image basic element that can realize feature extraction. The basic principle of feature matching is to realize the feature matching process by comparing the feature data of the desired image with the image feature information in the database, and using the similarity as the judgment criterion. There are five main categories of feature vector matching algorithms that are relatively advanced in development today. One of them is the histogram crossover algorithm described above, and the second one is the cardinality split-box algorithm, i.e., feature matching by means of cardinality test, when the cardinality value  $\chi$  is small, the correlation is weak, and vice versa, the correlation is strong [14]. The expression is shown in Equation (3):

$$\chi^2 = (Q, I) = \sum_i \frac{(Q_i - I_i)^2}{(Q_i + I_i)^2} \quad (3)$$

In the above Equation (3),  $Q$  and  $I$  represent the histogram of the target image and the histogram of any image in the database, respectively,  $i$  represents the stalk in each histogram. The Kolmogorov-Smirnov algorithm is a method of dimensionality reduction of data using spectral analysis, which can reduce the storage cost, but a large number of

decomposition clusters will increase the computational pressure and lead to lower efficiency. The distance method  $L^p$  is calculated as shown in Equation (4) [15].

$$L^p(x, y) = \left( \sum_i |x_i - y_i|^p \right)^{1/p} \quad (4)$$

In the above Equation (4),  $x$  and  $y$  represent the contents of the target image and the value of the image matched with it in the database, respectively. When the parameter  $p$  is 1, the algorithm uses the Euclidean paradigm, i.e., the distance of  $L1$ , as the basis of the calculation result; when the parameter  $p$  is 2, the Manhat tan paradigm, i.e., the distance of  $L2$ , is used as the basis of the calculation result. Considering according to the research needs and combining the advantages and disadvantages performance of each algorithm, the study selected  $L^p$  distance method as the matching feature method, which is not only applicable, but also has short computation time and relatively easier to implement [16].

### B. Extraction of Color Features in Video Images

The image retrieval requires a combination of feature matching and feature extraction. Then comes the feature extraction of video images, which can be roughly divided into three parts: color feature extraction, texture feature extraction, and shape feature extraction. In this study, color moments are used to achieve feature extraction, and the overall color feature matching process is shown in Fig. 2.

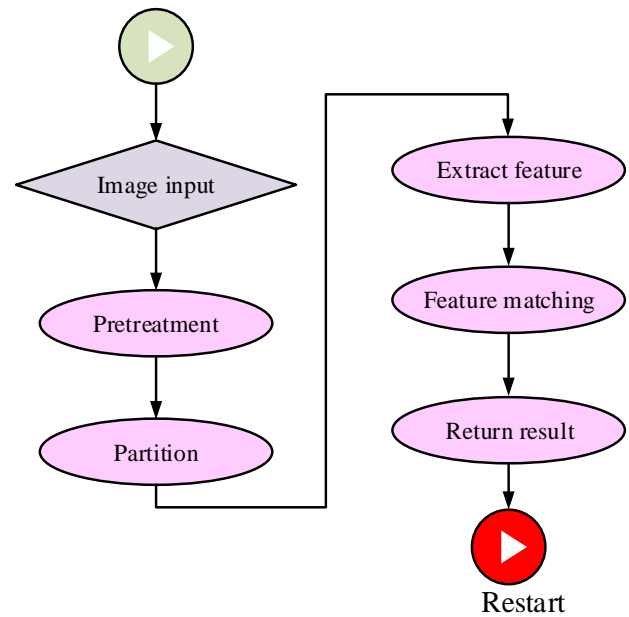


Fig. 2. Color feature extraction.

Different color models usually differ in their feature representation methods. The study is modeled by the perceptual color model HSV (Hue, Saturation, Value). This model describes colors according to the three attributes of hue, luminance and saturation, and input to the Munsell 3D spatial coordinate system for further analysis. Generally, video images are stored in the RGB model, so the first step is to change the video image from the traditional RGB format to the HSV



format [17]. It is known that all parameter values in the RGB model  $(r, g, b)$  are in the interval  $[0,255]$ , and the conversion expression is shown in Equation (5):

$$\left\{ \begin{array}{l} s = \frac{\max(r, g, b) - \min(r, g, b)}{\max(r, g, b)} \\ h' = \begin{cases} (5+b'), \text{if } r = \max(r, g, b) \text{ and } g = \min(r, g, b) \\ (1-g'), \text{if } r = \max(r, g, b) \text{ and } g \neq \min(r, g, b) \\ (1+r'), \text{if } g = \max(r, g, b) \text{ and } b = \min(r, g, b) \\ (3-b'), \text{if } g = \max(r, g, b) \text{ and } b \neq \min(r, g, b) \\ (3+g'), \text{if } b = \max(r, g, b) \text{ and } r = \min(r, g, b) \\ (5-r'), \text{otherwise} \end{cases} \\ h = 60 \times h' \end{array} \right. \quad (5)$$

It is known that the values of  $h$  in the HSV model are in the interval  $[0,360]$ , the values of  $s$  and  $v$  are in the interval  $[0,1]$ , and all the parameter values of  $(r, g, b)$  in the RGB model are in the interval  $[0,255]$ , when  $v' = \max(r, g, b)$ , then  $v = \frac{v'}{255}$  is defined. In the above Equation (5), the expressions of  $r'$ ,  $g'$  and  $b'$  are shown in Equation (6):

$$\left\{ \begin{array}{l} r' = \frac{v' - r}{v' - \min(r, g, b)} \\ g' = \frac{g' - g}{v' - \min(r, g, b)} \\ b' = \frac{b' - b}{v' - \min(r, g, b)} \end{array} \right. \quad (6)$$

The HSV color model has the most accurate description in terms of individual subjective perception. To further improve the accuracy of the model, the study segmented the output video images in the form of  $3 \times 3$ . Then it ensured that the description values of the three different dimensions were normalized and pre-processed before extracting the features, which can avoid the computational error of taking too high a local value. The accuracy of video images retrieved using only histograms is not high because histograms are weak in considering spatial location, lighting intensity and element correlation; This can lead to more subjective results [18]. Based on this, the study introduces the "color-space" theory, the principle of which is to infinitely partition the color space, and extract the corresponding color features from the divided small space, and finally form a sequence of feature vectors. The similarity of the feature vectors is used to compare and sort the video images for retrieval. This recognition method, which takes into account the spatial location information, greatly improves the accuracy of the model. In the retrieval of each feature in space, the center distance according to the three orders of the image is used as the index term, denoted by  $E$ ,  $\sigma$ , and  $S$ , corresponding to the description of the color mean, standard variance, and cubic root asymmetry, as shown in Equation (7):

$$\left\{ \begin{array}{l} E = \frac{1}{A} \sum_i \sum_j p_{ij} \\ \sigma = \left[ \frac{1}{A} \sum_i \sum_j (p_{ij} - E)^2 \right]^{\frac{1}{2}} \\ S = \left[ \frac{1}{A} \sum_i \sum_j (p_{ij} - E)^3 \right]^{\frac{1}{3}} \end{array} \right. \quad (7)$$

In the above Equation (7),  $A$  represents the number of pixel values of the complete image;  $E$  also represents the pixel values at the  $(i, j)$  coordinates. The image retrieval is achieved by comparing the target image with the color principal feature vector of the retrieved image  $Vector(E, \sigma, S)$ , and the expression is shown in Equation (8):

$$D(Q, I) = D(Vector_Q, Vector_I) = W_E |E_Q - E_I| + W_\sigma |\sigma_Q - \sigma_I| + W_S |S_Q - S_I| \quad (8)$$

In the above Equation (8),  $Q$  represents the target image;  $I$  represents an arbitrary image in the database;  $D(Q, I)$  represents the similarity value between the two images;  $Vector_Q$  and  $Vector_I$  represent the feature vectors of the target image and the arbitrary image, respectively;  $W_E$ ,  $W_\sigma$ , and  $W_S$  represent the weights corresponding to the color mean, standard variance, and cubic root asymmetry, respectively. Since the color mean is greatly affected by the light intensity, the study will moderately reduce its weight value.

### C. Extraction of Texture Features in Video Images

The study uses a grayscale co-occurrence matrix to extract the texture features of the image, which can be used to describe the pixel changes in a certain direction in space. The position distance of two pixels is defined as  $\delta = (D_x, D_x)$  and their probability of occurrence can be expressed by the gray value  $P(i, j | \delta, \theta)$ . Under the condition that the position  $\delta$  and the space  $\theta$  are certain, the gray value can be simplified to  $P(i, j)$  and the parameter  $(i, j)$  takes a range of values related to the number of gray levels  $L$ , which is a natural number less than or equal to  $L-1$ . The grayscale co-occurrence matrix uses the grayscale correlation of each pixel in the space to predict the probability of a certain grayscale value, and ultimately to achieve the description of texture features [19]. However, the computational pressure of the model would be too high if the probability of a gray value is calculated for all locations in the space. The study introduces moment of inertia, energy, entropy, and correlation as the four basic attributes of the feature vector. The flow of the algorithm implementation is shown in Fig. 3.

From Fig. 3, the system should first convert the original image to a gray image, and the conversion formula is shown in Equation (9):

$$gray = 0.30 \times R + 0.59 \times G + 0.11 \times B \quad (9)$$



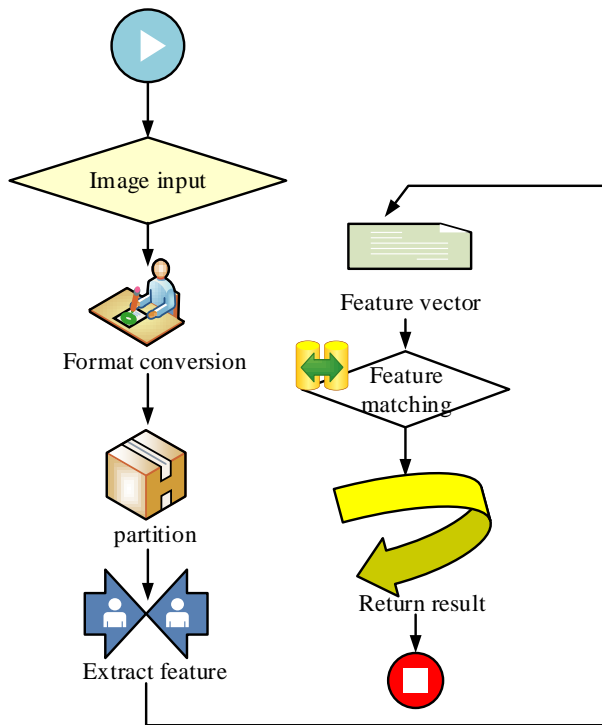


Fig. 3. Texture feature extraction.

where, the number of gray levels  $L$  is 256; however, too many gray levels will lead to the non-representation of viewing differences and increase the computational pressure. Consequently, before creating the gray symbiotic matrix, the number of gray levels should be compressed in advance, and the study sets the total number to 8, as shown in Equation (10):

$$\begin{aligned}
 Q1 &= \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} p(i, j)^2 \\
 Q2 &= \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} (i-j)^2 p(i, j) \\
 Q3 &= \left\{ Q1 = \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} (i+1)(j+1)p(i, j) - u_1 u_2 \right\} / (\delta 1 \delta 2) \\
 Q4 &= \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} p(i, j) \log_2 p(i, j)
 \end{aligned} \quad (10)$$

The four matrices constructed are all characterized by the four perspectives of  $\theta = 0^\circ, 45^\circ, 90^\circ, 135^\circ$  for the eigenvalues, and the interval between pixels  $d$  is set to 1. Then the pixels that meet the conditions such as location features are filtered and filled into the matrices respectively. The four attributes of each feature covariate in the formed gray co-occurrence matrix are further analyzed and calculated. Finally, the features are extracted and formed into a  $4 \times 4$  matrix. The mean as well as the standard deviation of the texture features are calculated. The sequence is shown in Equation (11) as follows:

$$F = [\mu_1, \mu_2, \mu_3, \mu_4, \sigma_1, \sigma_2, \sigma_3, \sigma_4] \quad (11)$$

It is also necessary to normalize the parameters in the above Equation (11) and rank the similarity by the Euclidean distance method to retrieve the most appropriate image.

#### D. Extraction of Shape Features in Video Images

Shape features are one of the most important aspects of image matching. The shape analysis starts with enclosing the region with a closed curve, which can be divided into two types: by boundary and by region. The extraction of shape features focuses on shape area, aspect ratio, and moment invariants, and therefore invariant moments are used to extract shape features. However, image area, orientation, and distortion affect the accuracy of the algorithm, so it is necessary to introduce algorithms that change with these three aspects to achieve feature extraction. The complete flow of shape feature extraction is shown in Fig. 4.

Fig. 4 showcases that the study first extracts image contours as well as core features based on the canny operator method. It is a method for boundary detection based on the first-order derivatives of Gaussian functions and strong and weak thresholds. However, there may be breakpoints at the edges, and the study uses a closed-loop operation to connect the edge breakpoints to form a complete closed loop to avoid the influence of noise signals. Then the seeds are filled using the diffuse water method, and whether they are filled or not is judged according to whether they match the pixel values of the initial image; If they are filled, the lightness and darkness of the pixel point as well as the color value need to be adjusted until all points within the closed loop are finished testing [20]. Then the invariant moments in the closed loop are calculated and the feature vectors are refined. The main purpose is to calculate the 7 HU invariant moment features in the image, and further revise the calculation results before completing the final vector sequence. Finally, a normalization operation is performed on all element values using Gaussian method to ensure that there is a difference between the elements. And even if there are extreme values, the complete shape matrix is guaranteed and normalized as shown in Equation (12):

$$\begin{cases}
 h_1 = \eta_{20} + \eta_{02} \\
 h_2 = (\eta_{20} - \mu_{02}) + 4\eta_{11}^2 \\
 h_3 = (\eta_{30} - 3\mu_{12})^2 + (3\eta_{21} - \mu_{03})^2
 \end{cases} \quad (12)$$

Finally, based on the calculation results, feature matching is performed using Euclidean distance. The calculation formula is shown in Equation (13):

$$S_{im}(Q, I) = \sqrt{\sum_{i=1}^n (h_i^q - h_i^l)^2} \quad (13)$$

In the above Equation (13),  $h_i^q$  and  $h_i^l$  are the normalized sequences of the two compared images. The three features of color, texture and shape of the images are considered together and the features are fused, as shown in Equation (14):

$$L^2(x, y) = \alpha \sqrt{\sum_i (x_{ia} - y_{ia})^2} + b \sqrt{\sum_i (x_{ib} - y_{ib})^2} + c \sqrt{\sum_i (x_{ic} - y_{ic})^2} \quad (14)$$

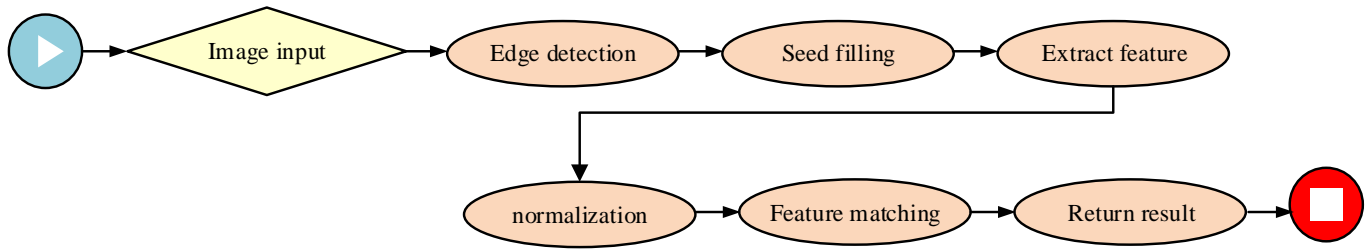


Fig. 4. Shape feature extraction.

In the above Equation (14),  $x$  and  $y$  represent the fused feature vectors of the target image and any image in the database, respectively;  $x_i$  and  $y_i$  represent the vector values of different features of each image, and  $abc$  represents the basic weights of color, texture and shape features, respectively. To ensure the normal and efficient operation of the system, the performance metrics are also required, which usually include response time, load condition and retrieval accuracy. If the bandwidth is sufficient, the response time should be less than or equal to 2 seconds, and vice versa, less than or equal to 5 seconds; And considering the possibility of a large number of search workers entering the system at the same time, the system should reach a minimum concurrency value of 100; Finally, the retrieval accuracy of the retrieval system designed in the study should be at least 75%.

#### IV. SIMULATION EXPERIMENTS

The study conducts simulation experiments for the designed video image retrieval system, which can be divided into function-based experiments as well as performance-based experiments, that is, to verify the reliability of the system's business capabilities and performance indicators. The experimental environment includes both the user platform and the server platform. The specific environment parameters and data sets are shown in Table I.

The implementation of the algorithm not only requires the aforementioned hardware facilities, but also the control of algorithm-related parameters. The color value in the color space must meet the condition of [0,255], and the h parameter

value converted to HSV color space should be in the range of [0,360], and the s and h parameters should be in the range of [0,1]. In the texture features, setting different concurrency numbers and testing the response speed of the model under different conditions can obtain the results shown in Fig. 5.

Fig. 5 demonstrates that the response times from 20-100 concurrency number all meet the requirements, i.e., the response time is no more than 2 seconds when the bandwidth is sufficient, and no more than 5 seconds when the bandwidth is not sufficient. In the case where the number of concurrency is 40 or less, the model responds quickly and does not fluctuate much over multiple attempts, and is relatively stable overall. When the number of concurrency is 20, the average response time of the model is only 1.38 s. As the number of concurrency increases, the response time of the model keeps rising, but all of them are at normal values. At 60 concurrency, the average response time of the model reaches 2.75 s, and the convergence speed decreases slightly. When the number of concurrency reaches 80 and 100, the average response time of the model is 3.87 s and 4.46 s, respectively, and the fluctuation increases, but it still falls within the good convergence speed. In summary, it can be concluded that the image retrieval model is in compliance with the corresponding performance and criteria. To further understand the recognition accuracy of the model, the study conducted a comparative test of the model according to different feature extraction requirements, which are known to be 40 for all retrieval results and 35 for all suspicious images, and the results of the number of recognition when only a single feature is retrieved are shown in Fig. 6.

TABLE I. ENVIRONMENTAL PARAMETERS AND DATA SETS

Database/server platform					
Configuration Content	CPU	Memory	Hard drive capacity	Operating System	Database/ Development Environment
Configuration details	5.4GH. Intel i5. Quad-Core Processor	16GB	20TB/ 5TB	Windows Server 2012.	Oracle11n Eclipse112
User Platform					
Configuration Content	Model		Operating system		Quantity
Configuration details	DELL530, Intelis, Memory 8G.		Windows 7		10
Number	1	2	3	4	5
Frame Rate	1525	1841	1562	1845	1956
Detailed parameters					
Regular video rate, resolution 720P.					
	420 keyframes	510 keyframes	432 keyframes	395 keyframes	448 keyframes

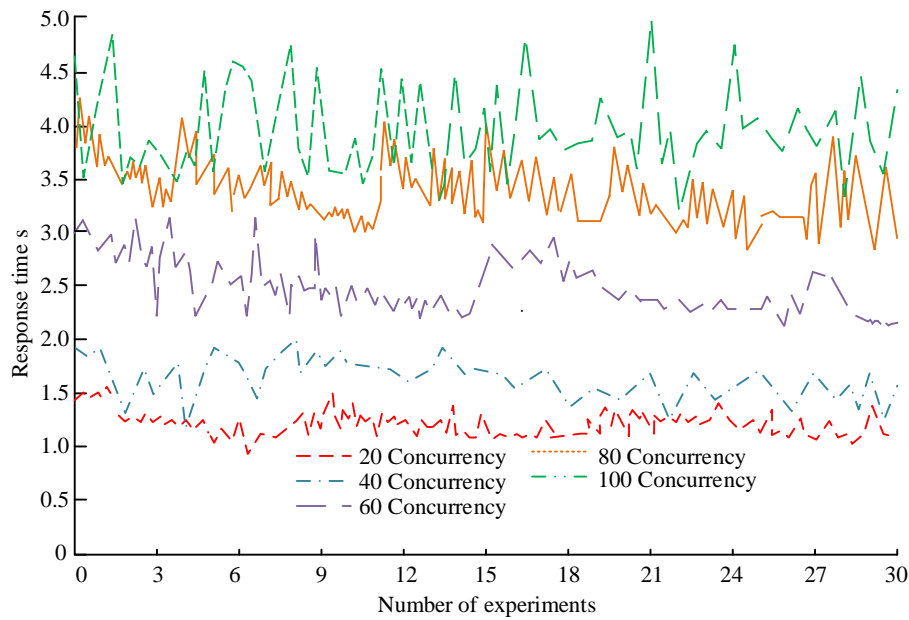


Fig. 5. Response time of the model with different number of concurrency.

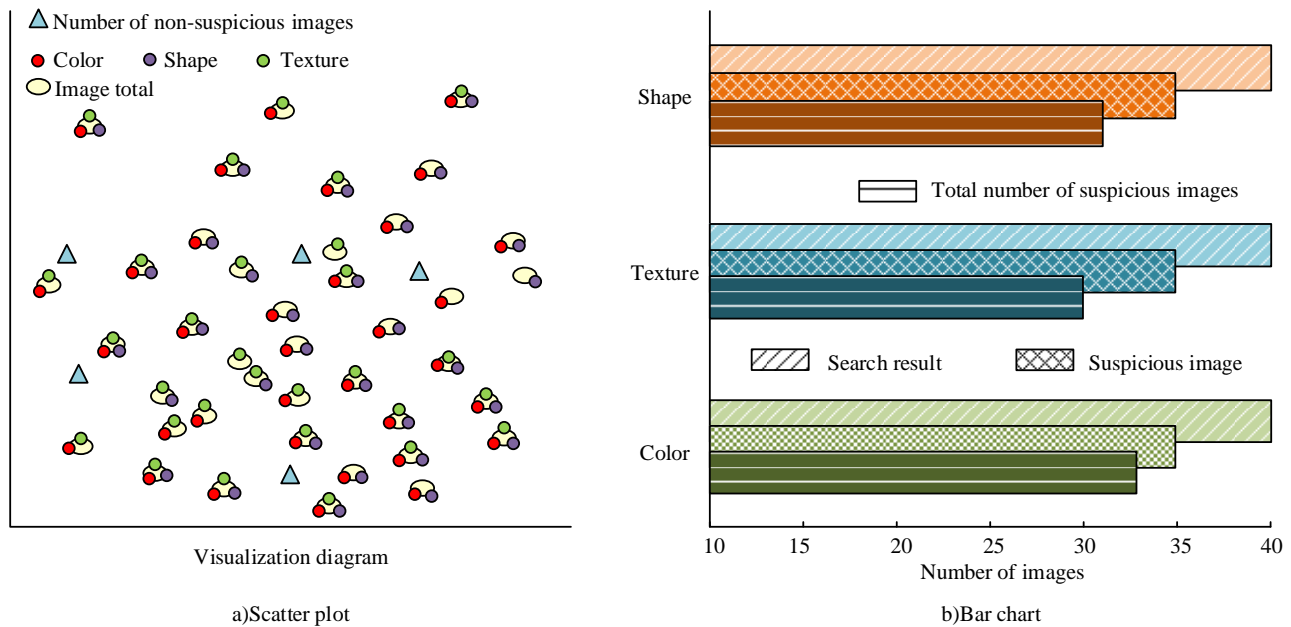


Fig. 6. Quantitative result graph for single feature retrieval.

Fig. 6 showcases that there is little difference in the number of results when the model retrieves a single feature, with the known number of all images being 40, the number of suspect images being 35, and the number of retrieved color, texture, and shape features is 32, 30, and 31, respectively. The algorithm performs best when retrieving color features, due to the fact that in traffic flow, color features are usually large in area and therefore they are also the easiest to detect. Texture features, on the other hand, are often hidden deeper and are not as easy to detect. Even so, the algorithm's detection results for each feature are relatively complete. The study conducted several experiments and finally the algorithm's detection rate and accuracy on a single feature are shown in Fig. 7.

Fig. 7 showcases that the retrieval accuracy of the algorithm for a single feature is in the reasonable range, with the highest retrieval accuracy and recall for a single color feature, 77.34% and 83.21%, respectively. Compared with the single texture feature with the worst retrieval performance, it has improved by 1.47% and 7.06%, respectively. It demonstrates that the accuracy of the algorithm is closely related to the feature attributes. Large area features are more easily recognized by the algorithm, and the average recall and precision of the algorithm on a single feature are 76.45% and 79.32%, respectively. Then, further analysis was conducted on the retrieval of mixed features in the experiment, and the results shown in Fig. 8 were obtained.

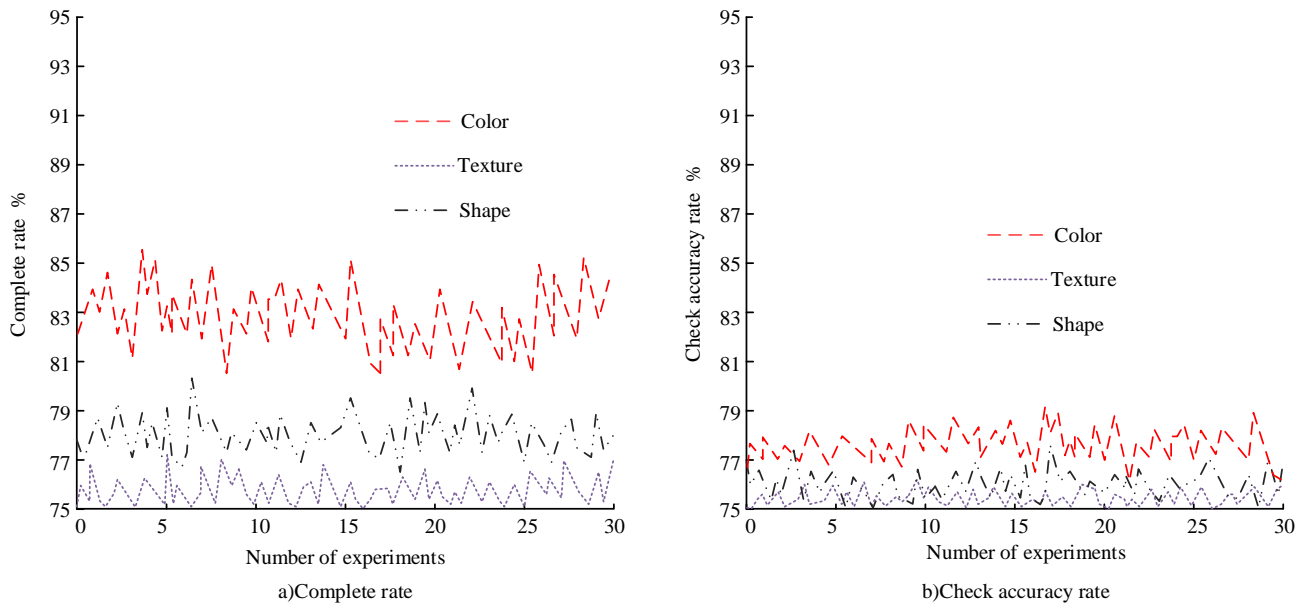


Fig. 7. Retrieval accuracy of single feature.

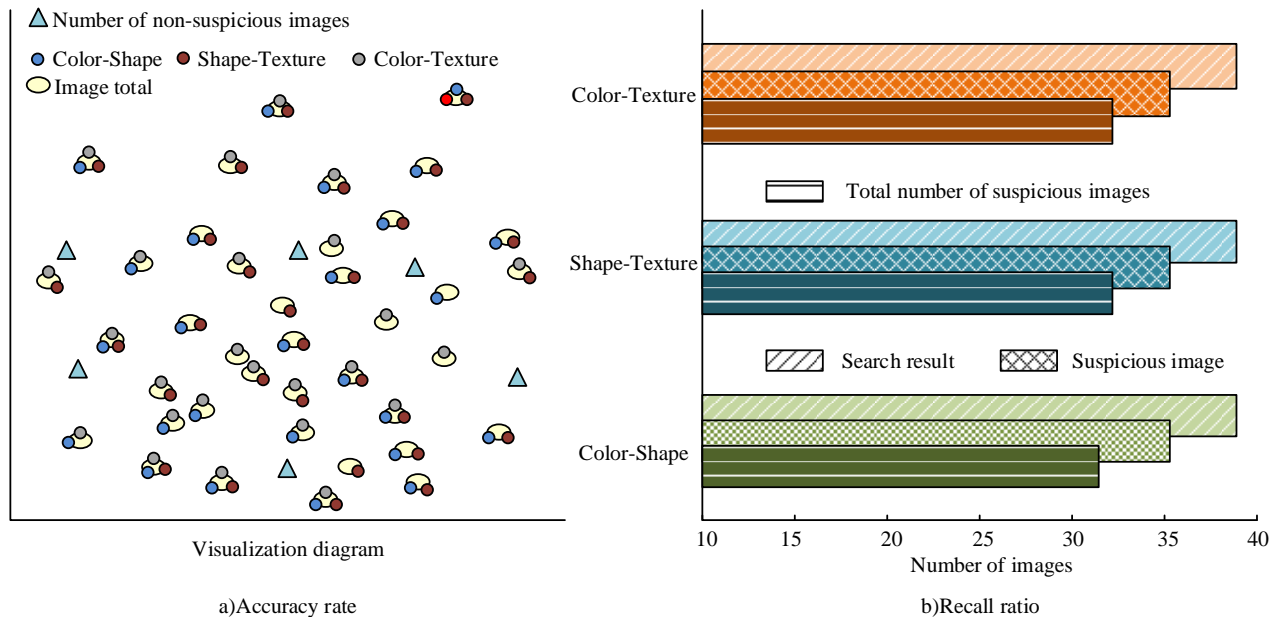


Fig. 8. Number of correct retrievals of mixed features.

Fig. 8 demonstrates that the model has a corresponding improvement for the retrieval of mixed features, which are color-shape, color-texture, and shape-texture, respectively. There are some differences in the correct retrieval values, but they can be ignored. The correct retrieval values of the three mixed features are 32, 33, and 33, which are less different from the correct values. The model's retrieval values for the color-shape hybrid features are relatively weak, but are within the good range. Thus the model also has excellent performance for the retrieval of both hybrid features. The study conducts several experiments and finally results in the algorithm's find-all and find-accurate rates on the two mixed features as shown in Fig. 9.

Fig. 9 showcases that the algorithm has significantly improved its performance in mixed features compared to single features. Among the three mixed features, the shape texture retrieval ability is the best, with a precision and recall rate of 85.35% and 88.24%, respectively. Compared with color shape features, the algorithm has improved by 1.13% and 3.45%, respectively. The average retrieval recall and precision of two-dimensional mixed features were 85.37% and 87.05%, respectively, which increased by 8.92% and 7.73% compared to single features. The study further validated the algorithm for 3D mixed features and obtained the results shown in Fig. 10.

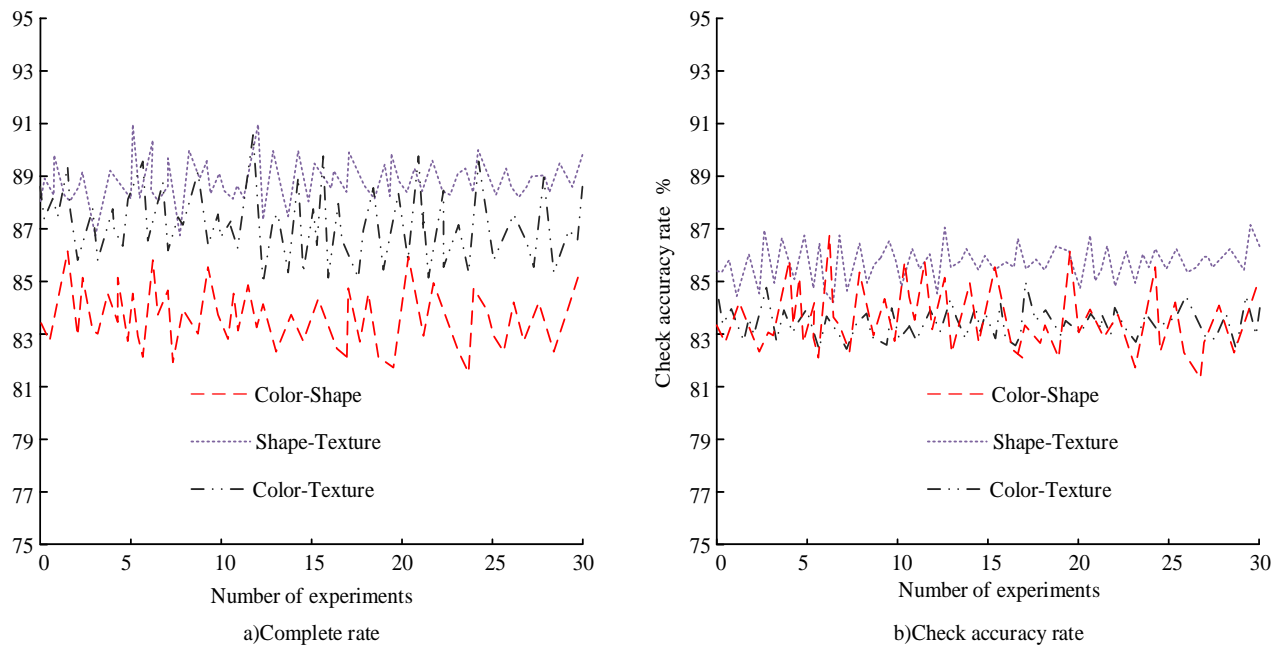


Fig. 9. Retrieval accuracy of two-dimensional features.

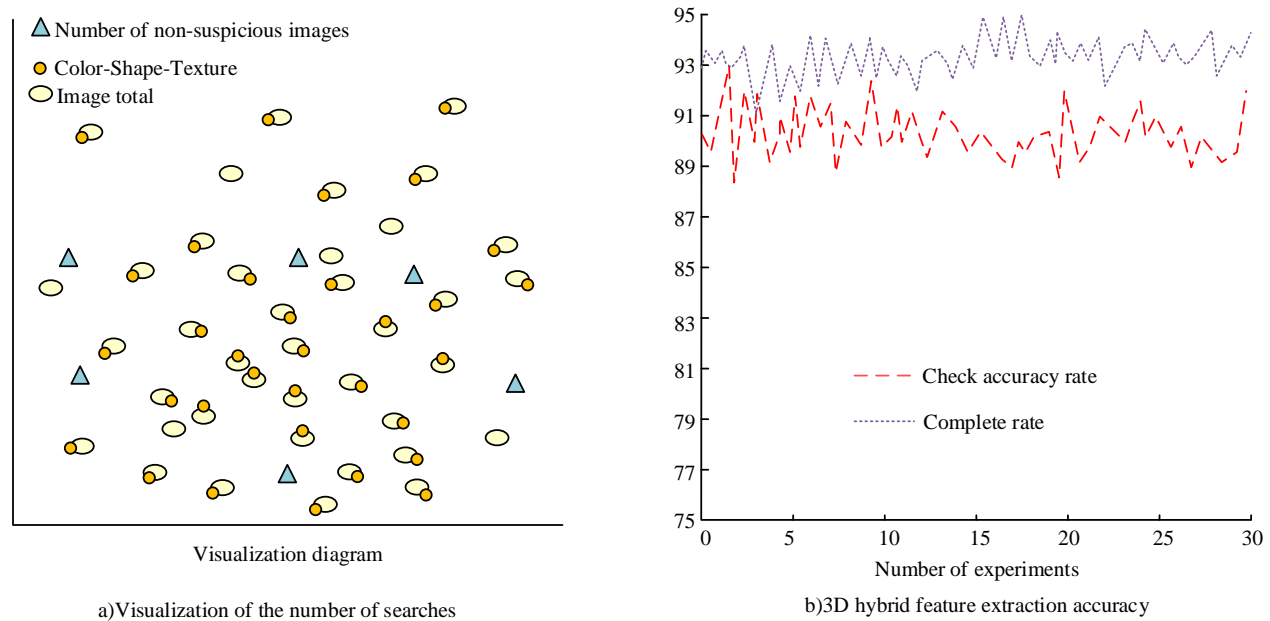


Fig. 10. Retrieval accuracy of 3D features.

Fig. 10 illustrates that the increase of feature parameters is not a decrease of algorithm accuracy, but an effective improvement. The total number of detected suspicious images reaches 34, which is only one bit away from the true value, and the detection accuracy and completion rates reach 90.23% and 94.96%, respectively. Compared with the retrieval averages of single features, the improvement is 13.78% and 15.64%, respectively; compared with the retrieval averages of 2D mixed features, the improvement is 4.86% and 7.91%, respectively. It can be seen that the increase of feature dimensionality leads to higher accuracy of the algorithm. In summary, it can be

concluded that the accuracy of the model meets the corresponding criteria and is excellent in the performance of mixed features.

To further validate the feasibility of the proposed method, the study conducted comparative experiments with other advanced methods to verify the feasibility of the research method. The experiment used Adaboost algorithm, Mean Shift algorithm, and Hard Triplet algorithm for comparative experiments. The model performance was tested through detection accuracy and recall indicators, and the results are shown in Table II.

TABLE II. ALGORITHM PERFORMANCE COMPARISON RESULTS

Algorithm	Rrecision	Recall	Reaction time (s)
Research algorithms	0.964	0.951	0.62
AdaBoost algorithm	0.958	0.946	0.58
Mean shift algorithm	0.967	0.948	0.64
Hard Triplet algorithm	0.955	0.952	0.59

In Table II, the accuracy of the AdaBoost algorithm is 0.958, the recall rate is 0.951, and the model response time is 0.58 seconds. The accuracy of the Mean shift algorithm is 0.967, the recall rate is 0.946, and the model response time is 0.64 seconds. The accuracy of the Hard Triplet algorithm is 0.955, the recall rate is 0.952, and the model response time is 0.59 seconds. It can be seen that the currently used algorithms have high accuracy and recall in video image detection, as well as fast response speed, which can meet the accuracy and real-time requirements of practical applications. The accuracy of the research method is 0.964, the recall rate is 0.951, and the reaction time is 0.62 seconds. From the analysis of the results, the proposed method has a relatively close performance to the current advanced methods, with an accuracy second only to the Mean shift algorithm, a recall second only to the Hard Triplet algorithm, and a reaction time difference of only 0.4 seconds. Therefore, the method proposed in the study can meet practical needs in use.

## V. CONCLUSION

The intelligent traffic system integrates digital information technology into traffic management, and is a novel method to achieve real-time and efficient monitoring and retrieval of traffic flow. The study has developed and designed the video image retrieval module in Java EE platform. Pre-processing measures such as normalization and equalization are performed to reduce the influence of irrelevant signals.  $L^p$  distance method and Euclidean distance method are used for data feature fusion and key frame extraction, and finally feature extraction methods are introduced according to three features: color, texture and shape, respectively. The study conducted simulation experiments on the model, and firstly, the convergence performance of the algorithm was tested, divided into 20-100 concurrency experiments. The experimental results show that the convergence effect of the algorithm decreases as the number of concurrency increases, but they are within the appropriate range, and when the number of concurrency is 20, the model retrieval time is only 1.38 s; and when the number of concurrency reaches 100, the retrieval time also reaches 4.46 s, which is less than the allowed the maximum value. Then the model was experimented for feature extraction, and several trials were done according to 1D, 2D and 3D features. The experimental results showed that the more feature elements, the higher the accuracy of the algorithm. The retrieval accuracy and completeness of 3D features, compared with the retrieval average of single features, improved by 13.78% and 15.64%, respectively. It can be seen that the model has better retrieval performance. However, the model also has some limitations, because video image retrieval should have a place in both the intelligent transportation field and other fields. This requires that the system should be extensible so that new modules can

be added at any time. The study has yet to improve its performance in this regard.

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# The Mechanism of the Role of Big Data Knowledge Management in the Development of Enterprise Innovation

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**Abstract**—The effectiveness and efficiency of enterprise knowledge management depends on the effectiveness and efficiency of the enterprise's implementation of knowledge management. Big data technology can collect, analyse and apply the massive amount of data in an organisation to support the implementation of knowledge management. Therefore, exploring the role of big-data knowledge management in the development of enterprise innovation will help enterprises to better implement knowledge management. Based on this, the study aims to propose a model for predicting big data knowledge management and enterprise innovation development for high-tech enterprises in China. The study firstly used Principal Component Analysis (PCA) to decrease the dimensionality of the model, and then used the particle swarm algorithm to optimize BP neural network (PSO-BP). Network (PSO-BP) was used to evaluate enterprise knowledge management and enterprise innovation development. The results of the study show that the absolute values of the relative errors of the pre-processed model do not exceed the 5% threshold, and only the relative errors of some indicators are relatively large, such as X5 and X7, with values of 4.5% and -3.8%, indicating that the model has a good performance in predicting the innovation effect of enterprises.

**Keywords**—Big data knowledge management; BP neural network algorithm; enterprise innovation development; principal component analysis; particle swarm optimization algorithm; correlation analysis

## I. INTRODUCTION

With the advent of the information age, the amount of data and information has increased exponentially, and how to effectively manage big data knowledge has become an important research direction for the current development of the country and enterprises [1,2]. At the same time, managing big data can strengthen enterprises' cognition of data-related knowledge, find their own positioning, better access the dividends of the times, and enhance their attention to big data capabilities. At the same time the rational use of big data can also enable the whole enterprise to enhance the innovation ability of products and improve the performance of the enterprise [3]. However, the current research on big data is at the initial stage, and many of the constructed algorithm models cannot comprehensively analyze the characteristics of big data knowledge management, for example, the commonly used back propagation neural network (BPNN) algorithm cannot analyze larger and broader data, while the slow computing speed also causes problems for data analysis of big data knowledge

management. Although the particle swarm optimization (PSO) algorithm is simple and easy to implement with few parameters, the poor performance and troublesome network parameters also make the algorithm unable to better solve the problems arising in big data knowledge management. Meanwhile, many current studies on big data knowledge management are still in the dialectical analysis stage [4-5]. Based on this, this experiment will study big data knowledge management by using principal component analysis (PCA) to organize and analyze the data, then using PSO algorithm to determine the weights of the factors influencing knowledge management on the development of enterprise innovation (EnIn), and finally using BPNN algorithm to predict the data set and determine the role of big data knowledge management on the development of EnIn and the feasibility of its development. This research is divided into four parts, the first part is to explain the current research status of big data knowledge management at home and abroad, the second part establishes a new optimization algorithm model by analyzing the indicators of big data characteristics, the third part is to analyze the performance of the optimization algorithm and the data processing results, and the fourth part is to conclude the whole article.

## II. RELATED WORK

Goncharenko et al. aimed to study the functional support of organisational and economic mechanisms of innovation and integration potential management in enterprises. The study examines the organisational and economic mechanisms of innovation and integration potential management in enterprises. The study showed that organisational and economic mechanisms are the basis for the management of innovation and integration potential of enterprises and that their functional support is divided into four areas: internal management support, market support, policy support and social support [6]. Zadorozhnyi et al. aimed to explore the determinants of innovation affecting enterprises and assessed them on the basis of actual data from financial statements. It was found that the financial statements of firms can provide useful information reflecting the innovation of the firm, which includes investment, profit and asset structure. In addition, financial statements can increase the transparency of financial statements by providing information on details such as technology development, organisation and management of the firm [7]. Katsarski discussed the relationship between integrated business management and water ecosystems,

summarised the importance of integrated business management and its role in water ecosystem conservation, and made recommendations for future research and practice [8]. Vasylytsiv et al. aimed to explore the creativity, information and knowledge determinants of economic growth in the EU region in the context of smart development strategies. The study provides an integrated analysis of smart development strategy research and economic growth. The findings show that economic growth in the EU region depends mainly on policy creativity, effective transmission of information and the driving force of knowledge. In addition, factors such as technological innovation and innovative social networks also have a significant impact on economic growth in the EU region [9]. Straková et al. examine trends in organisational and managerial structures, exploring many of the key issues involved in practice and research, such as organisational structure, management theory, organisational culture and leadership styles. The article also details the changes in organisational and management structures and how the changes affect organisational performance. Finally, the article offers suggestions for addressing these issues to help managers better manage organisational and management structures [10].

To explore the strategy of obtaining sustainable competitive advantages in emerging wine producing regions in southern Sweden, Kompaniets introduced the concept of this advantage and explored various strategies. This includes resource base, technology base, customer base, market base, and organizational base, which can be transformed into a sustainable competitive advantage for the region by implementing specific strategic measures [11]. Chatterjee et al. aimed to explore knowledge sharing for product and process innovation in international markets in order to better knowledge sharing and thus more benefits of innovation [12]. Lopes et al. aimed to explore how competitiveness management, knowledge management and corporate education are implemented in Brazilian companies, collecting data from three Brazilian companies. The study found that competitiveness management and knowledge management contributed to the efficiency of the enterprise, while corporate education helped to improve the skills and knowledge of employees [13]. Babgohari et al. aimed to explore the relationship between knowledge management competencies, entrepreneurial creativity, entrepreneurial passion and corporate performance, processing and analysing survey data from 385 of these companies. It verified that there was a prominent positive relationship between knowledge management capabilities and entrepreneurial creativity, entrepreneurial passion and firm performance, with the dual power of the firm playing a mediating role [14]. Wang et al. aimed to explore the relationship between market orientation

and service innovation, and the study used a quantitative research approach to analyse data from three major Chinese airlines. The conclusion was that there was a remarkable positive relationship between market orientation and service innovation, while knowledge sharing contributed moderately to this relationship. The results provide valuable management guidance for the company's market orientation and service innovation activities [15].

It can be seen through the research of scholars at home and abroad that there are more studies on the relationship between enterprise knowledge management and EnIn, but most of them stay in the perspective of empirical analysis and do not adopt algorithmic models to further dissect them. Based on this, the research is mainly built on the PCA-PSO-BPNN algorithm to design and study the role mechanism of big data knowledge management in the development of EnIn, and then analyse the specific mechanism of big-data knowledge management on the development of EnIn.

### III. BUILDING A MACHINE LEARNING-BASED ENTERPRISE INNOVATION MODEL IN A BIG DATA ENVIRONMENT

This chapter mainly provides an overview of the characteristics of big data knowledge management and data management process, discusses some data knowledge management metrics and pre-processing work, then establishes a big data knowledge management algorithm model by BP neural network, and finally improves and optimizes the BP neural network algorithm model by combining with PSO neural network.

#### A. Establishment of Big Data Knowledge Management in Enterprise Innovation Index System and Pre-Processing Work

Big data knowledge management mainly involves various aspects such as data collection, data cleaning, data analysis, knowledge discovery and knowledge application [16]. When establishing an EnIn model, the EnIn index system should first be established to detect the innovation level of the enterprise, and the technology of big data knowledge management can be used to realize data collection, data cleaning and data analysis, so as to establish an EnIn index system. In establishing the EnIn model, machine learning technology can be used to fully explore the innovation elements in the EnIn index system, so as to establish a machine learning-based EnIn model. According to the EnIn index system, a classification model can be constructed using supervised learning methods in combination with machine learning techniques to detect the innovation level of the enterprise. The research has initially constructed the big data capability index system and the EnIn performance system (Table I).

TABLE I. BIG DATA CAPABILITY INDICATORS AND ENTERPRISE INNOVATION PERFORMANCE INDICATOR SYSTEM

Main target	Subgoal	Numbering	Index
Metrics for big data capabilities	Access to resources Ability to access resources	X <sub>1</sub>	Ability to access internal and external data sources on a continuous, real-time basis to support the company's business
		X <sub>2</sub>	Possess and master the technical equipment required for big data analysis
	Analysis of integration Integration capabilities	X <sub>3</sub>	Ability to process large amounts of data and obtain valuable information
		X <sub>4</sub>	Ability to analyse a wide range of structured and unstructured data in real time
	Insightful anticipation Predictability	X <sub>5</sub>	The company is able to achieve real-time market insights based on big data and thus identify new business opportunities
		X <sub>6</sub>	Ability to forecast consumer behaviour and corporate opinion based on big data
	Knowledge Discover	X <sub>7</sub>	There is a dedicated process for obtaining relevant information from external sources
		X <sub>8</sub>	Access to timely and relevant information on customers and suppliers
	Knowledge Integration	X <sub>9</sub>	Ability to effectively integrate internally created knowledge with externally acquired knowledge
		X <sub>10</sub>	Ability to effectively integrate knowledge belonging to different technologies or application areas
	Knowledge Applications	X <sub>11</sub>	Regularly evaluate and adjust our forecasts based on new knowledge of market trends and technology Long-term forecasts
		X <sub>12</sub>	regularly evaluate our investment and resource allocation decisions in the light of new knowledge
A measure of corporate innovation and development	Patent results	A <sub>1</sub>	The research uses the R&D input ratio to total assets to express R&D intensity
	R&D intensity	A <sub>2</sub>	The research uses the amount of utility model, invention and design patents granted to measure the number of patent achievements in the innovation development of enterprises

As shown in Table I, the study divided the big data capability indicators into eight categories, based on which the study further divided them into six indicators of enterprise access to big data capability and two indicators of EnIn performance. The six indicators of enterprise access to big data capability were, in order, enterprise resource access capability, enterprise analysis and integration capability, enterprise insight and prediction capability, enterprise knowledge discovery capability, enterprise knowledge integration capability and enterprise knowledge application capability; the innovation development of enterprises is divided into two major indicators, namely patent achievement and R&D intensity. Based on this, the study selected the financial data of all A-share listed companies in the high-tech industry in Shanghai and Shenzhen from 2013 to 2020. The sample was selected as follows: firstly, A-share listed companies in the financial and insurance industries were excluded; secondly, there were and are only A-share shares in circulation; thirdly, listed companies with missing relevant data were excluded, and the final sample size was 1344; fourthly, R&D expenditure data were mainly collected manually by reviewing the annual reports of listed companies. In view of the differences between the old and new standards on the accounting treatment of R&D expenditures, we specifically divided the time periods from 2013 to 2016 and 2017 to 2020 for collection respectively, and other research

data were obtained from the CSMAR database.

The big data knowledge management in EnIn index system constructed by the study includes 14 indicators, and if all of them are incorporated into the BP neural network model, it will make the complexity and operation speed of the network increase significantly, the network performance decreases and the generalization ability of the neural network decreases [17]. Therefore, it is essential to comprehensively analyse the micro factors that affect the degree of innovation and scientific research of enterprises, and reduce the number of indicators while minimising information loss, which means reducing the dimensionality of evaluation indicators while ensuring the evaluation effect. PCA is a multivariate statistical correlation analysis of multivariate correlations, where a small number of main components (linear combination of the original variables) are used to account for changes in multiple variables, i.e. a small number of main components are deduced, thus keeping as much information as possible about the original variables and not correlating with each other, thus making the data more simplified. The specific working procedure is as follows, first setting the indicators for the evaluation of corporate innovation research as  $x' = (x_1', x_2', \dots, x_n')$  and assigning an empirical weight to these parameters  $W_x = (W_{x_1}, W_{x_2}, \dots, W_{x_n})'$ , where  $W_{x_1} + W_{x_2} + \dots + W_{x_n} = 1$ . Then find out its covariance, i.e., find

$$V = \begin{Bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{ni} & v_{n2} & \cdots & v_{nm} \end{Bmatrix}$$

out the eigenvalues of  $V$  and arrange them in order of alphabetical size, i.e.  $\lambda_1 > \lambda_2 > \cdots > \lambda_r, \lambda_{r+1} = \lambda_{r+2} = \cdots = \lambda_n = 0$ , find out the cumulative contribution ratio and get the first  $m$  eigenvolume at  $\sum_{j=1}^m (\lambda_j / \sum_{i=1}^n \lambda_i) \geq 90\%$  first and round off the others to find out the eigenvector corresponding to  $\lambda_j (j=1,2,\dots,m)$   $r_j (j=1,2,\dots,m)$ , find out its  $x_1 = y_1' w_x, x_2 = y_2' w_x, \dots, x_m = y_m' w_x$ , so there is  $x = (x_1, x_2, \dots, x_m)'$ . To better grasp the role of enterprise big data capability on the impact of R&D EnIn.

**B. Establishment of an Original Model of Corporate Innovation Based on the BPNN Algorithm**

Neural networks are a multidisciplinary intersection whose definition varies greatly across disciplines. Research has proposed one of the most widely used concepts to date, which can be used to simulate various informations in the brain by organising the network with a variety of intelligent behaviours such as self-organisation, self-learning and self-adaptation [18]. Its individual neuron model is Fig. 1.

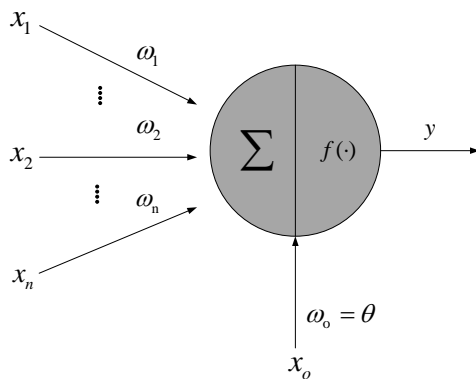


Fig. 1. M-P neuron model.

The specific neuron model listed in Fig.1 is also known as the M-P neuron model.  $x_i (i=1,2,\dots,n)$ ,  $x_0$   $\omega_i (i=1,2,\dots,n)$   $x_i$   $\theta$   $f(\cdot)$   $y$   $x_i$   $x_0$  The signal transmission procedure between  $x_0$  and  $x_i$  is approximately as follows: first, the input signal from the  $n$  neuron connected to the current neuron  $x_i$  is received and the corresponding connection weighting  $\omega_i$  completes the transmission of the full input signal, followed by the activation threshold  $x_0$  to compare the activation threshold of with the full input signal received. threshold  $\theta$  to compare the start threshold of  $x_0$  with the total input signals received. The final output  $y$  is displayed in the Equation (1).

$$y = f\left(\sum_{i=1}^n \omega_i x_i - \theta\right) \quad (1)$$

In the M-P neuron model, a step function is a temporal function with a specific continuum that converts inputs into outputs, and its expression is shown in Equation (2).

$$f(x) = \begin{cases} 0 & x < 0 \\ 1 & x \geq 0 \end{cases} \quad (2)$$

The Sigmoid function has the properties of a single increasing and inverse function, and its function image is shown in Fig. 2.

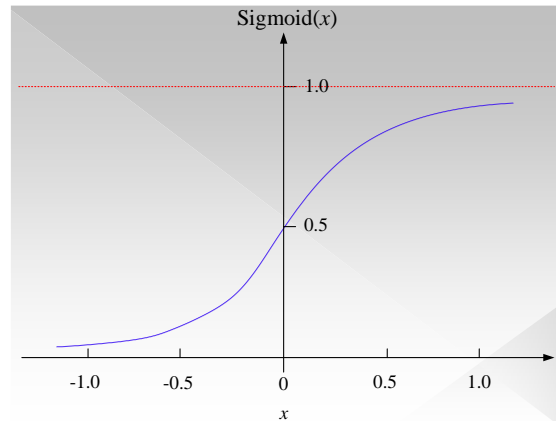


Fig. 2. Sigmoid function.

The M-P neuron model describes the neuron in terms of a logical function, which allows it to theoretically understand the information better. The input layer of the perceptron is in line with the M-P neuron as the output layer, and the specific model structure is Fig. 3.

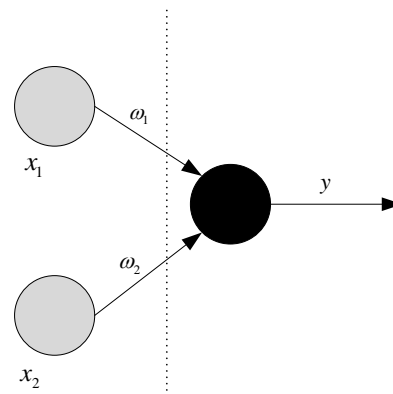


Fig. 3. Perceptron model with two input neurons.

During the training period of the perceptron, it is assumed that the weighting value at a node is  $\omega_i (i=1,2,\dots,n)$ . The training sample set denotes  $(x, y)$ , the actual output value is  $y'$  and the learning rate is  $\eta$ . Then the perceptron will modify the learning rules for the connection weighting  $\omega$  as shown in Equations (3) and (4).

$$\omega_i \leftarrow \omega_i + \Delta\omega_i \quad (3)$$

$$\Delta\omega_i = \eta(y - y')x_i \quad (4)$$

From Equation (3) and Equation (4), it can be seen that there is no change in the connection weighting  $\omega$ , when the sensing machine correctly predicts the training example  $(x, y)$ , which is  $y = y'$ , otherwise the connection weights  $\omega$  will be

adjusted and modified accordingly according to the learning rules. The multi-layer neural network structure is exhibited in the form of Fig. 4.

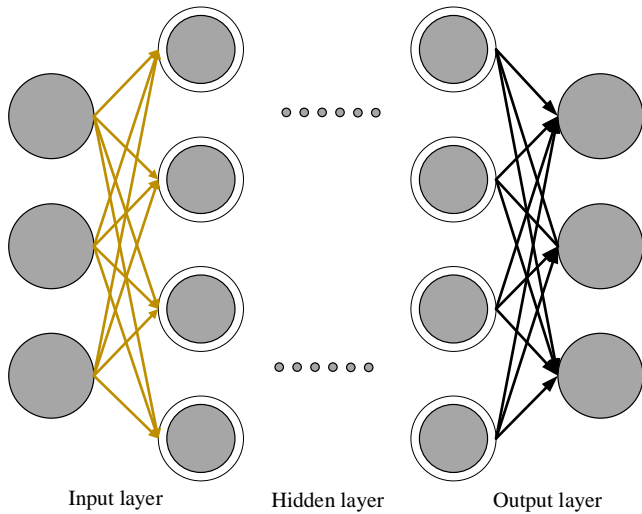


Fig. 4. Multilayer feedforward neural network model.

As shown in Fig. 4, the samples of the training set are fed from the input layer of the multilayer feedforward network, and then the output of the neuron in each layer is considered as its next input. The specific unfolded connection weight matrices  $W^1$  and  $W^2$  matrices are shown in Equations (5) and (6).

$$W^1 = \begin{bmatrix} \omega_{11}^1 & \omega_{12}^1 & \cdots & \omega_{1m}^1 \\ \omega_{21}^1 & \omega_{22}^1 & \cdots & \omega_{2m}^1 \\ \vdots & \vdots & \ddots & \vdots \\ \omega_{l1}^1 & \omega_{l2}^1 & \cdots & \omega_{lm}^1 \end{bmatrix} \quad (5)$$

$$W^2 = \begin{bmatrix} \omega_{11}^2 & \omega_{12}^2 & \cdots & \omega_{1l}^2 \\ \omega_{21}^2 & \omega_{22}^2 & \cdots & \omega_{2l}^2 \\ \vdots & \vdots & \ddots & \vdots \\ \omega_{n1}^2 & \omega_{n2}^2 & \cdots & \omega_{nl}^2 \end{bmatrix} \quad (6)$$

In Equations (5) and (6),  $m$ ,  $l$  and  $n$  denote the neurons number in the input, hidden and output layer, respectively. The neuron activation threshold vectors in the hidden and output layers of the network are distributed as  $\theta^1 = [\theta_1^1, \theta_2^1, \dots, \theta_l^1]^T$  and  $\theta^2 = [\theta_1^2, \theta_2^2, \dots, \theta_n^2]^T$ , and the output of the neuron  $O_j$  can be pushed out of the network's hidden layer, as Equation (7).

$$O_j = f\left(\sum_{i=1}^m \omega_{ji}^1 x_i - \theta_j^1\right) = f(net_j) \quad (7)$$

In Equation (7),  $j = 1, 2, \dots, l$  and  $f(\bullet)$  are the functions of the activation functions expressed in the hidden layer,  $net_j = \sum_{i=1}^m \omega_{ji}^1 x_i - \theta_j^1$ . The resulting expression for the neuron  $z_k$  in the output layer is shown in Equation (8).

$$z_k = g\left(\sum_{j=1}^l \omega_{kj}^2 O_j - \theta_k^2\right) = g(net_k) \quad (8)$$

In Equation (8),  $k = 1, 2, \dots, n$ ,  $g(\bullet)$  is the activation function of the output layer, and the error value  $E$  is derived by performing an error operation on the true output value and the desired output value as shown in Equation (9).

$$E = \frac{1}{2} \sum_{k=1}^n \left( y_k - g\left(\sum_{j=1}^l \omega_{kj}^2 f\left(\sum_{i=1}^m \omega_{ji}^1 x_i - \theta_j^1\right) - \theta_k^2\right) \right)^2 \quad (9)$$

The link weights of the neurons in the hidden and output layers were optimally learned by calculating the error value of the network  $E$  and the partial derivative of the error value  $E$  with respect to the link weights  $\omega_{kj}^2$  is expressed as shown in Equation (10).

$$\frac{\partial E}{\partial \omega_{kj}^2} = \frac{\partial E}{\partial z_k} \frac{\partial z_k}{\partial \omega_{kj}^2} = -(y_k - z_k) g'(net_k) O_j = -\delta_k^2 O_j \quad (10)$$

In Equation (10),  $\delta_k^2 = (y_k - z_k) g'(net_k)$ , the connection weights of the neurons in the input and hidden layers are optimally investigated and the link weighting of the neurons in the input and hidden levels is optimally investigated and the error values are biased differential for the connection weights  $\omega_{ji}^1$  as shown in Equation (11).

$$\frac{\partial E}{\partial \omega_{ji}^1} = \sum_{k=1}^n \sum_{j=1}^l \frac{\partial E}{\partial z_k} \frac{\partial z_k}{\partial O_j} \frac{\partial O_j}{\partial \omega_{ji}^1} = -\delta_j^1 x_i \quad (11)$$

In Equation (11),  $\delta_j^1 = \sum_{k=1}^n (y_k - z_k) g'(net_k) \omega_{kj}^2 f'(net_j) = f'(net_j) \sum_{k=1}^n \delta_k^2 \omega_{kj}^2$ , the connection weights between its networks  $\omega_{ji}^1$  and  $\omega_{kj}^2$  modified by Equation (10) can be derived as shown in Equation (12).

$$\begin{cases} \omega_{ji}^1(t+1) = \omega_{ji}^1(t) + \Delta \omega_{ji}^1 = \omega_{ji}^1(t) - \eta^1 \frac{\partial E}{\partial \omega_{ji}^1} = \omega_{ji}^1(t) + \eta^1 \delta_j^1 x_i \\ \omega_{kj}^2(t+1) = \omega_{kj}^2(t) + \Delta \omega_{kj}^2 = \omega_{kj}^2(t) - \eta^2 \frac{\partial E}{\partial \omega_{kj}^2} = \omega_{kj}^2(t) + \eta^2 \delta_j^2 O_j \end{cases} \quad (12)$$

In Equation (12), the learning efficiencies in the hidden and output layers are  $\eta^1$  and  $\eta^2$ . For the neuronal activation threshold of the network output layer  $\theta_k^2$ , the partial differential representation of the computational error value  $E$  is shown in Equation (13).

$$\frac{\partial E}{\partial \theta_k^2} = \frac{\partial E}{\partial z_k} \frac{\partial z_k}{\partial \theta_k^2} = (y_k - z_k) g'(net_k) = \delta_k^2 \quad (13)$$

For the neuronal activation threshold of the hidden layer  $\theta_j^1$ , the partial differential representation of the error value  $E$  is calculated as shown in Equation (14).

$$\frac{\partial E}{\partial \theta_j^1} = \sum_{k=1}^n \frac{\partial E}{\partial z_k} \frac{\partial z_k}{\partial O_j} \frac{\partial O_j}{\partial \theta_j^1} = \sum_{k=1}^n (y_k - z_k) g'(net_k) \omega_{kj}^2 f'(net_j) = \delta_j^1 \quad (14)$$



Thus, based on Equations (13) and (14), the modulation formulae for the neuronal activation thresholds  $\theta_j^1$  and  $\theta_k^2$  can be derived and expressed as shown in Equation (15).

$$\begin{cases} \theta_j^1(t+1) = \theta_j^1(t) + \Delta\theta_j^1 = \theta_j^1(t) + \eta^1 \frac{\partial E}{\partial \theta_j^1} = \theta_j^1(t) + \eta^1 \delta_j^1 \\ \theta_k^2(t+1) = \theta_k^2(t) + \Delta\theta_k^2 = \theta_k^2(t) + \eta^2 \frac{\partial E}{\partial \theta_k^2} = \theta_k^2(t) + \eta^2 \delta_k^2 \end{cases} \quad (15)$$

### C. Establishment of an Innovation Model for PSO-based Optimization Neural Network Firms

BP neural networks can better reflect the complex non-linear relationships in the model, thus improving the prediction accuracy. However, BP neural networks also have their limitations. Firstly, BP neural networks are basically in a "black box" state during the solution process, and their results are difficult to be understood, and secondly, the neural networks have the phenomenon of overfitting. Based on big data technology, a sound knowledge management system can be established to collect and collate innovation indicators of enterprises and build an innovation model to measure the innovation capability of enterprises. Machine learning techniques, especially neural networks, can be effective in building an EnIn model, but it is difficult to find the optimal parameters due to the large number of parameters in a neural network model. For this reason, particle swarm algorithms (PSO) can be used to optimise neural network models to obtain the optimal parameters. Therefore, a corporate innovation model based on PSO optimised neural networks can be effectively constructed to measure the innovation capability of a company. The particle swarm algorithm model can be used to efficiently search for optimal parameters and to obtain a more accurate model of corporate innovation.

The PSO is an evolutionary algorithm, which is a technique based on group intelligence and on the simulation of group forces. The basic idea of the PSO algorithm is that each particle has a current position and an optimal position, and the current position of the particle is influenced by two forces, one from the particle itself and the other from the global optimal position. The current position of the particle is influenced by both forces, while the force of the global optimum position is influenced by the global optimum position, which is the influence of the optimum positions of all the previous particles. The optimization steps of the PSO algorithm are: first, initialize the particle swarm, each particle has a position and a velocity; then, calculate the fitness function of each particle; then, calculate the optimum position of each particle, the global optimum position. Finally, the particle positions and velocities are updated and terminated when convergence to the optimal solution is achieved. The particles have both velocity and position properties and are adapted using independent search and position sharing, with the update rules shown in Equations (16) and (17).

$$v_i = v_i + c_1 rand(pbest_i - x_i) + c_2 rand(gbest_i - x_i) \quad (16)$$

$$x_i = x_i + v_i \quad (17)$$

In Equations (16) and (17),  $v_i$  represents the particle

velocity,  $rand$  represents the random number,  $x_i$  represents the current particle position,  $c_1$  and  $c_2$  represent the learning factors. The PSO is a commonly used parameter search method, which can find the best parameters in the training set, and it can cut down the optimization time and strengthen the accuracy of the search with fewer iterations compared with the traditional grid search method [19]. The steps of its optimisation algorithm are shown in Fig. 5.

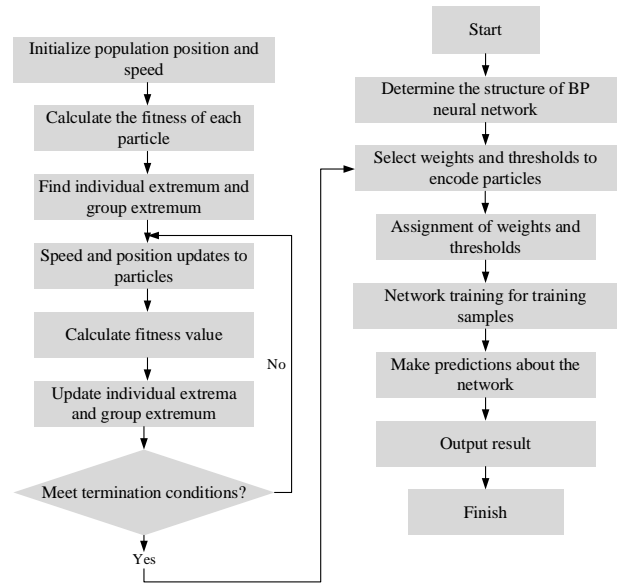


Fig. 5. Flow chart of PSO optimizing BP neural network model.

The node numbers in the input layer are first considered, as the system is based on the sample data of the enterprise big data knowledge evaluation index, and the node numbers in the input layer is decided by the amount of features extracted through PCA transformation [20]. The number of nodes in the output layer is decided by the size of the network connection power, i.e. the number of input nodes, output nodes and implied nodes, for both "yes" and "no" judgments. A particle is randomly generated with a position at (0,1) and the dimension of the velocity vector. The starting position of the particle is assumed to be pbest, and the optimal value of pbest is gbest. For each particle, if the exactness requirement is satisfied or the full evolution has reached the max iteration number (set to 2000), the algorithm ends and the current optimal individual in the full population is recorded, otherwise return to step 5.

## IV. ANALYSIS OF THE EFFECT OF THE APPLICATION OF MACHINE LEARNING-BASED ENTERPRISE INNOVATION DEVELOPMENT ASSESSMENT MODEL IN THE BIG DATA ENVIRONMENT

The study carried out a PCA using Matlab software-based on the above model and its theory. The data used for the study was derived from references, using a PCA of the 14 main use assessment indicator factors to derive the contribution of each major component, as shown in Fig. 6.

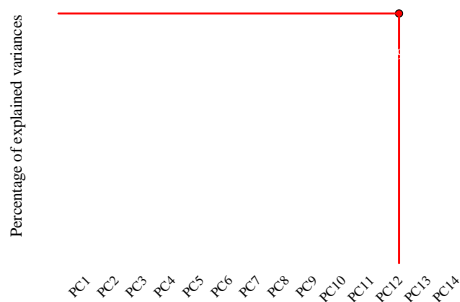


Fig. 6. PCA contribution rate statistics chart.

As can be clearly seen from Fig. 6, the cumulative contribution of the 20 indices when the number of principal components is 12 is a cumulative 89.365%. This method reduces the input nodes of the neural network from 14 to 12 and simplifies the input indices, causing a significant reduction in the size of the neural network and its reduction of 30%.

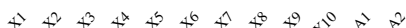


Fig. 7. Colour temperature diagram for the analysis of various factors related to the development of corporate innovation.

From Fig.7, we can see that among the 12 enterprise knowledge management and research innovation assessment indicators, the correlation coefficients are mostly around 0.5, for example, the correlation coefficients of X2, X8 are 0.519 and 0.553 in order, which have higher correlation, indicating that the previous PCA is effective, and the factors with poor correlation have been eliminated. The factors with high correlation are used as input data matrices, which lays the foundation for the next action of introducing the PSO-BPNN model.

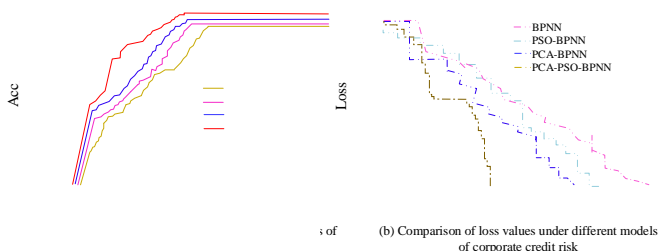


Fig. 8. Model training set accuracy curve and loss value curve.

The prediction error curves for the training samples are given in Fig. 8(b), with the number of training steps on the horizontal axis and the results of the errors on the vertical axis. Through 15 epochs of learning and training, the error results of the model proposed in the study were obtained close to 0. The other three lines in Fig. 8 are the model combining BP neural network and particle swarm algorithm, the model combining PCA method and BP neural network, and the model combining PCA method, particle swarm algorithm and BP neural network. Comparison shows that the PCA-PSO-BPNN has the highest training efficiency, reaching the target expectation after 15 steps. The training accuracy plots of the four models are given in Fig. 8(a), which clearly shows that the PCA-PSO-BPNN achieves 98% accuracy after 20 steps, which is significantly better than the other three models, so the model proposed in the study has good performance.

As can be seen in Table II, when the four algorithms were tested on the test and training sets, the RMSE values of the PCA-PSO-BPNN algorithm model for both the test and training sets were much lower than those of the other three algorithms, as can be seen from the enterprise R&D intensity dataset which has an RMSE value of 3.56 for the training set and 3.18 for the test set, and a value of 0.9982 for the R2 training set and 0.9915, which is higher than the other three algorithms. Meanwhile, from the data of corporate patent licensing, the RMSE values of the PCA-PSO-BPNN algorithm for the test set and training set are much lower than the other three algorithms, with 3.09 for the test set, 3.18 for the training set, 0.9451 for the R2 training set, and 0.9569 for the test set, which are also higher than the other three algorithm models. This shows that the PCA-PSO-BPNN algorithm model has better test results, higher test accuracy and more stable model.

The relative error histogram in Fig. 9 clearly displays that the absolute value of the relative error of each indicator does not exceed the 5% threshold, and only the relative errors of individual indicators have relatively large problems, such as X5 and X7 with the values of 4.5% and -3.8%. But the relative errors of the rest of indicators remain at correspondingly low levels. Better predictive capability for corporate innovation R&D and has excellent practicality. Finally, the study compared the training accuracy analysis of the PCA-PSO-BPNN algorithm with the conventional BP algorithm, PCA-BPNN and PSO-BPNN algorithms under different data set capacity sizes, and the results are shown in Fig. 10.

TABLE II. RMSE AND R2 FOR FOUR MODELS ON X1 AND X2 DATASETS

Datasets	Algorithm	Training		Testing	
		RMSE	R <sup>2</sup>	RMSE	R <sup>2</sup>
A <sub>1</sub>	BPNN	30.85	0.8545	32.11	0.8351
	PSO-BPNN	25.66	0.8965	26.78	0.8647
	PCA-BPNN	15.98	0.9014	16.85	0.8994
	PCA-PSO-BPNN	3.56	0.9982	3.18	0.9915
A <sub>2</sub>	BPNN	31.49	0.8214	30.98	0.8211
	PSO-BPNN	26.77	0.8851	27.54	0.8913
	PCA-BPNN	16.56	0.9052	16.99	0.9115
	PCA-PSO-BPNN	3.18	0.9451	3.09	0.9569

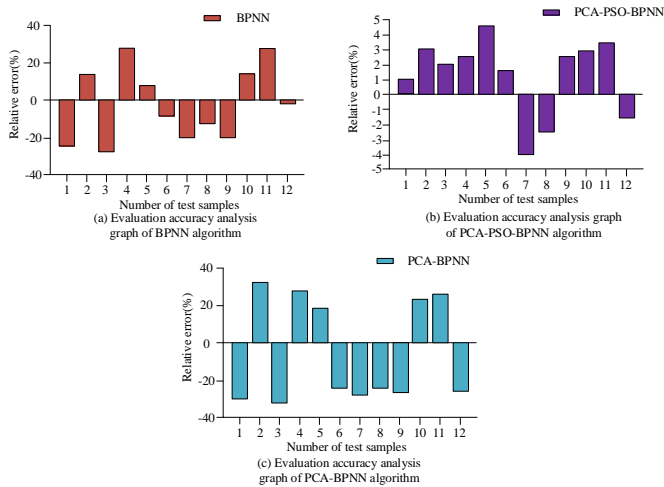


Fig. 9. Relative error in predicting corporate knowledge management and corporate innovation indicators based on the PCA-PSO-BPNN.

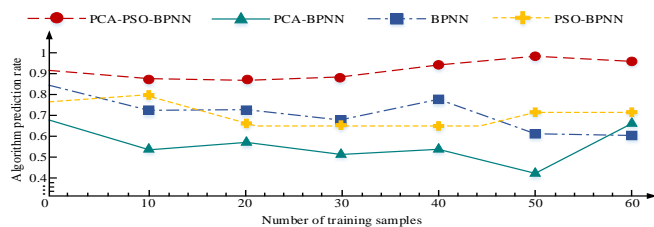


Fig. 10. Comparison of recognition accuracy of different algorithms trained on different datasets.

From Fig. 10, the study of the PCA-BPNN algorithm optimised by the PSO has the highest prediction accuracy among the four algorithms that conducted the experiment, and its average recognition rate can reach 94.21%; the recognition rate of the traditional BP algorithm model is slightly lower than that of the PCA-PSO-BPNN algorithm model, with an average recognition rate of 74.52%; the PSO-BPNN model The average recognition rate was 72.74%; the PCA-BPNN model had the lowest average recognition rate of 53.1%. The experimental results verify that the PCA-BPNN model optimised by the particle swarm algorithm is the best among the four models.

## V. CONCLUSION

With the development of Internet technology and big data technology, knowledge management has become one of the important factors for enterprise innovation and development. In this study, we first introduce the improved PSO-optimized BP neural network (PSO-BP) for evaluating the degree of the role of big data knowledge management in EnIn development, based on which PCA is conducted to reduce the dimensionality of the model and the weights of PSO-optimized BP neural network are used. The test results verified that the cumulative contribution value of the 14 indicators reached 89.365% cumulatively when the master-formation score was 12, which simplified the input indicators and made the neural network much smaller, and its reduction reached 30%. Secondly, the color temperature plot of Spearman rank correlation test shows that its correlation is high among 12 enterprise knowledge management and innovation evaluation indexes, which indicates that the previous PCA is effective, and the factors

with poor correlation are eliminated and entered into the established model as input data. It can be concluded that the model is effective with RMSE and R2 values of 3.56 and 0.9982 for the X1 training set and 3.18 and 0.9915 for the X2 test set, respectively. The results show that PSO-BP neural network can effectively reduce the dimensionality of the input indicators, simplify the neural network, and achieve a significant reduction in size. The high correlation between 12 corporate knowledge management and innovation assessment indicators indicates the importance of these factors in promoting corporate innovation. Although this study has achieved considerable results but there are still many problems, firstly, the study for enterprise big data knowledge management only evaluates enterprise innovation development without considering other factors and the feasibility of the algorithm will be considered subsequently for market conditions, regulatory environment and other factors. In addition, for this data study only one set of data was used for testing, and more data will be used to test the generality and accuracy of the algorithm in the follow-up.

## ACKNOWLEDGMENT

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# A Roadmap Towards Optimal Resource Allocation Approaches in the Internet of Things

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**Abstract**—Introducing new technologies has facilitated people's lives more than ever. As one of these emerging technologies, the Internet of Things (IoT) enables objects we handle daily to interact with each other or humans and exchange information through the Internet by being equipped with sensors and communication technologies. IoT turns the physical world into a virtual world where heterogeneous objects and devices can be interconnected and controlled. IoT-based networks face numerous challenges, including energy and sensor transmission limitations. New technologies are needed to spread the IoT platform, optimize costs, cover heterogeneous connections, reduce power consumption, and diminish delays. Users of IoT-based systems typically use services that are integrated into these networks. Service providers provide users with on-demand services. The interrelationship between this request and response must be managed in a way that is done using a resource allocation strategy. Therefore, resource allocation plays a major role in these systems and networks. The allocation of resources involves matters such as how much, where, and when available resources should be provided to the user economically. The allocation of resources in the IoT environment is also subject to various challenges, including maintaining the quality of service, achieving a predetermined level of service, storing power, controlling congestion, and reducing costs. As the IoT resource allocation problem is an NP-Hard one, many research efforts have been conducted on this topic, and various algorithms have been developed. This paper reviews published publications on IoT resource allocation, outlining the underlying principles, the latest developments, and current trends.

**Keywords**—Internet of things; resource utilization; resource allocation; systematic review

## I. INTRODUCTION

Over the last decade, the Internet of Things [1] has acquired popularity as a worldwide network, allowing physical objects to be controlled, monitored, and managed via the Internet and communication networks [2]. The integration of 5G connectivity [3], cloud computing [4], smart grids [5], and plasma sources [6] in IoT plays a vital role in enabling high-speed, scalable, reliable, and energy-efficient communication, storage, energy management, and advanced sensing capabilities, paving the way for a new era of interconnected devices and intelligent systems. Physical objects become smart by integrating radio frequency identification tags, sensors, actuators, etc. The most important characteristic of IoT objects is the ability to sense the surroundings, communicate, and interact with other objects. IoT devices operate on rechargeable batteries and non-renewable energy sources [7]. Whenever this equipment is deployed for permanent purposes, like ongoing environmental monitoring, it becomes imperative to extend the

life of the network. Wireless communication is the main source of energy consumption in IoT devices, which must operate over an extended time with limited resources [8]. The development of IoT devices requires both hardware and software to facilitate access at any place and at any time, and they also need to use the most efficient method for communication and resource allocation [9].

The optimum allocation of resources has always been of significant importance in improving the efficiency of the network. Resource allocation in IoT networks is challenging due to complex and large-scale communication between objects, heterogeneity, and the traditional characteristics of Wireless Sensor Networks (WANs) [10]. In addition, the IoT is not characterized by a uniform and fixed correlation. Therefore, in this environment, where the order and location of the nodes change regularly and quickly, resource allocation should be done in a distributed manner. Also, as mentioned above, owing to the limitations of energy sources, low power processors, limited memory capacity, wireless communication range, and communication bandwidth, the allocation of resources in this environment should bear lower overhead, reducing communication costs [11].

Two general aspects of resource allocation should be discussed and investigated to ensure high performance and create resource allocation strategies within an acceptable time frame. Several factors influence resource allocation, including cost, energy, response time, and security. The problem of reducing delay in resource allocation is also a critical and fundamental issue facing researchers in this research area [12]. The IoT has become an important and fundamental issue because of the connection of countless objects, the high volume of traffic, the storage of data and information, and the need for high-speed resources [13].

Machine learning and Artificial Intelligence (AI) have emerged as indispensable tools in the field of IoT resource allocation, revolutionizing the way resources are managed and utilized in complex and dynamic IoT ecosystems. The sheer volume and heterogeneity of IoT devices, coupled with the varying resource requirements and dynamic nature of IoT applications, pose significant challenges for efficient resource allocation. Machine learning algorithms, coupled with AI techniques, offer a powerful solution by leveraging data-driven insights and intelligent decision-making capabilities [14, 15]. One of the primary benefits of machine learning and AI in IoT resource allocation is their ability to analyze vast amounts of data collected from IoT devices and sensors. These technologies can extract meaningful patterns, detect anomalies, and predict resource demands with high accuracy. By

leveraging this data-driven intelligence, resource allocation algorithms can dynamically adapt and optimize resource allocation strategies based on real-time conditions and demands [16].

Moreover, machine learning algorithms can learn from historical resource allocation patterns and optimize resource utilization, leading to enhanced efficiency and cost-effectiveness [17]. These algorithms can identify resource bottlenecks, predict resource congestion, and dynamically allocate resources to alleviate these issues. By intelligently managing resource allocation, machine learning and AI techniques can improve system performance, reduce energy consumption, and enhance the overall quality of service in IoT networks [18, 19]. Furthermore, machine learning and AI can enable proactive resource allocation by considering contextual information, user preferences, and application requirements [20]. These technologies can learn from past user behavior and application performance to make intelligent predictions and allocate resources accordingly [21]. This personalized resource allocation approach can lead to enhanced user satisfaction, improved application performance, and efficient resource utilization.

This paper makes several significant contributions to the field of resource allocation in the IoT. First and foremost, it provides a comprehensive review of existing literature on IoT resource allocation, outlining the underlying principles, latest developments, and current trends. Furthermore, the paper analyzes the characteristics of datasets used in the evaluation of resource allocation algorithms. It considers factors such as the heterogeneity of IoT devices, data traffic patterns, and resource requirements. This analysis provides insights into how these dataset characteristics can impact the performance and suitability of resource allocation algorithms. It highlights the need for tailored approaches that consider the specific requirements of different types of data and IoT scenarios. The paper also conducts a detailed analysis of comparative results obtained from different datasets. It identifies patterns, trends, and discrepancies in algorithm performance, shedding light on the strengths and weaknesses of various resource allocation approaches. This analysis enhances our understanding of which algorithms may be better suited for specific types of data or IoT deployments.

The rest of the paper is organized as follows. Section II will provide a comprehensive background on the IoT and its significance in enabling objects to interact and exchange information through the Internet. It will highlight the challenges faced by IoT-based networks, particularly in terms of resource allocation, and emphasize the need for efficient resource utilization and allocation strategies. In Section III, we will conduct a systematic review of published publications on IoT resource allocation. We will discuss the underlying principles and concepts related to resource allocation in IoT systems. The review will encompass various algorithms, techniques, and methodologies proposed in the literature, highlighting their strengths, limitations, and applicability in different scenarios. We will analyze the latest developments and trends in resource allocation approaches, considering factors such as quality of service, power consumption, congestion control, and cost reduction. Section IV will provide

a comprehensive discussion and analysis of the reviewed resource allocation approaches. We will compare the different strategies, identify common challenges and emerging trends, and discuss their implications for future research and practical implementations. Additionally, we will address any gaps or limitations in the existing approaches and propose potential avenues for further exploration and improvement. Section 5 outlines V the potential research directions. The final section of the paper will summarize the key findings and contributions of the research.

## II. BACKGROUND

In this section, general information about IoT, resource allocation, and the challenges of resource allocation is given.

### A. Internet of Things

The rapid development of hardware and network technology has allowed a variety of smart devices to connect to the Internet and exchange data. This has led to the development of a new technology called the IoT [22]. IoT has evolved into a worldwide network of physical objects that can be controlled, monitored, and managed through the Internet and communication networks [23]. In IoT-based networks, physical objects are transformed into smart objects using radio frequency identification tags, sensors, actuators, and other components and then managed and controlled via mobile applications. With these capabilities embedded in the IoT, many applications have been developed, including home automation, industrial automation, the medical and healthcare industry, energy management, traffic management, and many more. By connecting physical objects, such as sensors, with the Internet, IoT technology can capture real-time data and then process and analyze it to create insights that can decide and take action. This makes it possible to automate various processes and create intelligent systems that can respond to events in real-time [24].

The IoT devices communicate with each other, share information, and take coordinated actions by sharing their vision, hearing, and thinking. IoT also faces challenges, such as technical difficulties, standardization, security, efficient resource utilization, and privacy concerns. With the significant growth of IoT resources in recent years, much data has been produced, which requires storage, processing, security, and management. To handle and manage such a large amount of data, it is necessary to use new technologies [25]. IoT-based networks and their nodes are challenging to manage due to the increase in data volume, the diversity of the nodes, and the requirement for resource allocation. Because countless objects in this network generate data in real time [26], IoT is characterized by the architecture shown in Fig. 1. Several factors have been considered and addressed in this architecture, including scalability, interoperability, reliability, and quality of service. This architecture is composed of five layers, which are described as follows.

- Perception layer: This layer, called the objects layer, represents the lowest layer of physical or hardware components. Data is collected at this layer and converted into signals that can be transmitted over networks and accessed by applications.



- Network layer: This layer facilitates the exchange of information between objects by connecting them. This layer ensures the secure transfer of information from sensor devices to the information processing system.
- Service management layer: This layer allows IoT programmers to work on heterogeneous devices regardless of their hardware configuration. Also, this layer handles the management of services, gathers data from the network layer, and archives it in the database.
- Application layer: This layer is typically responsible for providing services and applications that enable the integration and analysis of information received. This layer is crucial to providing high-quality intelligent IoT services.
- Business layer: This layer manages IoT services and activities and creates flowcharts, graphs, and business models based on the information derived from the application layer.

IoT capabilities are based on six key elements. These six key elements are essential for maximizing the potential of IoT technology.

- Identification: Identification is crucial in determining the IoT's purpose and providing services under customer demand. Identification can be accomplished using a variety of methods. An electronic product code is a permanent tagging technology containing a unique code for everything anywhere in the world.
- Sensing: Sensing in the IoT involves capturing data generated by sensors located on the network and forwarding it to a central repository, database, or the cloud. The collected data is processed to perform specific tasks in accordance with the requested services.

This data can identify patterns, anticipate future needs, and improve the efficiency of the IoT system.

- Connectivity: This technology enables heterogeneous objects to communicate with each other to provide intelligent services. IoT nodes should be capable of operating with limited power supplies and weak or noisy communication links. Bluetooth, IEEE 802.15.4, and Wi-Fi are common IoT communication protocols.
- Computing: The computing ability of the IoT is represented by the processing unit (for example, a microcontroller) and application software. A variety of software platforms provide IoT capabilities. For instance, Amazon Web Services (AWS) provides users with a range of tools for developing and deploying applications for the IoT, such as AWS Greengrass, AWS IoT Core, and AWS IoT Analytics.
- Services: IoT services are classified into four groups, namely ubiquitous, collaborative, information aggregation, and identity-related. Identity-related services provide valuable services that can be incorporated into other services. Aggregation services summarize or aggregate sensed data. Collaborative services use information obtained by information-gathering services to react and decide. Ubiquitous services make collaborative services available to anyone, anywhere, at any time.
- Semantics: to provide services, knowledge must be intelligently extracted from different devices. Knowledge extraction includes discovery, resource utilization, and information modeling. It involves identifying and analyzing data to provide accurate services.

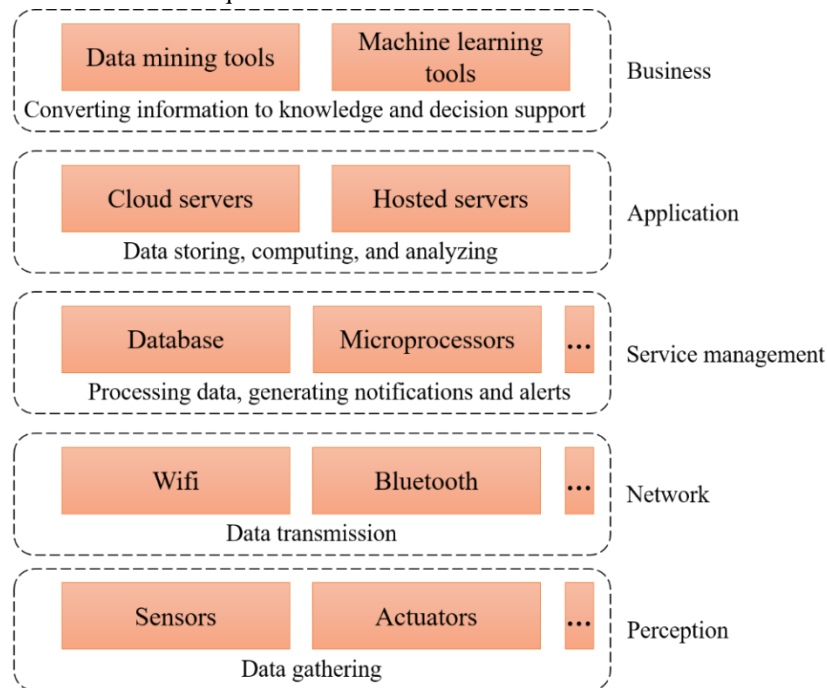


Fig. 1. IoT architecture.

## B. Resource Allocation

Resource allocation refers to allocating available resources to users efficiently regarding CPU, memory, network, bandwidth, etc. Also, resource allocation in IoT environments is subject to several challenges, including maintaining the quality of service, ensuring an agreed service level, conserving energy, handling congestion, and reducing costs. These challenges arise from the need to balance the conflicting objectives of allocating resources fairly and equitably to all users, while also optimizing the utilization of those resources. Resource allocation must consider that IoT environments are often characterized by heterogeneity, dynamism, and unpredictability [27]. Key considerations in allocating IoT resources are briefly stated in the following.

- **Heterogeneity:** The main idea of IoT is the widespread presence of objects in human life. Such an environment contains a wide range of different hardware and devices in diverse shapes and sizes. These devices can be very diverse. Computers, mobile phones, personal digital assistants, and wireless devices, such as radio frequency identification chips, have various communication ranges. Therefore, resource allocation should be conducted by considering the different computing capabilities of objects.
- **High adaptability:** IoT objects operate in unpredictable patterns and establish ad hoc connections with other nearby objects. Therefore, the movement of nodes cannot be ignored, and the network is expected to be highly dynamic. Centralized resource allocation is inappropriate in a dynamic structure, where nodes are moved around regularly and frequently. The resource allocation process must be flexible to respond to the dynamics of network connectivity.
- **Scalability:** Another challenge in IoT resource allocation is the need for interaction between thousands of devices at any time and place. As the network dimensions increase, creating a logical structure, such as a tree structure, becomes more challenging. It is also difficult to allocate and manage resources because of a lack of uniform coordination.
- **Energy awareness:** Energy consumption for communication and computing is a significant constraint for various IoT entities. Since IoT devices are powered by batteries for a long period, resource allocation should be done in a manner that minimizes energy consumption so that the network's energy status is used when allocating resources.
- **Load balancing:** The system load must be balanced for optimal resource utilization. During the resource allocation process, the workload, which includes energy consumption and communication activities, should be distributed throughout the network so that no part of the network runs out of resources more quickly than others.

## C. Mathematical Formulations of the Problem

It is first necessary to define the parameters, conditions, and characteristics of resources and tasks to explain the resource

allocation problem. Virtual Resources (VRs) are expressed as follows.

$$VR = \{CP_r, SR_r, SW_r, CO_r, ER_r\} \quad (1)$$

In Eq.1,  $CP_r$  refers to the number of computing resources,  $SR_r$  denotes the memory space,  $SW_r$  represents the set of software supported by VR,  $CO_r$  signifies the cost of VR per unit of time, and  $ER_r$  reflects the energy consumption of VR. Since certain tasks may require more than one machine, each task is divided into sub-tasks based on priority and execution order. Subtasks are defined as follows:

$$ST = \{CP_t, SR_t, SW_t\} \quad (2)$$

STs are measured in terms of three parameters: number of computing resources required ( $CP_t$ ), memory space required ( $SR_t$ ), and software type required ( $SW_t$ ). Therefore, the following tasks are included in each task.

$$T = \{ST_1, ST_2, \dots, ST_{nT}\} \quad (3)$$

In the above definition,  $nT$  indicates the number of sub-tasks related to task  $T$ . Assuming that there are  $N$  tasks and  $M$  VR nodes, the problem of assigning tasks to resources involves assigning all the sub-tasks of these  $N$  tasks to  $M$  VRs. Allocation is subject to several basic conditions as follows.

- **Software limitation:** Each task with its sub-tasks must be assigned to a machine that can execute the software requirements of the corresponding task.
- **The number of resources:** The number of resources required for the task with its sub-tasks should not exceed the number of VR resources to which the task is allocated.
- **Order and priority of execution of sub-tasks:** The order of execution of sub-tasks should be based on the sequence of its execution process, and all the sub-tasks of the sequence should be assigned to a VR for execution.
- **Time:** Tasks must be assigned to resources executed and completed within a specified time frame. The execution of all sub-tasks must start and end within the specified time interval.

## III. REVIEW OF RESOURCE ALLOCATION APPROACHES

In this section, previous methods in IoT resource allocation are examined in five different categories.

### A. QoS-aware Approaches

Two key factors in an IoT ecosystem are providing different service quality requirements and quick access to resources. These parameters represent resource distribution across different layers of the IoT environment, encompassing context awareness, performance, response time, and availability. Fog computing is one of the effective techniques to increase service quality, reduce network latency and energy consumption for IoT devices.

In [28], to minimize the network overhead, including delay and energy consumption, while meeting the quality of service requirements, a quality of service-aware resource allocation

approach is proposed that jointly communicates between fog nodes and IoT nodes. Transfer and allocation of computing resources are considered optimizing allocation decisions and minimize network overhead. First, an evaluation framework based on a hierarchical process is developed to prioritize the QoS parameters and different IoT tasks. Then, a resource block allocation algorithm is proposed to allocate resources to IoT devices based on device priority, satisfaction level, and resource quality. In addition, a QoS-aware bilateral matching game is introduced to optimize communication between cloud computing nodes and IoT devices. The simulation results show that the proposed method effectively ensures network load balance, improves resource utilization, and reduces network overhead.

New-generation networks have become increasingly important in the transfer of heterogeneous data streams. In fact, besides typical data and multimedia traffic, intelligent IoT applications create new types of traffic and interactions among millions of devices. This traffic creates a scalability issue, particularly regarding resource management and decision-making. The method presented in [29] aims to synthesize a flexible 5G radio frame by packing heterogeneous streams from multiple users into rectangular grids of time-frequency resources. The proposed approach includes the classification of flows based on quality of service, followed by the development of two offline databases.

In [30], a new QoS-aware resource allocation policy based on users' implicit feedback ratings is proposed for mobile edge computing for IoT to overcome service delays. The proposed method selects the user based on previous purchase preferences and implicit feedback from the cluster generated using similarity calculation. Using time-based collaborative filtering, resources are recommended for qualified users according to users' implicit feedback. The selected user receives the resource according to the minimum distance between the user and the resource. In [31], an effective algorithm is presented to solve the resource allocation problem in an IoT environment to minimize communication costs. A multi-layered resource allocation strategy is presented based on the meta-heuristic and data clustering paradigm for reducing latency in IoT applications. Several aspects of the proposed algorithm are discussed in depth, such as the coding of solutions for resource allocation, transitive operators, an objective function, and an analysis of the algorithm's time complexity.

In [32], a cellular-based frequency resource sharing (CFRM) approach is introduced for multi-cell device-to-device connectivity. Each cell consists of two zones, each with a different spectral source assigned to it to minimize interference between neighboring cells. The uplink resources of cellular users are shared between D2D users, thereby reducing the interference from device-to-device users to cellular users. The proposed design of the paper is a frequency multiplexer based on cross-cell FFR in D2D communication. It distributes different frequency resources to system users and cells in the local area while also investigating how well each cell can multiplex resources to a system that maximizes system/network performance. This paper provides the following key contributions: 1) In the cross-cell and FFR-based D2D communication context, an optimization scheme is

planned to optimize the network capacity, which supports the SINRs of cell users and devices, and the interference with cell users and devices in comments 2) A Cross-Cell Frequency Resource Sharing (CFRM) strategy for multi-cell D2D communications is developed to enhance network throughput and reduce interference with cell and system users.

### B. Context-aware Approaches

Context awareness in ICT refers to considering the state of entities, such as users or devices. Context-aware computing performs well in the IoT due to its importance in handling very large data sets. In [33], In 2, the optimization of channel selection is discussed, which is critical for reliable and efficient task delivery. The proposed approach's primary goal is to maximize the long-term throughput of energy and service reliability limitations. A combination of machine learning, matching theory, and Lyapunov optimization proposes a learning-based channel selection approach with conflict awareness, energy awareness, and service reliability awareness.

In [34], resource allocation for wireless IoT networks with short packet communications is discussed. A wireless IoT network with short packet communications is studied and investigated, where a hybrid access point first wirelessly supplies power to IoT devices. Then the devices transmit their short data, which has disadvantages: the destruction rate and packet error. To increase the efficiency and reliability of transmission, first, the efficiency values and the effective amount of information are defined as parameters to ensure a balance between transmission rate and packet error rate, and then the transmission time and packet error for each user is maximized so that the total throughput is Maximize or minimize the total transfer time that is effective for the user and this is achieved through the algorithms used in this paper.

In [35], the authors presented a method for allocating resources in edge computing for the IoT. Connecting objects to the Internet to make them intelligent is very important, but massive connectivity, big data processing, and significant energy consumption limit the use of the IoT. To address these challenges, a novel architecture for resource allocation at the edge is presented in this paper. Radio resource management and computing resource management in the IoT have also been evaluated in edge computing to improve system performance. The evaluation and review of the conducted studies show that the proposed resource allocation through this method can improve the system's efficiency and minimize the delay.

In [36], the authors have taken advantage of the satisfaction level of the quality of experiments (QoE) to obtain smart center-based services. The innovation of this paper is that it uses reinforcement learning (RL) to achieve superior accuracy in resource allocation. Two algorithms based on reinforcement learning are presented to obtain the cost of mapping tables and optimal resource allocation. The proposed method of the article is entitled "Smart Center-Centered Services for IoT (SCCS-IoT)," which uses an address and route-oriented architecture for communication. The term intelligent in the proposed model is intelligent operation capable of providing the most optimal solution using low-level or cost-effective computing resources. Furthermore, the proposed strategy focuses on two aspects. The first area of interest is the IoT resource allocation problem,

and the paper has proposed a new method that uses the RL mechanism to construct the resource allocation strategy. Implementing the RL mechanism is aimed at avoiding conflicts and intelligent resource allocation operations. As a second focus, QoE is considered when constructing RL value functions. A method that incorporates the quality of experience with learning power is being proposed. The cost of each type of task for a computing node comprises a state. The response given by the user determines the status value.

### C. SLA-aware Approaches

The heterogeneity and dynamic nature of IoT have made service-level agreements a key component of consumer-provider relationships. Ongoing monitoring of quality-of-service features shall be performed actively to provide this agreement. Furthermore, customers should consider several factors, such as trust (in the provider). In [1], a new mechanism for resource allocation considering buffering, scheduling, and rate limiting methods is proposed to address service level agreement problems.

In [37], the execution time constraint is considered the service level agreement constraint in the hybrid auction system. In the proposed approach, to optimally allocate resources and reduce costs, the winners in each tender round are determined according to the urgency of the tasks and based on the execution time deadline. To evaluate the performance of the suggested mechanism, the resource provider's profit and task completion success rate is compared to existing mechanisms using real workload data.

Collaboration between cloud computing and fog computing has proven extremely effective for resource allocation modeling and service delivery. The authors in [38] have developed a new approach for resource allocation to provide QoS requirements and service level agreement. This algorithm considers three parameters of completion time, service size and virtual machine capacity to manage user requests.

### D. Resource Utilization-aware Approaches

These approaches focus on the optimal use of IoT resources. Optimal resource utilization impacts profits and revenue in the IoT. For this purpose, usage-aware resource allocation methods are essential for reducing energy consumption, optimizing resources, and distributing resources fairly. In [39], a hierarchical architecture using a gateway connects IoT devices to eNB to use network resources optimally, and a multi-class resource allocation algorithm is presented for LTE-based IoT communications. The simulation outcomes indicate that the proposed algorithm performs well regarding latency and data rate.

Software-oriented networks are a promising technology for simplifying network management due to the provision of reconfigurable network elements; therefore, integrating this approach and the IoT provides a potentially practical solution to enhance the management and control capabilities of the IoT network. By using software-based networking technology, resource efficiency in the IoT network can be further improved. In [40], the authors have proposed a new architecture for allocating IoT resources based on software-oriented networks. In this article, the resource allocation

problem is planned as a Markov decision process, and the optimal solution is obtained using the relative value iteration algorithm.

In [41], a new solution to the resource allocation problem by adopting cooperative game values is presented. In the proposed game model, the concept of Shapley value is developed and used to design a bandwidth allocation algorithm. The results demonstrate that the proposed approach enhances the optimal use of network resources while ensuring performance balance compared to previous methods.

In [42], the fifth-generation mobile communication system is mentioned as an important factor in increasing the importance, value, and increasing use of the Internet of Things, which requires high speed in data transmission, permanent and uninterrupted connection, and very low delay. Therefore, to achieve these requests, this paper presents a new biologically inspired resource allocation method for network slices in the 5th generation IoT with activation capability. Personal service allocation and users' evolutionary interest relationships are used to model the dynamic and complex network, and a biological allocation strategy inspired by nature is used, which is continuously updated. By observing the proposed results, the evidence shows that the proposed method has improved efficiency and flexibility in resource allocation.

### E. Energy-aware Approaches

Energy consumption and heat production in data centers are important factors in dealing with challenges related to energy consumption-aware resource allocation techniques. The primary cause of energy consumption and unnecessary heat generation is the increase in the number of servers, rapid data center growth, power loss, high load, and high demand.

Integrating mobile edge computing and IoT enables IoT devices with limited computational and energy capabilities to offload their latency-sensitive computing tasks to the edge of the network, providing quality services to the devices. In [43], a non-orthogonal multiple access technique is used to enable widespread connectivity, and how to use this technique to achieve efficient mobile edge computing in IoT networks is investigated. To maximize the energy efficiency for loading and the maximum tolerable delay limits of IoT devices, the radio and computing resource allocation problem is formulated in which intra- and extra-cellular interferences are considered.

In [44], a 5G-based communication framework supports the physical-cyber deployment of the IoT in a centrally controlled manner. Based on this structure, several actuators and sensors can communicate with the central controller in a two-way fashion. The resource allocation problem is formulated as an exact non-convex programming problem aiming to maximize energy consumption within the available channel band.

Cognitive radio can reduce the spectrum scarcity issue of IoT applications, and wireless energy harvesting eliminates the need for battery charging or replacement for IoT and cognitive radio networks. For this purpose, in [45], the authors have used wireless energy harvesting for cognitive radio, where cognitive radio devices cannot only cooperatively detect available radio frequencies but also collect the wireless energy transmitted by an access point. An optimization framework is proposed to

strike a balance between the energy efficiency and spectral efficiency of the network.

In [46], an energy-aware and network density-aware approach to address the resource allocation problem in IoT networks based on hybrid optimization strategies is presented. This paper uses data clustering and meta-heuristic algorithms to reduce congestion between IoT devices and gateways. Furthermore, this paper contributes to the path discovery mechanism by proposing a queue-based collective intelligence optimization algorithm that selects the optimal path for the future path based on multiple constraints.

#### IV. DISCUSSION

The processing of an application generates a workload on the IoT system. The workload refers to the number of resources required to complete the tasks required by the program. Workload includes the amount of bandwidth and measurement devices consumed by the program and the amount of memory and processing power consumed. In the previous section, the existing methods for the resource allocation problem in the IoT were examined in 5 categories: service quality-aware, context-aware, service-level agreement-aware, resource-use optimization-aware, and energy-aware approaches. In this section, the main features of the approaches are studied, and the important factors that have been improved in the mechanisms are briefly shown in Table I. Increasing the performance of IoT resource allocation is one of the most important goals in the reviewed articles. In addition, the increase in service quality and its use has been examined in some studies. The reduction of energy and time consumption has been investigated in these articles. Optimizing resource allocation approaches can be obtained by guaranteeing availability and reliability and reducing the failure rate in the IoT ecosystem. The objective functions presented in the reviewed works can be stated as follows:

- Reducing the cost of the network: due to the existence of a large volume of services, users, information, and resources in networks based on the Internet of Things, the cost of creating this type of network has become a fundamental challenge; therefore, minimizing network cost is one of the important functions in IoT-based networks.
- Reducing the number of base stations: with the increase in the number of base stations, the consumption cost of the entire network will increase; therefore, adopting the efficient number of base stations is one of the other objective functions.
- Improving network lifespan: In these models, improving network lifespan is achieved by reducing energy consumption and increasing the lifespan of IoT devices.
- Increasing network coverage: In this model, the area covered by base stations increases.
- Increasing the network output: By maximizing the total transmission rate by the base stations, the output, which is one of the most basic parameters of the network, increases.
- Reducing the total mobile power consumption of base stations: if mobile base stations are used, the lifespan of these stations is improved by minimizing their mobile power consumption.
- Reducing the number of stopping points of base stations: in the models that use mobile base stations, telecommunication communication is considered only if the stations are stationary to reduce the complexity. As the number of static points increases, the delay in the network increases.

According to the previously reviewed articles and works, in most of the presented articles, two types of nodes are studied in the proposed system model for resource allocation in the Internet of Things. The first type of these nodes are resource nodes that provide appropriate services. The second node is the gateways that are connected to the resources. Gateways connect different parts of the IoT system. Each gateway is responsible for controlling the path of several resources. Resources can be connected to different gateways. The communication cost between a gateway and all resources is predetermined. One aspect of this problem is that the resources are distributed among the gateways to create the lowest communication cost. Cost between gateways is also an important part of the total cost, so another aspect of this issue is how the gateways are connected.

Due to the high communication cost between gateways, each solution to the problem connects the gateways with the least number of connections. This connection can be linear or loop. Fig. 2 shows an example of connecting resources and gateways. The communication cost is also different with the change in the communication model. One of the goals of the problem is to find a model for resource allocation with the lowest communication cost. This figure can be considered as an outline of the proposed system model. Of course, parts of this system can be slightly changed depending on the designed scenario.

According to Fig. 2, the considered environment includes IoT resources, gateways, and connections between them. These components are deployed in the environment to respond to users' needs and create integrated services. A composite service includes instances of a service formed by establishing connections between IoT resources to provide capabilities and respond to users' needs. Data must be exchanged between IoT resources to create a suitable hybrid service and perform interaction between services.

A service gateway is a computing node that provides computing capabilities to implement service instances and communication capabilities to enhance IoT resources. Each gateway has a resource-binding capacity that can limit the number of IoT resources allocated to the gateway. IoT resources assigned to different gateways can communicate with each other through gateway connections. Possible connections between gateways are determined when they are deployed. Although not all gateways are directly connected to each other, all gateways must be reachable from any other gateway in the IoT environment. Each resource must be assigned a gateway to pass data to other resources to create a hybrid service. The

connection between a source and a gateway creates this allocation. Each resource has a list of connectable gateways, and the number of connectable gateways varies by resource type. Connections between gateways should also be specified. Gateways can be connected directly or indirectly through other

gateways. Each gateway can directly connect with other gateways within the range of connection capacity. To overcome the limitation of connection capacity, redundancy or ring connections between gateways should be avoided, and connections between gateways should form a tree structure.

TABLE I. A SIDE-BY-SIDE COMPARISON OF IOT RESOURCE ALLOCATION APPROACHES

Category	Reference	Service quality	Delay	Energy consumption	Reliability	Availability	Overhead	Scalability
QoS-aware	[28]	↑	↓	↓			↓	
	[47]	↑	↓				↓	↑
	[30]	↑	↓			↓		
	[31]	↑	↓					
	[32]	↑						↑
Context-aware	[33]		↓	↓	↑			
	[34]			↓	↑	↑	↑	
	[35]	↑	↓	↓				
	[36]	↑		↓				
SLA-aware	[1]						↓	
	[37]	↑						
	[38]		↓		↑			
Resource utilization-aware	[39]	↑	↓					
	[40]				↑			↓
	[41]	↑						↑
	[42]	↑	↓		↑			
Energy-aware	[43]		↓	↓				
	[44]	↑		↓				
	[45]			↓				
	[27]		↓	↓			↓	↑

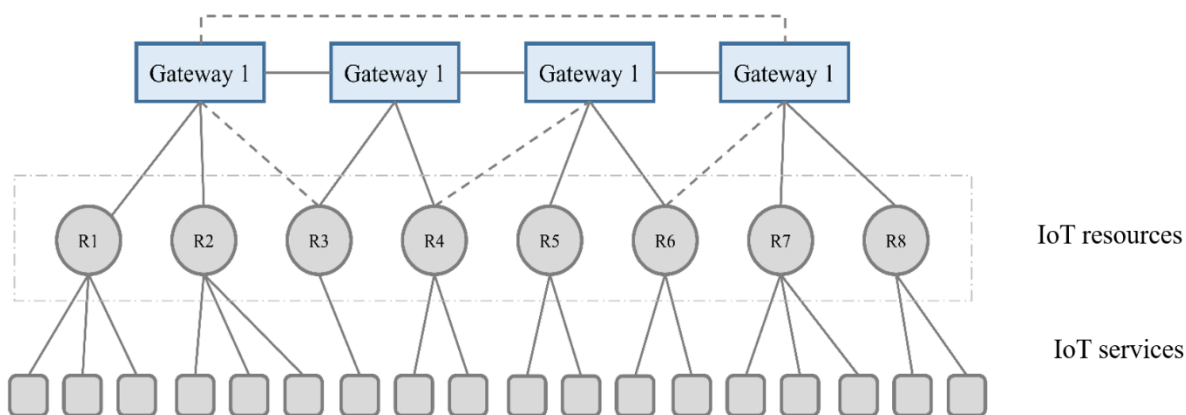


Fig. 2. Resource allocation model.

In the evaluation of the existing resource allocation approaches, it is essential to consider their limitations and

assess their suitability for addressing the resource allocation problem in the IoT. While many of the reviewed methods have



shown promising results, certain limitations need to be acknowledged. One common limitation is the assumption of homogeneous IoT devices in some approaches, which may not accurately reflect the real-world scenarios where devices exhibit varying capabilities and resource requirements. This limitation can impact the performance and effectiveness of resource allocation algorithms in heterogeneous IoT environments. Another limitation is the neglect of dynamic data traffic patterns in certain methods. The resource allocation algorithms that do not consider the varying data traffic characteristics may not be optimal in scenarios where the data flow changes dynamically, leading to suboptimal resource utilization and potential congestion issues.

Furthermore, some existing methods may lack scalability and fail to handle the increasing number of IoT devices and the growing complexity of IoT deployments. As the IoT ecosystem continues to expand, resource allocation approaches should be capable of accommodating the larger scale and diverse requirements of IoT networks. Additionally, the trade-off between energy consumption and service quality is a critical aspect that needs to be addressed. Some methods may prioritize energy efficiency at the cost of compromising service quality, while others may focus more on providing high-quality services but consume excessive energy. Striking a balance between energy conservation and maintaining satisfactory service quality remains a challenge in resource allocation.

## V. FUTURE RESEARCH DIRECTIONS

Future research directions in IoT resource allocation can focus on several key areas to address emerging challenges and further enhance the efficiency and effectiveness of resource allocation strategies. Some potential research directions include:

- **Dynamic resource allocation:** Develop adaptive resource allocation algorithms that can dynamically adjust resource allocation based on changing network conditions, varying demands, and evolving IoT environments. This can improve resource utilization and optimize the allocation of resources in real-time.
- **Energy-efficient resource allocation:** Design energy-aware resource allocation techniques that consider the limited energy resources of IoT devices. Explore energy-efficient algorithms that minimize energy consumption while maintaining desired levels of service quality and network performance.
- **Security-aware resource allocation:** Investigate resource allocation approaches that integrate security considerations into the allocation process. Develop mechanisms to allocate resources in a way that ensures data privacy, confidentiality, and integrity within the IoT ecosystem.
- **Multi-objective optimization:** Explore multi-objective optimization techniques that consider multiple performance metrics simultaneously, such as energy consumption, network latency, resource utilization, and quality of service. Develop resource allocation algorithms that strike a balance between conflicting

objectives to achieve optimal resource allocation outcomes.

- **Edge and fog computing:** Investigate resource allocation strategies that leverage edge and fog computing capabilities to enhance the efficiency of IoT systems. Explore how resources can be allocated across edge devices and fog nodes to minimize latency, improve response times, and optimize overall system performance.
- **Machine learning and AI-based approaches:** Explore the use of machine learning and artificial intelligence techniques to optimize resource allocation in IoT networks. Develop intelligent algorithms that can learn from historical data, predict resource demands, and dynamically allocate resources based on real-time conditions.
- **Scalability and heterogeneity:** Address the challenges of resource allocation in large-scale IoT deployments with heterogeneous devices and varying resource requirements. Develop scalable and adaptive resource allocation algorithms that can handle the complexities of diverse IoT environments.

## VI. CONCLUSION

The IoT provides an environment in which physical and digital devices, equipped with identification, processing, diagnosis, and network functions, can communicate through the Internet to achieve a specific goal. In fact, the IoT turns everyday devices into a diverse set of smart objects in order to realize useful applications such as traffic management, energy management, education, finance, and smart transportation. Generally, in IoT-based systems, IoT users use the services available in these types of networks. Service providers offer services on demand to users. Resource allocation strategy as an effective method is used to manage requests and responses. In line with the allocation of resources in the IoT environment, this article presented a background of the IoT and the resource allocation issue. Then the available methods were divided into five categories and examined. Finally, a proposed model for the allocation of IoT resources was presented. The IoT network is often used as a special purpose network according to the application that the network has; therefore, in this network, some nodes (network resources) have a high priority according to the type of data they produce, and therefore these resources should have a high priority in network activities, including resource allocation.

In most of the methods used for resource allocation, all network nodes and their resources are considered with the same priority. This causes network power, network delay, and network resources to be used in a non-optimal way in these networks. Resources with high priority are considered the same as resources with low priority, and optimal resource allocation is not done. Therefore, in the IoT network, for the users of this network to have optimal access to the network resources and to somehow allocate the resources according to the wishes and expectations of the network users and the network requirements, it is better to use the network and also prioritizes the data that the network nodes produce and sent and processed

to be determined. For example, in networks used for real-time applications, a series of resources are more important than other network resources in terms of time and delay, so an optimal allocation should be made for these types of resources.

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# Social Media Mining to Detect Online Violent Extremism using Machine Learning Techniques

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**Abstract**—In this paper, we explore the challenging domain of detecting online extremism in user-generated content on social media platforms, leveraging the power of Machine Learning (ML). We employ six distinct ML and present a comparative analysis of their performance. Recognizing the diverse and complex nature of social media content, we probe how ML can discern extremist sentiments hidden in the vast sea of digital communication. Our study is unique, situated at the intersection of linguistics, computer science, and sociology, shedding light on how coded language and intricate networks of online communication contribute to the propagation of extremist ideologies. The goal is twofold: not only to perfect detection strategies, but also to increase our understanding of how extremism proliferates in digital spaces. We argue that equipping machine learning algorithms with the ability to analyze online content with high accuracy is crucial in the ongoing fight against digital extremism. In conclusion, our findings offer a new perspective on online extremism detection and contribute to the broader discourse on the responsible use of ML in society.

**Keywords**—NLP; machine learning; social networks; extremism detection; textual contents

## I. INTRODUCTION

In the burgeoning digital age, the ubiquity of social media as the world increasingly navigates towards digitization, the rise of social media and the vast landscape of user-generated content it produces have opened up new vistas of communication and social interaction [1]. However, this digital evolution has also given rise to formidable challenges, one of the most pressing being the proliferation of online extremism. The cloak of anonymity provided by the internet, along with the unprecedented reach of social media, has exacerbated the spread of extremist ideologies, thereby necessitating effective detection mechanisms. This paper is dedicated to exploring the application of Machine Learning (ML) techniques for the detection of online extremism on social media platforms [2].

The cornerstone of our study revolves around the deployment of six specific Machine Learning algorithms. The comparative analysis of these methodologies forms a significant part of our research, enabling us to discern the relative strengths and weaknesses of each in the context of online extremism detection.

The nature of online extremism is as complex as it is harmful [3]. To address it effectively, we need to delve into the intricacies of online communication patterns, exploring how coded language and digital interaction networks serve as conduits for the spread of extremist ideologies [4]. In this context, our study is not merely a technical exploration of

machine learning techniques but also a sociolinguistic inquiry into the nature of online extremism itself [5].

Machine Learning has an ability to sift through vast datasets and identify patterns that may be invisible to the human eye [6]. By training ML algorithms to recognize and flag extremist sentiments, we aim to create an effective line of defense against the spread of dangerous ideologies.

However, the application of Machine Learning in such a sensitive domain also raises ethical considerations. With the power to scrutinize digital communication comes a responsibility to use it wisely and fairly. Therefore, we also dedicate a portion of our research to discussing ethical considerations surrounding the use of ML for online extremism detection.

In essence, our exploration is multifaceted, combining a technical examination of Machine Learning methodologies with an investigation into the sociolinguistic phenomena that characterize online extremism [7]. We conclude with a discussion on the ethical implications of applying these techniques, thereby providing a holistic view of the challenge at hand.

In this paper, we investigate the challenge of identifying extremist views and appeals for violence on social media platforms. More specifically, our emphasis is on comprehending and identifying extremist ideas in the information posted by online users. In order to comprehend the appeals made by extremist groups through a data extraction point of view, we first undertake an in-depth study of the material, including vocabulary and subject descriptors [8]. In order to detect extremist views included in the data, six distinct sets of relevant traits were uncovered, and multiple training methods were evaluated against one another. This is an original use for the automated identification of violent extremism in material, and it uses a mix of the efficient attribute architecture and classifiers that we have provided.

The following are some of the ways in which this paper significantly contributes to the body of knowledge and pioneers new ground in the field:

1) The use of information extraction as well as knowledge mining to identify the distinctive characteristics of violent extremism and appeals to conduct violent actions that are included in the material created by internet users. This technique exposes details regarding extremist ideologies through the lens of data analytics.

2) Corpus: this paper introduces the social network and compiles a fresh collection of information for the purpose of identifying extremist communications and appeals to extremism [22], which is now the most widespread social network among young people in Kazakhstan [9]. Psychologists divide the dataset into two groups based on whether or not it contains extremist statements or appeals to violence. The dataset was acquired from a social network that is extensively utilized in the republics of the Commonwealth of Independent States (CIS).

3) Applying machine learning: There, we applied six machine learning algorithms to violent extremism detection problem. The results are given using different evaluation parameters of machine learning methods.

This paper provides an in-depth analysis of the use of ML in online extremism detection, offering insights into both the technical and ethical aspects of this issue. Our findings contribute to the broader conversation on online safety, the responsible use of AI, and the role of digital platforms in our society. This research underlines the necessity of a multidisciplinary approach to address the escalating issue of online extremism and exemplifies the crucial role of machine learning in curbing this growing menace. Our paper contributes to the broader discourse on online safety, the responsible use of artificial intelligence technologies, and the role of digital platforms in maintaining the fabric of our social structure. Through our research, we strive to shed light on how a multidisciplinary approach can effectively address the escalating issue of online extremism and underline the pivotal role of Machine Learning in combating this digital menace.

## II. RELATED WORKS

Machine learning models are used in different applied tasks as smart city and smart energy [10], security-related problems [11], and text processing [12]. The issue of detecting and mitigating online extremism has evolved over time, calling for more sophisticated, adaptable, and scalable solutions. This review delves into the transition from traditional methodologies to machine learning (ML) techniques and offers a comparative analysis of these two broad categories.

### A. Conventional Methods for Online Extremism Detection

The initial responses to online extremism have largely been traditional in nature, utilizing manual review processes and rule-based algorithms [13]. These methods involve human moderators, who, based on their interpretation of the content, decide on its appropriateness or otherwise. Similarly, rule-based algorithms operate by matching specific patterns, keywords, or blacklisting certain types of content or users known to promote extremist views [14].

While these traditional methods have proven effective to some extent, they are not without significant limitations. The major constraint is the issue of scalability, given the exponential growth of user-generated content on social media [15]. Manual review processes are inherently time-consuming and labor-intensive, making them less practical for large scale operations [16]. Rule-based algorithms, despite being automated, are often rigid, unable to adapt to the evolving

nuances of online extremism [17]. Furthermore, both methods carry the risk of inherent bias due to the subjective nature of interpretation, which can lead to both over-censorship and under-censorship.

Traditional methods of addressing online extremism have relied predominantly on manual and rule-based approaches [18]. While these methods have provided a starting point, they grapple with issues related to scalability, adaptability, and inherent bias. As user-generated content has grown exponentially, the limitations of these methods, in terms of time, resources, and subjectivity, have become increasingly pronounced [19].

### B. Machine Learning Methods for Online Extremism Detection

To overcome these limitations, researchers have turned to ML techniques that can handle vast amounts of data and adapt to evolving online communication patterns. These techniques rely heavily on feature extraction methods, which transform raw text data into a structured format that ML algorithms can understand and analyze.

The limitations of traditional methods have driven the exploration of more advanced solutions, leading to the adoption of Machine Learning (ML) techniques. These methods offer key advantages including scalability, accuracy, adaptability, and the potential for real-time detection [20]. This study focuses on six ML algorithms: Support Vector Machine (SVM), Decision Tree, Random Forest, K Nearest Neighbors (KNN), Naive Bayes, and Logistic Regression. Each algorithm exhibits unique strengths and weaknesses, offering a versatile toolkit for addressing the multifaceted challenge of online extremism detection [21].

A critical component of ML success in detecting extremist content lies in feature extraction, where raw data is transformed into a format that these algorithms can utilize. Techniques such as Term Frequency-Inverse Document Frequency (tf-idf) [22], Bag of Words (BoW) [23], and Word2Vec have been commonly employed for this purpose [24]. Tf-idf emphasizes the importance of words in a document, BoW assesses the frequency of words independent of the order or grammar, and Word2Vec encapsulates semantic relationships between words, by mapping them as vectors in a multidimensional space.

In a seminal work, authors employed the tf-idf method in text categorization, highlighting its effectiveness in weighing the importance of words within a given document [25]. By measuring the frequency of a term adjusted by its rarity in the entire corpus, tf-idf helps identify key terms that might indicate extremist content.

The BoW method, despite its simplicity, has been extensively used due to its effectiveness and interpretability. In this approach, text is reduced to a 'bag' of its words, disregarding grammar and word order but preserving frequency. Researchers have shown how BoW can be powerful when combined with ML techniques, particularly in topic modeling [26].

Part of Speech (PoS) tagging has also been used to improve the performance of ML algorithms in detecting extremist

content. Next study demonstrated that PoS features, when used in conjunction with SVM, significantly improved the detection of hate speech [27].

Word2Vec, goes beyond simple frequency-based methods and captures the context and semantic relationships between words [28]. By representing words as vectors in a high-dimensional space, it enables the detection of patterns and associations that can be indicative of extremist ideologies.

.When comparing traditional methods with ML techniques, it's evident that each offers distinct advantages. Traditional methods are relatively straightforward to implement and their outputs are easily interpretable. However, their scalability issues and inability to evolve with the changing landscape of online extremism significantly limit their efficacy.

Conversely, ML methods present greater adaptability and scalability. Their ability to learn from data patterns, adapt to new information, and handle extensive and diverse content make them a promising solution for online extremism detection. However, the complexity of ML models can pose challenges, specifically in interpretability and transparency [29]. Additionally, the effectiveness of ML methods is inherently tied to the quality of input data and the relevance of the features extracted.

In conclusion, despite the efficacy of traditional methods in certain contexts, ML techniques appear to be a more potent solution for detecting online extremism on a large scale. However, careful consideration must be given to ethical

implications, such as potential privacy infringements and biases, as we harness the power of these advanced technologies in our quest to maintain safe and respectful online environments.

### III. DATASET

We first wanted to establish the hazard criterion before we could decide if a text was connected to extremism or not. Putting together a list of phrases is one such method. For the purpose of defining the term, a collection of key terms was compiled and used to conduct an investigation into the data contained inside the social networking site [30]. The software program deduces that the text should be further investigated because it contains the stated keywords, and this conclusion is based on the fact that these keywords are present in the content. The whole data collection, an analysis of the postings, and a categorization of the texts are shown in Fig. 1.

The achievement of data collecting might be carried out differently depending on the source of information, but the fundamental idea of its framework should be maintained throughout. The component of the program that is required for the extraction knowledge from publicly accessible sources has as its primary objective the successful completion of tasks in a timely and efficient manner. It is vital to make advantage of the built-in techniques for receiving data from sources (API) in order to achieve a high level of effectiveness [31]. In the event that such techniques are not available, it will be essential to collect the relevant data via making HTTP queries.

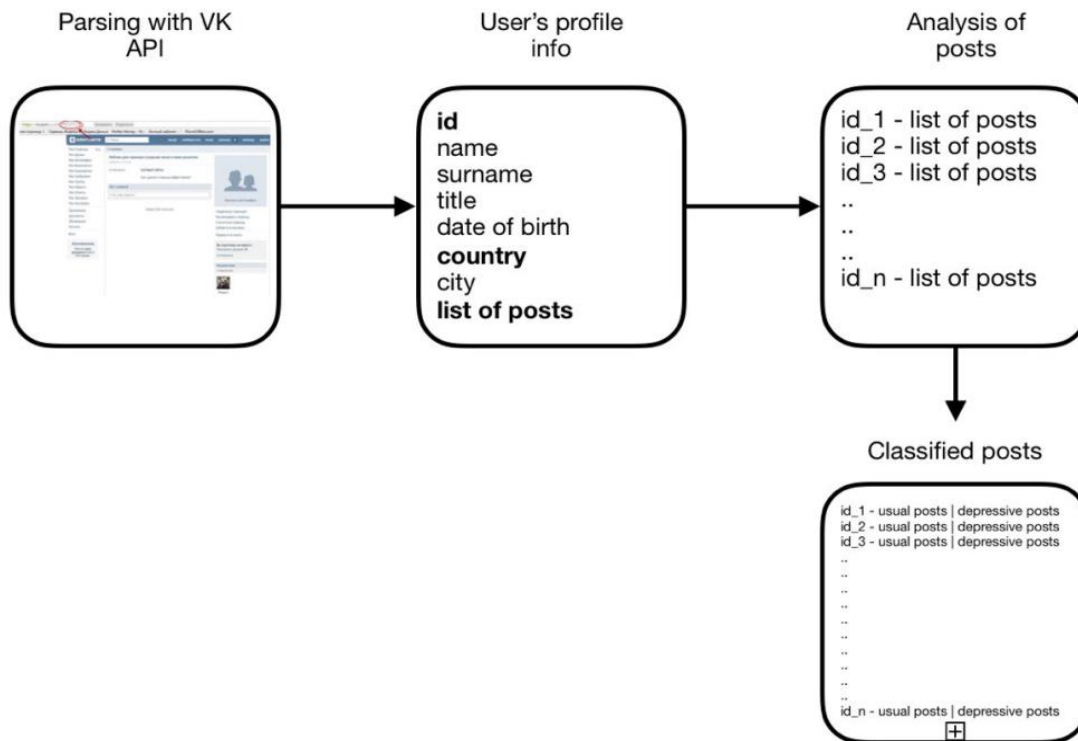


Fig. 1. Architecture of the data collection unit.



The application is comprised of three separate components as data collection unit, keyword scan unit, and machine learning unit which are as follows:

1) The Data Collection Unit is in charge of gathering data from publicly available channels and sending it on for further processing; In order to process the data coming from the VKontakte social network, an application written in Python programming language has been created. We partly parsed open access profiles using the publicly available VK API [32], which we accessed.

2) The Keyword scan unit is liable for detecting keywords in a vast quantity of data; because we had earlier a list of keywords that are often discovered in communications connected to violent extremism, we used a linear search for terms in each written content, and then partitioned the text into tokens. Specialists were consulted and had a role in the development of keywords that may be utilized when searching for potentially harmful content;

3) The determination of whether or not the data is connected to violent extremism falls within the purview of the textual content classification module. In this stage, we apply different machine learning algorithms for online extremism detection problem.

Data collection unit is the initial stage of the proposed framework. For the purpose of data collection, we make use of the VKontakte social network. For the purpose of data collecting, a parser is developed in Python version 3.6. The query was used in order to interact with the application

programming interface (API) of the social networking site. It was decided that the program package Pycharm will serve as an experimental platform.

#### IV. MATERIALS AND METHODS

##### A. Feature Engineering

It is vital to specify the criterion of "hazard" before assigning the material to being associated to violent extremism in any way. Defining a list of keywords is one possible solution to the problem. The produced application made use of this strategy for identifying the different kinds of information that may be found. For the purpose of defining the term, a list of keywords was developed, and those keywords were utilized to conduct an analysis of the material contained inside the social network VKontakte. The conclusion reached by the software application about the text's suitability for more investigation is based on whether or not the text contains the keywords that were provided. In our research, we used statistics, POS features, features based on LIWC features, and features based on TF-IDF word frequency.

In order to get an understanding of the informativeness of these feature sets, we use principal component analysis (PCA) [33] in Fig. 2 to create a visual representation of the features on the gathered corpus in a two-dimensional space. When we look at Fig. 2, we can see the polarity and subjectivity of the explored dataset to detect violent extremism. This suggests that our classifier should have an easier time distinguishing between the two categories.

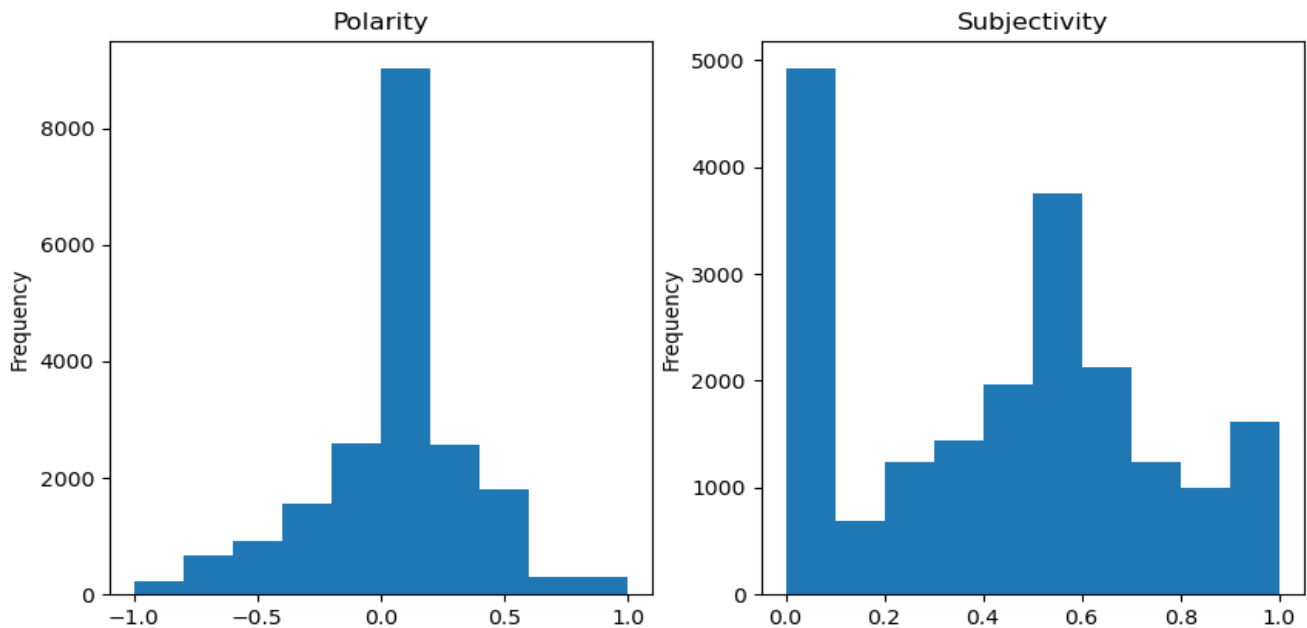


Fig. 2. Extracted features.

1) *Classification Models:* Messages relating to extremism that are found within the content of social networks may be detected using the normal supervised learning based classification problem. We created classifiers to train data couples of input objects  $\{x_i, y_i\}_i^n$  and supervisory signals

$\{x_i\}_i^n$  [34], taking into consideration a corpus that consisted of texts with tags  $\{y_i\}_i^n$ .

$$Y_i = F(x_i) \quad (1)$$

If  $y_i=1$  indicates that the text in question is "extremist intended text," then  $y_i=0$  indicates that the text in question is "not extremist intended text." The goal of training phase of the classification is to reduce the amount of incorrect classifications made in the data used for training. The inaccuracy in the prediction is going to be presented in the form of a loss function called  $L(y, F(x))$ , where  $y$  will represent the actual label and  $F(x)$  will represent the anticipated label. In broad strokes, the purpose of training is to arrive at the best possible prediction model  $F(x)$  by finding solutions to the following optimization problems:

$$\hat{F} = \arg \min_F E_{x,y} [L(y, F(x))] \quad (2)$$

The categorization of extremism-related writings is shown in Fig. 3, which illustrates the schema. The methods of oversampling and undersampling, in addition to statistics, LIWC, POS, and TF-IDF, are included in the features. These approaches are used to manage unbalanced data. The machine learning models were given access to all of the retrieved characteristics.

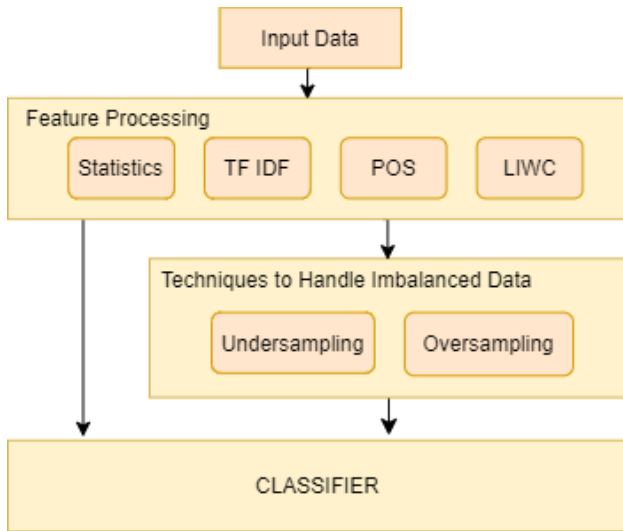


Fig. 3. Architecture of the proposed framework.

Our primary objective is to detect and isolate any content within the chosen dataset that exhibits ties to violent extremism, sourced from any participating users. The initiation of our text classification process involves engaging with the entirety of the domain, which consists of multidimensional objects procured from the dataset under scrutiny.

Our fundamental feature extraction mechanisms stem from a diverse array of methodologies, namely, possibilities offered by N-gram [34], Linguistic Inquiry and Word Count (LIWC) category functions [35], the Latent Dirichlet Allocation (LDA) model [36], and an assortment of their combinational elements. These characteristic traits, constituting the foundation of our analytical tools, are solely derived from the training data that we have meticulously collated.

This holistic approach facilitates a comprehensive understanding of the data, subsequently enabling the successful identification of any material that may be associated with

violent extremism. It is through the deployment of these robust methods and their respective combinatory factors that we are able to achieve our mission in an effective and efficient manner.

The confusion matrix is an instrumental method for collating an encapsulated summary of the results stemming from a classification process. Relying on accuracy as a solitary metric can potentially lead to misleading interpretations, particularly in scenarios where the volume of observations in individual classes is imbalanced. This tool offers a comprehensive insight into our methodology's effectiveness in discerning correct classifications from erroneous ones, and its proficiency in successfully obtaining correct outcomes.

It becomes manifestly clear through the confusion matrix that correct classification occurrences for classes with low extremity are fewer, which is predominantly responsible for their dismal accuracy and recall rates. This phenomenon underlines the importance of considering multiple performance metrics beyond mere accuracy, especially when dealing with data that is inherently imbalanced. It underscores the necessity to implement more nuanced approaches that can accurately reflect the capabilities of the classification model in diverse scenarios, thereby contributing to a more informed interpretation of its performance.

Accuracy is sometimes referred to as positive predictive value, while precision is the ability to remember information. This is the fraction of comparable examples that were retrieved from the total number of instances. The sensitivity is measured by the recall, which is the percentage of the total number of appropriate cases that is equal to the number of relevant examples that have been retrieved. When it comes to classification, accuracy is determined by dividing the number of true positives (TP) by the total number of labeled members (TP + FP) that belong to this class. It is important to keep in mind that the total number of true positives (TP) in classification is split into the number of instances that do in fact belong to the class (TP+FN), so, in this research we used accuracy [37], precision [38], recall, and F1-score [39].

$$accuracy = \frac{TP + TN}{TP + FN + TN + FP} \quad (3)$$

$$precision = \frac{TP}{TP + FP} \quad (4)$$

$$recall = \frac{TP}{TP + FN} \quad (5)$$

$$F1 = \frac{2 \cdot precision \cdot recall}{precision + recall} \quad (6)$$

In this part, we evaluate the outcomes of using several ML techniques for the categorization of violent extremism using a variety of distinct feature sets.

As can be seen in Table I, the general efficacy of each approach increases when more characteristics are combined

into one cohesive whole. This finding provides further evidence that the traits that were obtained are both informative and useful. However, the role of each characteristic fluctuates quite a bit, which shows that there are oscillations in the outputs of the different techniques. When using all groupings

of characteristics as input data, the SVM and LR techniques showed the highest levels of productivity compared to the other methods that were utilized. Both Random Forest and Naive Bayes have shown impressive performance in F1.

TABLE I. RESULTS OF APPLYING MACHINE LEARNING IN ONLINE EXTREMISM DETECTION

Approach	Applied Feature	Accuracy	Precision	Recall	F-measure	AUC-ROC
SVM	Statistics	78.64%	78.17%	77.29%	74.16%	74.72%
	Statistics&TF-IDF	79.35%	79.08%	79.75%	79.43%	78.17%
	Statistics&TF-IDF&POS	81.31%	81.15%	81.68%	81.37%	81.07%
	Statistics&TF-IDF&POS&LIWC	84.97%	84.28%	83.21%	83.08%	83.01%
Decision Tree	Statistics	58.64%	58.17%	57.29%	54.16%	54.72%
	Statistics&TF-IDF	61.35%	61.08%	60.75%	60.43%	60.17%
	Statistics&TF-IDF&POS	62.31%	62.15%	61.68%	61.37%	61.07%
	Statistics&TF-IDF&POS&LIWC	64.97%	64.28%	63.21%	63.08%	63.01%
RF	Statistics	60.64%	60.17%	59.29%	56.16%	56.72%
	Statistics&TF-IDF	63.35%	63.08%	62.75%	62.43%	62.17%
	Statistics&TF-IDF&POS	64.31%	64.15%	64.68%	64.37%	64.07%
	Statistics&TF-IDF&POS&LIWC	66.97%	66.28%	65.21%	65.08%	65.01%
KNN	Statistics	62.64%	62.17%	61.29%	58.16%	58.72%
	Statistics&TF-IDF	65.35%	65.08%	64.75%	64.43%	64.17%
	Statistics&TF-IDF&POS	66.31%	66.15%	65.68%	65.37%	65.07%
	Statistics&TF-IDF&POS&LIWC	68.97%	68.28%	67.21%	67.08%	67.01%
Naive Bayes	Statistics	56.64%	56.17%	55.29%	52.16%	52.72%
	Statistics&TF-IDF	59.35%	59.08%	58.75%	58.43%	58.17%
	Statistics&TF-IDF&POS	60.31%	60.15%	59.68%	59.37%	59.07%
	Statistics&TF-IDF&POS&LIWC	62.97%	61.28%	61.21%	61.08%	61.01%
LR	Statistics	79.64%	79.17%	78.29%	77.16%	77.72%
	Statistics&TF-IDF	82.35%	82.08%	81.75%	81.43%	81.17%
	Statistics&TF-IDF&POS	83.31%	83.15%	82.68%	82.37%	82.07%
	Statistics&TF-IDF&POS&LIWC	85.97%	85.28%	84.21%	84.08%	84.01%

The Area Under the Receiver Operating Characteristic Curve (AUC-ROC), encompassing all of the extracted features, is a crucial metric employed for evaluating the performance of each classification task [40]. This measure offers a comprehensive overview of the effectiveness of our classification model across different thresholds, serving as a critical instrument for performance evaluation.

Based on our empirical findings, it was observed that an incremental enhancement in the AUC-ROC performance was intimately linked with an increase in the quantity of incorporated features. This positive correlation signifies the importance of feature richness in enhancing classification performance and illuminates the consequential role these characteristics play in fine-tuning the efficacy of our model.

This discovery substantiates the concept that extending the complexity of our feature space, through the addition of more

discriminative characteristics, is likely to augment the accuracy and reliability of our classifier. Therefore, this observation can inform future developments and refinements to optimize the model's predictive capabilities.

Employing the Logistic Regression methodology yielded an Area Under the Receiver Operating Characteristic Curve (AUC-ROC) score of 0.893. This value surpasses the AUC generated by any other method, signifying its superior performance in the classification task. Remarkably, a considerable portion of the alternate strategies we explored also achieved AUC values exceeding 0.9, an indication of their substantial classification prowess.

In an attempt to critically evaluate the performance of our textual classification model and its capability to discern content affiliated with extremism from a diverse set of online communities, we embarked on a systematic enhancement of

our textual corpus. The purpose of this extensive augmentation was to ensure a broad array of data sources, providing a more diverse and encompassing data set for the model to learn from.

The expanded corpus, characterized by a heterogeneous amalgamation of data, was deployed to test the efficiency of our algorithms across a wide spectrum of contexts. These contexts comprised news articles, which offer a formal representation of language, content identified as toxic that typically involves aggressive or harmful language, spam that usually entails repetitive or irrelevant content, promotional material characterized by persuasive language, and humoristic entries, encapsulating a different style and tone of language.

Upon examination of the results, it was observed that our models exhibited a remarkable precision exceeding 90% in successfully identifying and distinguishing text related to extremism from the various other domains tested. Thus, these findings indicate that the utilization of our chosen methodology to extract distinctive features was indeed efficacious in categorizing instances of extremist rhetoric emanating from diverse sources.

This suggests a significant potential of our models to detect and isolate such extremist content from a wide array of online communities, thereby reaffirming their reliability and precision. The success of our approach opens a new path in text classification, particularly in areas related to security and online community management, demonstrating the power of advanced artificial intelligence in dealing with complex, real-world challenges.

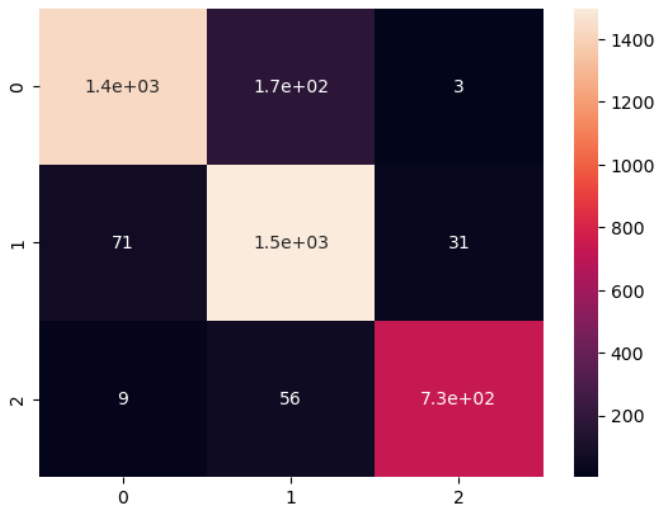


Fig. 4. Confusion matrix of three class classification.

Fig. 4 provides a visual representation of a confusion matrix, a potent tool adopted in the context of discerning violent extremism through textual analysis. This specific matrix employs a tripartite classification scheme. Class 0 constitutes texts which display no correlation with violent extremism, thereby serving as a benchmark of non-extremist discourse. Class 1 comprises neutral texts which, although not explicitly extremist, contain terminology and phrases associated with violent extremism. Consequently, these texts present a subtler form of discourse that necessitates nuanced understanding.

Finally, Class 2 envelops texts that are unequivocally linked to violent extremism, highlighting the most explicit and overt instances of such discourse.

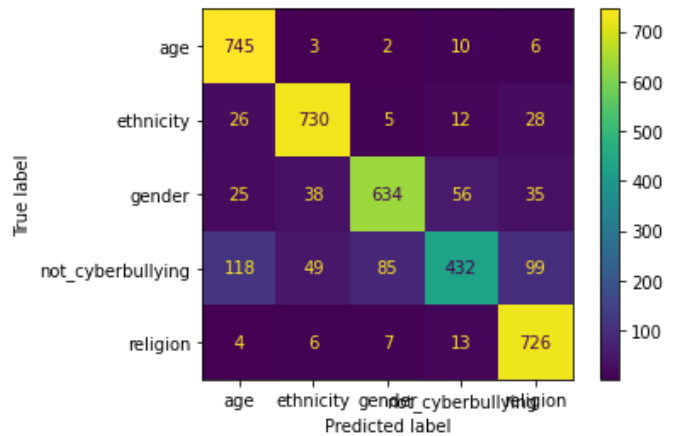


Fig. 5. Confusion matrix of five class classification.

The empirical evidence gleaned from the outcomes of this classification scheme underscores the effectiveness of the proposed framework. Not only does it showcase a capacity for binary classification - differentiating between extremist and non-extremist content - but it also adeptly navigates the intricate landscapes of multi-classification challenges. This includes distinguishing between varying degrees and types of extremist discourse. Thus, the framework's success in such a complex task accentuates its potential for broader application in the realm of text classification.

Fig. 5 provides an illustrative exposition of the application of a five-category classification scheme, implemented within the conceptual framework of the proposed model. The quintuple classification strategy organizes the data into five unique classes, namely: age, ethnicity, gender, non-cyberbullying incidents, and religious considerations. This categorization delineates a wide-ranging spectrum of potential data types, offering a comprehensive perspective on the classification abilities of the model across diverse contexts.

The findings derived from the subsequent results suggest the occurrence of a minimal number of false negatives. In classification tasks, false negatives represent instances where a particular data point has been incorrectly labeled, signifying a discrepancy between the anticipated and actual classification. The paucity of false negatives in the results implies a considerable degree of precision in the classification process undertaken by the proposed model.

This high level of accuracy not only provides testimony to the model's proficiency in accurately classifying data but also underpins its potential for trustworthy deployment in scenarios necessitating precise data categorization. Therefore, this finding bolsters the robustness and versatility of the proposed model in undertaking a variety of data classification tasks.

## V. DISCUSSION

As we navigate the complexities of detecting and mitigating online extremism, the power of Machine Learning (ML) stands out as a promising tool in this ongoing struggle. This

discussion delves into the practical applications, limitations, and future perspectives associated with the use of ML for online extremism detection.

#### A. Practical Use

The emergence of ML techniques in the realm of online extremism detection opens up myriad practical applications. As a technology that can process large volumes of data swiftly and accurately, ML algorithms provide a feasible solution for monitoring the vast and rapidly expanding universe of user-generated content on social media platforms.

In the context of public safety and national security, ML algorithms can help law enforcement agencies to proactively identify potential threats by detecting extremist narratives or recruitment attempts within the vast amount of social media content [41]. On a similar note, social media companies can leverage these technologies to maintain community standards, flagging and removing harmful content, thereby preserving the platform's integrity and ensuring the safety of their users.

Furthermore, the use of feature extraction methods like tf-idf, Bag of Words, Part of Speech, and Word2Vec facilitates the identification of underlying themes, patterns, and trends that may not be apparent to human observers [42]. This assists not only in the identification of extremist content but also in understanding its context, evolution, and influence.

#### B. Limitations

Despite its promise, employing ML in this arena is not without its challenges. First and foremost is the issue of accuracy. False positives (non-extremist content wrongly flagged as extremist) and false negatives (extremist content that goes undetected) can both have severe implications [43]. The former risks infringing upon freedom of speech, while the latter fails to stem the spread of harmful content. Balancing sensitivity and specificity in model performance is an ongoing challenge.

Secondly, the effectiveness of ML algorithms heavily depends on the quality of the training data. Gathering extensive, representative, and accurately labeled data for training purposes is a significant challenge due to the sensitive and dynamic nature of extremist content.

Thirdly, ML algorithms often suffer from a 'black box' problem, where the decision-making process is opaque and hard to interpret. This can lead to difficulties in understanding why certain content was flagged, hindering improvements and adjustments to the system.

Lastly, there are ethical considerations. While using ML to detect online extremism has clear security benefits, it may also raise concerns about user privacy and data misuse. Achieving a balance between security needs and user privacy is a delicate and complex task.

#### C. Future Perspectives

In this research we consider detection of violent extremism in online user contents. Nowadays, different methods are used to teach students in low school and high school to give children and students good knowledge ethics [44] and righteousness [45]. In our study, we used a machine learning approach that is

the one of the state-of-the-art methods in this area. Looking forward, the application of ML for online extremism detection presents a vibrant research area with numerous exciting prospects [46]. The development of more sophisticated algorithms and feature extraction methods can further improve the accuracy and efficiency of detection systems.

Further exploration into hybrid models combining multiple ML algorithms or integrating ML with traditional rule-based methods could leverage the strengths of both approaches. Moreover, the integration of ML with Natural Language Processing (NLP) and sentiment analysis techniques could offer a more nuanced understanding of extremist narratives and rhetoric [47].

Additionally, interpretability of ML algorithms is a critical area for future work. Developing techniques to enhance the transparency of these models will not only increase trust in their decisions but also provide more insight into the underlying patterns of extremist content [48].

Finally, research should also focus on ethical and privacy-preserving ML methodologies. This includes exploring how to minimize data requirements, anonymize data used, and ensure that the application of these technologies respects user rights and societal norms.

In conclusion, the adoption of Machine Learning for online extremism detection presents a potent tool with numerous practical applications. However, addressing its limitations and considering future directions is crucial for the responsible and effective use of this technology in ensuring a safer digital landscape.

## VI. CONCLUSION

Online extremism poses a significant challenge in today's digital society, with its rapid dissemination and evolving nature causing widespread concern. This research has examined the use of Machine Learning (ML) methods as a valuable solution for detecting such extremist content within the vast landscape of user-generated social media content. The use of ML techniques, particularly in conjunction with feature extraction methods such as tf-idf, Bag of Words, Part of Speech, and Word2Vec, has been demonstrated to offer a scalable, adaptable, and effective approach.

However, as we progress in the application of ML techniques for online extremism detection, it is crucial to address the inherent limitations. These include issues of accuracy, dependency on the quality of training data, the interpretability of ML models, and the ethical implications related to user privacy and data usage.

Looking forward, there is vast potential for further development and refinement of ML algorithms, particularly in enhancing interpretability, improving data collection and labeling, integrating with other computational techniques, and considering ethical and privacy-preserving strategies. We must strive to balance security needs with preserving user rights and societal norms.

Ultimately, the objective of this research and the broader field is to contribute towards a safer and more respectful online

environment. ML has demonstrated significant promise in this regard, but its application must be conscientiously guided, ethically aware, and continually adapting to the evolving challenges of online extremism. It's a powerful tool in our arsenal, but like any tool, its effectiveness will depend on how we wield it.

#### ACKNOWLEDGMENT

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# Text Mining-based Enterprise Financial Performance Evaluation in the Context of Enterprise Digital Transformation

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**Abstract**—As enterprises gradually move towards digitalization, it is increasingly difficult to accurately evaluate changes in corporate financial performance. To improve this situation, the study uses a text mining algorithm based on the web crawler principle to extract keywords from corporate annual reports, select representative financial performance indicators through IF-FDP, and construct a corporate financial performance evaluation model using the entropy weighting method. The performance comparison experiments of the text mining algorithm proposed in the study show that the accuracy-recall rate area under the line of the text mining algorithm proposed in the study is 0.83 and the average F-value is 0.34, which are both better than other algorithms. In the empirical analysis of the financial performance evaluation model, it was found that the financial performance evaluation model had the smallest absolute error of 0.3%, which was lower than the other models. The above results indicate that both the text mining algorithm and the performance evaluation model proposed in the study outperform the comparison algorithm and model. Therefore, the performance evaluation model proposed by the study can be used to effectively evaluate the financial performance of enterprises accurately and promote the development of enterprises, which has practical application value.

**Keywords**—Web crawler; text mining; IF-FDP; entropy method; financial performance; evaluation model

## I. INTRODUCTION

As the world enters the information age in the 21st century, the traditional economy is surging towards the digital economy. In the face of the impact of the digital economy, traditional enterprises are transforming and upgrading with the help of digital technology [1]. In order to explore the financial changes of traditional enterprises in the process of digital transformation and to understand the significance of digital transformation to the development of enterprises, the study will delve into the financial performance performance of transforming enterprises. Studies have mainly focused on the analysis of the financial mechanism of digital transformation and the analysis of the path of digital transformation, and there is less analysis of the financial performance changes in the process of digital transformation of enterprises [2]. However, in the face of the performance assessment of digitally transformed enterprises, the use of traditional performance assessment methods may not be comprehensive and accurate enough. Therefore, there is an urgent need to develop a performance evaluation model that is suitable for use by

transforming companies.[3] Text mining algorithms are intelligent algorithms that extract knowledge from large amounts of unstructured or semi-structured text, organise that knowledge into complete information and apply it [4]. Text mining algorithms have a wide range of applications in financial management because of their multi-scientific knowledge advantages due to their integration of multiple scientific fields[5]. In order to better evaluate the financial performance of enterprises accurately, the study applies text mining technology to the enterprise financial performance evaluation model, using its function of extracting textual information to complement the traditional evaluation model and thus improve the overall performance of the performance evaluation model. This research innovatively combines the Text mining algorithm based on the Pathon crawler principle with enterprise financial performance evaluation, and proposes a new enterprise financial performance evaluation model. This model not only makes up for the gap in the integration of enterprise finance and Text mining related fields, but also improves the accuracy of enterprise financial performance evaluation, It provides data support for the development of enterprise financial performance evaluation in the process of Digital transformation. This paper is mainly divided into the following five parts. The first section is the analysis of the research status in the field of performance evaluation and Text mining technology. The second section mainly constructs the financial performance evaluation model based on Text mining algorithm. The third section mainly analyzes the actual performance of the financial performance evaluation model constructed through research. The fourth section discusses the results of this experiment. The fifth section is the conclusion of this study.

## II. REVIEW OF THE LITERATURE

Performance evaluation is a clear indication of performance over time, so performance evaluation metrics are widely used in many fields [6]. Xu et al. apply machine learning techniques to a performance evaluation model based on a two-layer overlay framework to address the lack of accuracy in the transaction and risk assessment of second-hand property prices. The results of the empirical analysis of the model show that the performance evaluation model has higher accuracy and outperforms traditional performance evaluation methods [7]. The Fanelli team proposed a performance evaluation model based on a specific frequency of survey results to address the issue of poor performance in the public health sector. Empirical analysis of

this performance evaluation model found that its implementation can improve the performance of the public sector, which has practical significance [8]. Karimi et al. propose a performance evaluation model based on enhanced additivity ratios to address the problem of inaccurate performance evaluations of knowledge workers, and test the model to find that it outperforms traditional methods for evaluating the performance of knowledge workers, with a significant increase in accuracy over traditional models [9]. The Galagedera team addresses the question of whether mutual funds The results of an empirical analysis of a network data envelopment analysis model of mutual fund management performance, which addresses the question of whether costs and expenses can be effectively managed, show that the performance indicator model proposed in the study can effectively improve the efficiency of payment management and has practical application [10].

Text mining has applications in the fields of intelligent systems, information retrieval, information processing, etc. Akundi et al. observed a significant increase in academic and industrial research in the field of systems engineering and proposed a comprehensive and structured integration of research in the field through the use of text mining techniques in order to understand the existing research directions in the field. “system modelling language”, “physical system” and “production” are the most used terms in systems engineering research, with system modelling language being the most widely used modelling language [11]. Leem et al. propose a text mining approach to sentiment analysis of customers’ online evaluations for Kakao mobile banking service, which is ambiguous and unclear. Through regular analysis, it was found that the proposed method is of practical use to improve service quality, increase customer satisfaction and assist in maintaining and upgrading the application, thus effectively increasing the completion rate of mobile banking services [12]. Zhou’s team proposed to use text mining techniques to extract experimental data related to minimum streaming speed to address the problem that the selection of minimum streaming speed is easily influenced by subjective impressions, and to build a database was established. The method was validated and found to be 83% accurate in extracting the function

parameters and more objective and accurate in selecting the minimum fluidisation velocity, which can effectively solve the problem of high empirical correlation in data selection [13]. An empirical study found that anaesthesia, oestrogen receptors and fengi hydrogen receptor mediators were the most important event drivers in aquatic systems distributed across China, and the proposed approach can provide objective and valid information for water quality assessment in the era of big data [14].

To sum up, text mining method has strong text processing ability, which can meet the need of extracting and processing a large amount of text data in financial performance evaluation model. In addition, it can be found that the current financial evaluation model often only focuses on a single index, ignoring other important factors. This kind of single index evaluation is easy to ignore the overall risk and performance of the enterprise, and cannot fully and accurately evaluate the value of the enterprise. At present, there are few researches on the combination of text mining technology and financial performance evaluation model, so the combination of performance evaluation model built based on text mining algorithm is studied, hoping to improve the overall evaluation performance of enterprise financial performance evaluation model with the help of the comprehensive performance of text mining, so as to accurately evaluate the value of enterprises.

### III. CONSTRUCTION OF A FINANCIAL PERFORMANCE EVALUATION MODEL BASED ON TEXT MINING ALGORITHMS

#### A. Text Mining Algorithms based on Pathon Crawler Principles

A web crawler, also known as a web spider, is a web technology in which a computer automatically collects specific data through a program or script according to certain rules [15-16]. Python, one of the most widely used crawler programming, can not only automatically crawl text, images, audio and video information in large quantities, but Python also provides a large number of third-party libraries to assist in information crawling [17]. The principles of web crawling technology are shown in Fig. 1.

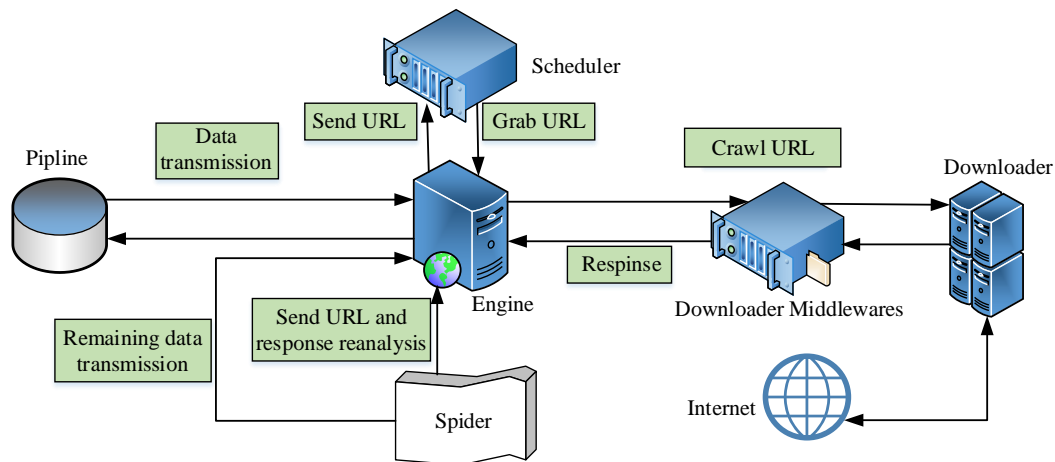


Fig. 1. Web spider principle.

As shown in Fig. 1, first the web crawler needs to send a URL to the engine, which in turn forwards the URL to the scheduler. The dispatcher then processes the URL, and the processed URL is returned to the engine. The engine takes the received URL and gets the response information through the downloader intermediate component, which is then parsed, filtered and stored by the crawler. Finally, the remaining filtered data is forwarded to the pipeline for processing. Text mining algorithms are a process of fusing word processing techniques with intelligent learning algorithms to extract

valuable textual information and knowledge from text and reorganise the extracted information. The research uses text mining algorithms as semi-structured text information processing algorithms, the process of which can be divided into three parts, i.e. text information acquisition and processing, text information parsing and thesaurus building and text information quantitative analysis. The structure of the text mining algorithm proposed in the study is shown in Fig. 2.

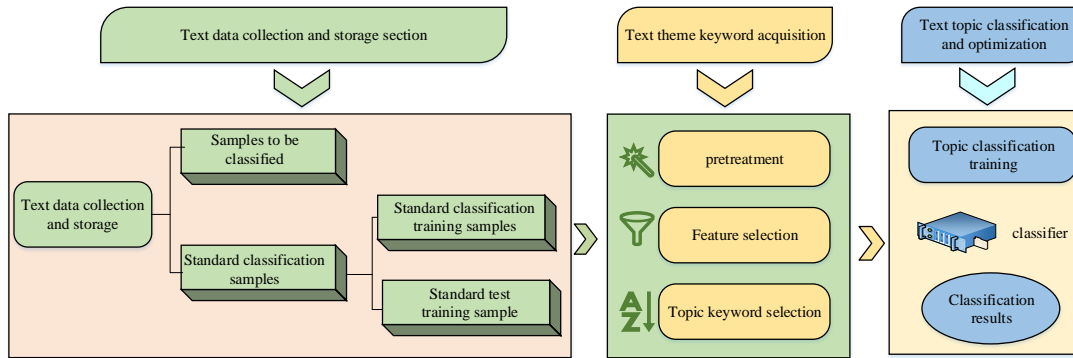


Fig. 2. Text mining algorithm structure.

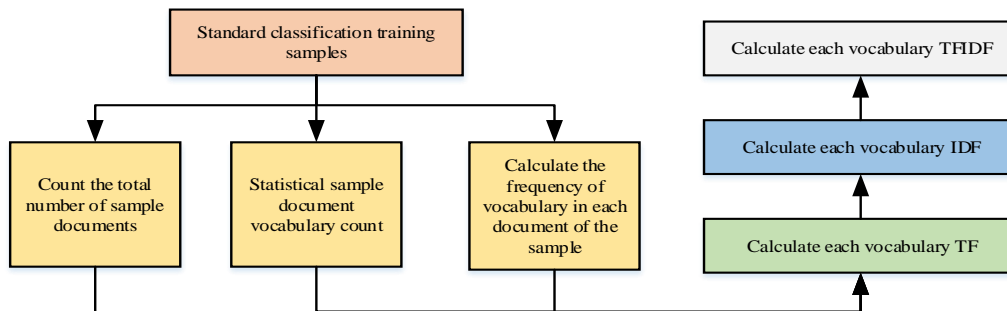


Fig. 3. Text word frequency feature weight calculation process.

As shown in Fig. 2, the proposed text mining algorithm firstly crawls the annual report text of enterprises through Python web crawler technology technique, and pre-processes, feature selection and keyword selection for the crawled text. Finally, the keywords are classified and calculated statistically through classifier and word frequency statistics techniques. In the text data acquisition and storage part of the text mining algorithm, the study collected the text of annual reports of A-share high-end manufacturing enterprises in Shanghai and Shenzhen from 2012 to 2022, converted the text to TXT format through PDFminer, and then carried out word separation processing, de-duplication operations, word extraction and information storage on the converted text. In the subject keyword acquisition part, the algorithm uses the jieba word splitter to cut words and clean the stored information, eliminating companies with abnormal financial or other conditions, as well as samples with serious data deficiencies, and completing the operation of removing obsolete words, thus obtaining the text word set. The text mining algorithm filters out the discontinued words according to the text requirements, selects the appropriate keywords and

calculates their corresponding feature weights. Finally, the selected keywords are fed into the classifier to build a subject classification keyword database. As an important technique for text mining, the word frequency statistical calculation method is an objective statistical method that can identify hot words and quantify the change trend by the frequency of occurrence of keyword words of a specific topic. The process of calculating the word frequency feature weights is shown in Fig. 3.

As can be seen from Fig. 3, after the study has counted the pre-processed text information, the feature weights will be calculated by the feature algorithm, i.e. Term Frequency-Inverse Document Frequency (TF-IDF) algorithm for the feature words.  $tP$  is the number and frequency of occurrences of the feature words in the text, and its calculation formula The formula is shown in equation (1).

$$TP_{i,j} = \frac{n_{i,j}}{\sum_k n_{k,j}} \quad (1)$$

In equation (1),  $n_{i,j}$  indicates the number of times the keyword  $t_i$  appears in the document  $d_j$ . IDF is the frequency of the subject keyword in other texts, and is a quantitative indicator of the prevalence of the keyword. If the IDF value of a keyword is smaller, it means that this keyword has a good classification function; if its IDF value is larger, it means that this keyword is common. The formula for calculating IDF is shown in equation (2).

$$IDF_i = \log \frac{|D|}{1 + |j: t_i \in d_j|} \quad (2)$$

In equation (2),  $|D|$  is the number of all documents;  $|j: t_i \in d_j|$  indicates the number of documents containing the keyword  $t_i$ . TF-IDF is a quantitative indicator of the importance of keywords in the text and is calculated as shown in equation (3).

$$TP-IDF_{i,i} = \frac{n_{i,j}}{\sum_k n_{k,j}} * \log \frac{|D|}{1 + |j: t_i \in d_j|} \quad (3)$$

In equation (3),  $n_{i,j}$  indicates the number of occurrences of the keyword  $t_i$  in the document  $d_j$ ;  $|D|$  is the number of all documents;  $|j: t_i \in d_j|$  indicates the number of documents containing the keyword  $t_i$ . After calculating the TF-IDF values of the keywords, the study used the cardinality check combined with the weights of the feature terms to evaluate and select the feature terms. The formula for calculating the keyword cardinality value is shown in equation (4).

$$x^2 = \frac{N(AD - BC)^2}{(A + C)(A + B)(B + D)(B + C)} \quad (4)$$

In equation (4), indicates the frequency of the keyword  $A$   $t_i$  in positive documents; indicates the frequency of the keyword  $B$   $t_i$  in positive documents;  $C$  indicates the frequency of the keyword  $t_i$  not in positive documents;  $D$  indicates the frequency of the keyword  $t_i$  not in negative documents. The study derived the text feature word selection score based on normalisation, which is shown in equation (5).

$$Score(t_i) = \alpha \cdot \left[ \frac{n_i}{N} * 100 \right] + \beta \left[ \frac{c_i}{N} * 100 \right] \quad (5)$$

In equation (5),  $n_i$  denotes the keyword  $t_i$  in the TF-IDF positive order number;  $c_i$  denotes the keyword  $t_i$  in the chi-square test positive order number;  $\alpha$  and  $\beta$  set the parameter value to 0.5. The feature words were sorted into sequences according to the selected scores, and the weight scores of the keyword propagation nodes were calculated as shown in equation (6).

$$S(V_i) = (1-d)W'(V_i) + d * W'(V_i) \sum_{j \in Ln(V_i)} \frac{w_{ji}}{\sum_{k=V_j} w_{ji}} S(V_j) \quad (6)$$

In equation (6), is the weight of the node  $S(V_i) V_i$ ,  $w_{ji}$  is the weight of the nodes  $V_i$  and  $V_j$ , is the set of nodes, and  $j \in Ln(V_i) V_i k = V_j$  is the set of nodes  $V_j$  refers to. After convergence of the weights of the nodes, the nodes are normalised for sorting, so that keywords can be selected. The normalisation formula is shown in equation (7).

$$Score(t_i) = \left[ \frac{n_i}{N} * 100 \right] \quad (7)$$

In equation (7),  $n_i$  denotes the positive ordinal number of the keyword  $t_i$  in the keyword weighting. After counting the frequency of the main keywords, the study selects the companies that are in digital transformation from 2012-2022 by portraying the degree of digital transformation through the weight of digital keywords. The specific calculation formula equation (8) is shown.

$$q_i = \frac{a_{it}}{\sum_i a_{it}} \quad (8)$$

In equation (8),  $a_{it}$  indicates the total number of digitised keywords for the company  $i$  in the year  $t$ .

## B. Construction of a Financial Performance Evaluation Model based on the Entropy Method

Financial performance evaluation models are models that quantify financial data through performance evaluation indicators, and then make a comprehensive evaluation of performance based on set evaluation criteria [18]. The most widely used performance evaluation models are the financial management theory performance evaluation model, and the mathematical and statistical model financial performance evaluation model [19]. The financial evaluation model proposed in the study belongs to the mathematical statistical model, which is a performance evaluation model based on the text mining algorithm and the entropy weight method.

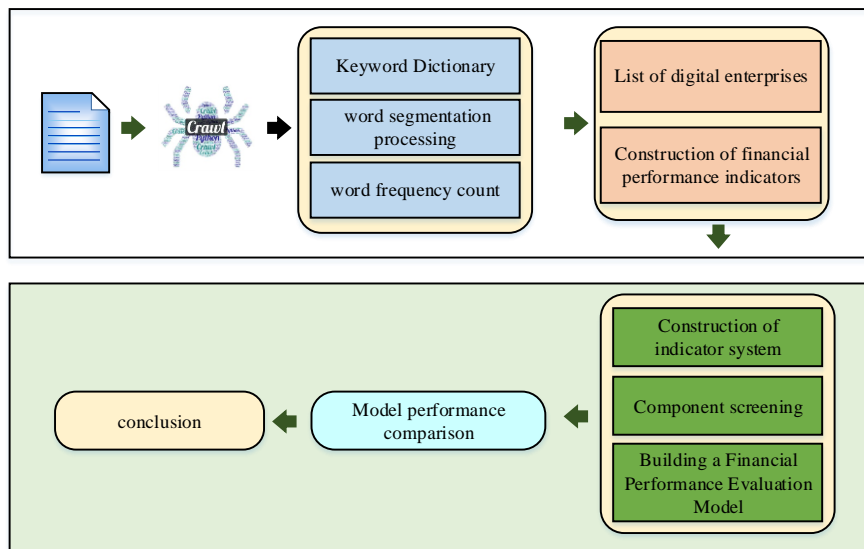


Fig. 4. Structure of performance evaluation model based on text mining.



Fig. 5. Structure of enterprise financial performance evaluation index system.

As can be seen from Fig. 4, the first step of the model is the processing of text information. The model constructs a digital keyword dictionary through a text mining algorithm based on the principle of crawlers, and carries out word separation processing to obtain the required digital keywords, and finally carries out quantitative analysis on the obtained keywords, calculates the keyword word frequency and inverse document frequency, and selects a list of enterprises for digital transformation. The second step is to build an enterprise financial performance evaluation index model. In order to comprehensively reflect the business quality and financial performance of the enterprise into the whole cycle, and to solve the problem that a single financial indicator can only evaluate the unilateral financial situation of the enterprise, the

study integrates the entropy weight method with each indicator of the financial dimension to build a more scientific and reasonable enterprise financial performance evaluation index model. An empirical analysis of the current financial situation is carried out, and statistical descriptions of the full range of financial conditions in each dimension are separately conducted to explore the changes in the financial performance of manufacturing enterprises. Finally, the entropy method financial performance evaluation model is compared with the performance of other algorithmic financial performance evaluation models to verify the reasonableness of the improved performance evaluation model proposed by the study. The structure of the enterprise financial performance evaluation index system is shown in Fig. 5.



As shown in Fig. 5, the study establishes an enterprise financial performance evaluation index system in terms of the relevance, systematicity, importance and feasibility of the enterprise's financial performance in accordance with four

dimensions: profitability, debt servicing, development and operational capability. The study constructed a total of 17 indicators for the preliminary index system of enterprise financial performance evaluation, as shown in Table I.

TABLE I. PRELIMINARY SELECTION INDEX SYSTEM FOR ENTERPRISE FINANCIAL PERFORMANCE EVALUATION

Dimension	Indicator code	Financial index	Indicator Definition
Profitability	A1	Return on assets	Pre tax profit/average total assets
	A2	Net profit margin of total assets	Net profit/average balance of total assets
	A3	Net return on assets	Net profit/average balance of shareholders' equity
	A4	Operating profit margin	Operating profit/revenue
	A5	Return on invested capital	(Net profit+financial expenses)/(Total assets -Current liabilities+Notes payable+Short term borrowings+Non current liabilities due within one year year)
	A6	Cost profit margin	Total profit/total cost expenses
	A7	Earnings per share	Current net profit attributable to ordinary shareholders/weighted average number of outstanding ordinary shares in the current period
Debt repayment ability	A8	Quick ratio	Quick assets/current liabilities
	A9	Current ratio	Current assets/current liabilities
	A10	Asset liability ratio	Total liabilities/total assets
	A11	Cash to current liability ratio	Net cash flow from operating activities/total liabilities
	A12	Total asset growth rate	Increase in total assets this year/total assets at the beginning of the year
Development capability	A13	Net asset growth rate	Increase in net assets this year/total net assets last year
	A14	Operating revenue growth rate	(Current year's operating revenue - previous year's operating revenue)/previous year's operating revenue
	A15	Current Asset turnover	Operating income/average occupancy of current assets
Operational capacity	A16	Net profit growth rate	(Current net profit - Previous net profit)/Previous net profit
	A17	Total Asset turnover	Main business income/total assets

As shown in Table I, the study divided the financial performance indicators into four dimensions, in which profitability is the ability of an enterprise to earn profits within a certain period of time; solvency is the ability of an enterprise to use its assets to repay short-term and long-term debts, and cash payments; development capacity refers to the trend of future cash flows from operating activities; and operational capacity is the ability of an enterprise to manage its operations within a certain operating period [20]. The study uses principal component analysis to screen the 17 primary indicators under these four dimensions, determines the principal components through the cumulative variance contribution rate, and selects representative indicators according to the criterion of cumulative variance contribution rate of 75%. The formula for calculating the contribution value of financial indicators' contribution ratio is shown in equation (9).

$$a_i = \frac{\lambda_i}{\sum i^m \lambda_i} \tag{9}$$

After determining the representative indicators for performance evaluation, the weighting of each financial indicator needs to be assigned, and the weighting method used in the study is the entropy method. The entropy weighting method is a method of objectively assigning weights to the indicator system using known data, which can avoid errors arising from subjective impressions and has the advantages of high calculation precision and accuracy. The higher the entropy value, the less information the indicator contains, and

the more information it contains. The entropy weighting method first requires pre-processing of the original data, including the standardisation of positive indicators, negative indicators and moderate indicators. The formula for the standardisation of positive indicators is shown in equation (10).

$$Y_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \tag{10}$$

The formula for the standardisation of negative indicators is shown in equation (11).

$$Y_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} \tag{11}$$

The formula for the standardisation of moderate indicators is shown in equation (12).

$$Y_{ij} = 1 - \frac{|X_{ij} - X_j|}{\max |X_{ij} - X_j|} \tag{12}$$

In equation (12),  $X_j$  is the fixed value of the moderate indicator. After pre-processing the indicators, the characteristic contribution of the indicators is calculated as shown in equation (13).

$$P_{ij} = \frac{Y_{ij}}{\sum_{ij}^n Y_{ij}} \quad (13)$$

In equation (13),  $P_{ij}$  is the characteristic contribution of the  $j$  indicator for the  $i$  company. The higher the value, the more information is contained in the indicator. The calculation formula is shown in equation (14).

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n P_{ij} \ln(P_{ij}), 0 \leq e_j \leq 1 \quad (14)$$

For the calculation of the degree of variation of the indicators, the formula for calculating the coefficient of variation is shown in equation (15).

$$g_j = 1 - e_j \quad (15)$$

Finally, in order to calculate the comprehensive evaluation score of the indicators and determine the weight of the

evaluation indicators, the calculation formula is shown in equation (16).

$$W_j = \frac{g_j}{\sum_{i=1}^m g_j}, j = 1, 2, \dots, m \quad (16)$$

#### IV. TEXT MINING ALGORITHM PERFORMANCE COMPARISON AND PERFORMANCE EVALUATION MODEL EMPIRICAL ANALYSIS

The study extracts keywords from corporate annual report texts by text mining algorithms and classifies the results, using the TF-IDF metric to calculate the frequency of keywords in corporate annual report texts. In order to better analyse the keywords with higher hotspots, the study results only show the top ten digitisation-related keywords that appear frequently in the text of corporate annual reports from 2012 to 2022. Also to verify the practicality of the text mining algorithm, the study verifies the accuracy of the classification results of the text mining algorithm. The keyword frequency calculation results and text mining ROC curves are shown in Fig. 6.

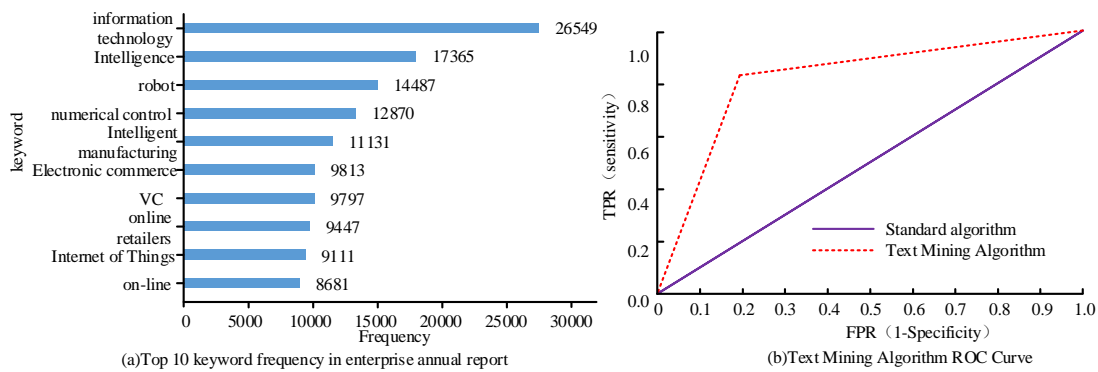


Fig. 6. Keyword frequency results and text mining algorithm ROC curve.

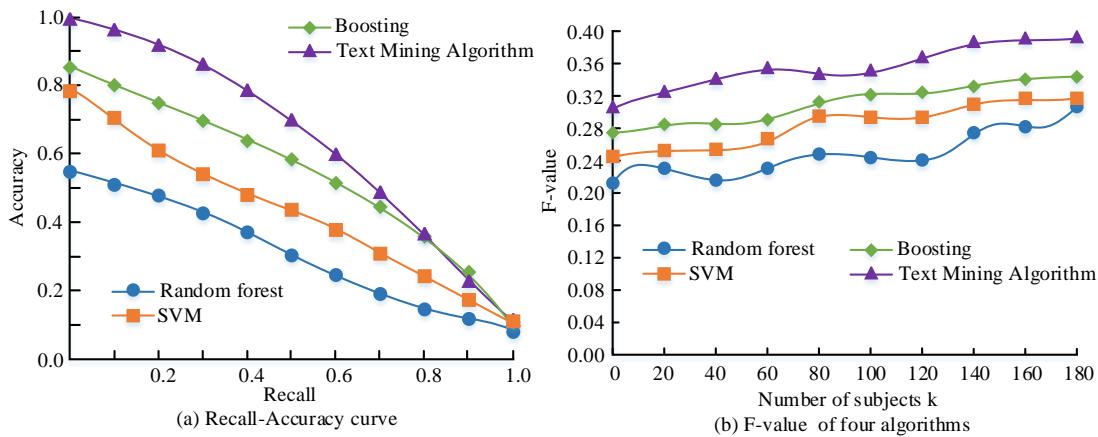


Fig. 7. Accuracy-recall rate and f-value results of four algorithms.

Fig. 6(a) shows the top ten digital keywords appearing in the text of annual reports from 2012 to 2022, of which the top three are “information technology”, “intelligence” and “robotics”. The top three keywords are “informatization”, “intelligence” and “robotics”. Fig. 6(b) shows the ROC curve of the text mining algorithm. From Fig. 6(b), it can be seen

that the area under the ROC curve of the text mining algorithm is 0.87, which is significantly higher than that of the traditional standard algorithm and has practical application value. The study compares the performance of the text mining algorithm with other algorithms. The experiment was conducted in MATLAB 2017b and simulated using Simulink.

The basic experimental environment settings are shown in Table II.

TABLE II. THE EXPERIMENTAL BASIC ENVIRONMENTAL PARAMETERS

Parameter variables	Parameter selection
Overall implementation platform	Simulink
Operating system	Windows10
Operating environment	MATLAB
PC side memory	12G
CPU main frequency	2.62Hz
Global procurement unit	RTX-2070
Central Processing Unit	i7-8700
Data storage	MySQL data bank
Data regression analysis system	SPSS26.0

The results of the accuracy-recall curve and F-value comparison of the four algorithms are shown in Fig. 7.

Fig. 7(a) shows the accuracy-recall curves of the text mining algorithm and the comparison algorithm, the comparison algorithm is the random forest algorithm, the support vector machine (SVM) algorithm, and the boosting method algorithm. From Fig. 8(a), it can be seen that the accuracy-recall curves of both the text mining algorithm and the comparison algorithm algorithms show a decreasing trend, with the area under the line of the text mining algorithm being 0.83, the area under the line of the SVM algorithm being 0.56, the area under the line of the boosting method algorithm being 0.62, and the area under the line of the random forest algorithm being 0.46. From the above results, it can be concluded that the area under the line of the accuracy-recall rate of the text mining algorithm is significantly larger than

that of the rest of the algorithms, with the best performance. Fig. 7(b) shows the F-values of the text mining algorithm and the comparison algorithm. From Fig. 7(b), it can be seen that the F-values of the four algorithms show an overall increasing trend with the increase of k. The average value of the F-value of the text mining algorithm is 0.34, the average value of the SVM algorithm is 0.31, the average value of the boosting method is 0.29, and the average value of the random forest algorithm is 0.23, and all the F-values of the text mining algorithm are higher than the F-values of the remaining algorithms values, and the keyword selection accuracy performance was significantly better than the other compared algorithms. The study conducted principal component analysis on the nine indicators under the profitability dimension in Table I, and selected representative indicators by calculating the correlation coefficient selection and score coefficients through SPSS, and the correlation coefficient matrix is shown in Fig. 8.

As shown in Fig. 8, the horizontal and vertical coordinates are the coefficients of the corresponding indicators A1-A9. From the results of Fig. 8, it can be seen that the index coefficients of five indicators, A1, A2, A3, A4 and A6, are relatively high, so these five indicators are selected as the main component representative factors. The study then evaluates the 2012-2022 annual reports of enterprises through the entropy weighting method financial performance evaluation model, and Fig. 9 shows the results of the evaluation of enterprise profitability and development capability.

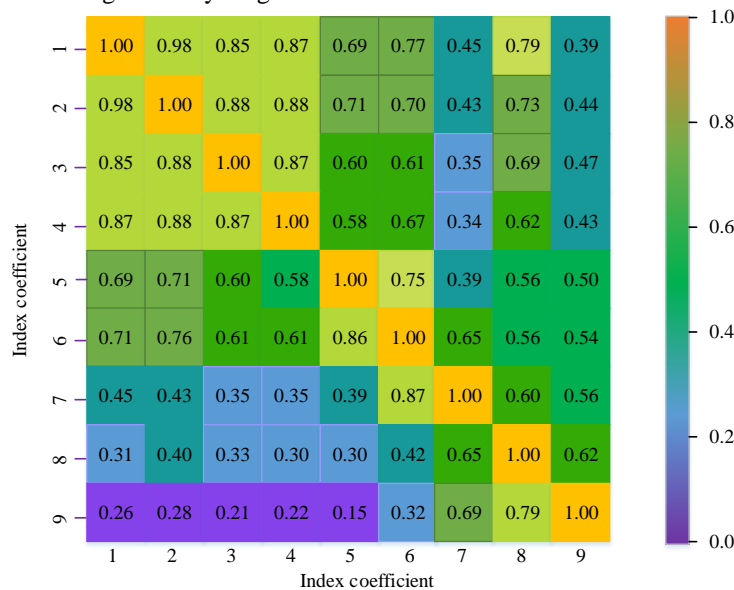


Fig. 8. Correlation matrix.

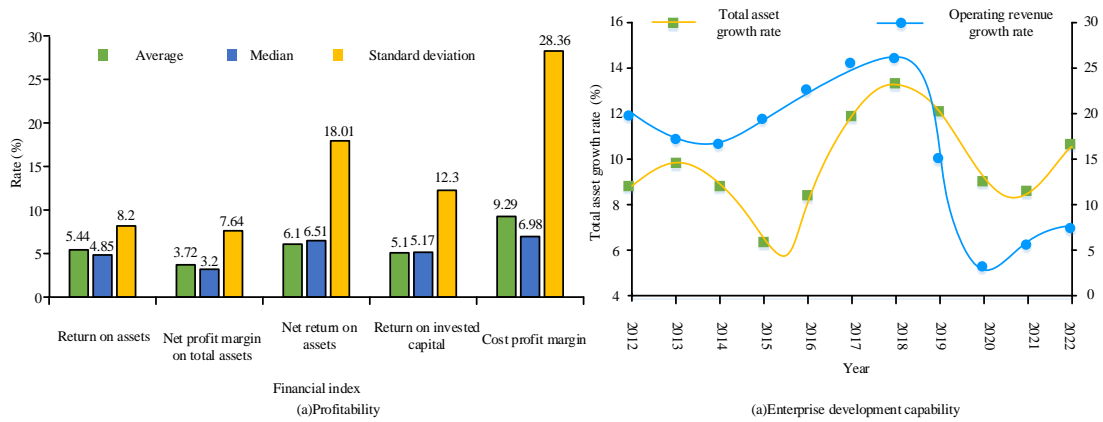


Fig. 9. Profitability and development ability of the enterprise.

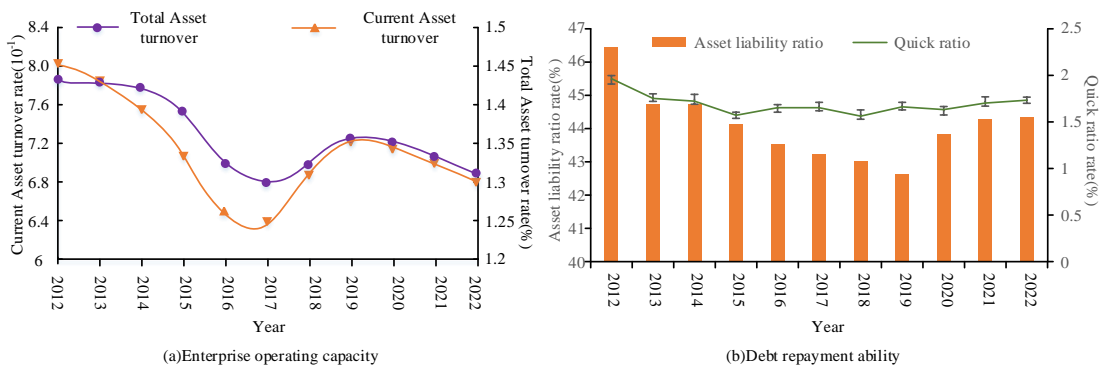


Fig. 10. Enterprise operational capability and debt repayment capability.

Fig. 9(a) shows the results of the enterprise profitability assessment. From Fig. 9(a), it can be found that the mean of return on assets, total profitability of assets, return on assets, return on assets and cost margin in enterprise finance are 5.44%, 3.70%, 6.10%, 5.15% and 9.29% respectively, and the standard deviation in enterprise profitability indicators are 8.2%, 7.64%, 18.01%, 12.3% and 28.36%, indicating a high degree of dispersion in the profitability indicators. Fig. 9(b) shows the results of the assessment of the development capability of the enterprise. The development curve of the enterprise fluctuates greatly during the period 2012-2022, with the growth rate of total assets and operating income reaching a peak of 15.4% and 23.2% respectively in 2018; the growth rate of total assets reaches a minimum of 5.3% in 2020; and the growth rate of operating income reaches a minimum of 12.4% in 2021. Fig. 10 shows the results of the evaluation of the company's operating capacity and debt servicing capacity for the period 2012-2022.

Fig. 10(a) shows the analysis of the operating capacity of the enterprise during the period 2012-2022. In 2012, the

company's operating capacity reached a maximum with a total asset turnover ratio of 1.46% and a current asset turnover ratio of 0.78%; in 2017, the company's operating capacity reached a minimum with a total asset turnover ratio of 1.29% and a current asset turnover ratio of 0.68%. Fig. 10(b) shows the analysis of corporate debt service capacity results for the period 2012-2022, with the corporate quick ratio reaching a maximum value of 1.95% in 2012 and the quick ratio reaching a minimum value of 1.52% in 2016. In 2019, it reaches a minimum value of 42.9%, with a difference of 3.5%. In order to test the performance of the entropy method performance evaluation model proposed by the study, the study compared the performance of the entropy method financial performance evaluation model with other algorithmic models for performance experiments. The study used the scores of the four dimensions of performance and the absolute difference with the actual value as the comparison index for performance analysis. Fig. 11 shows the performance comparison results between the entropy method performance evaluation model and the comparison model.

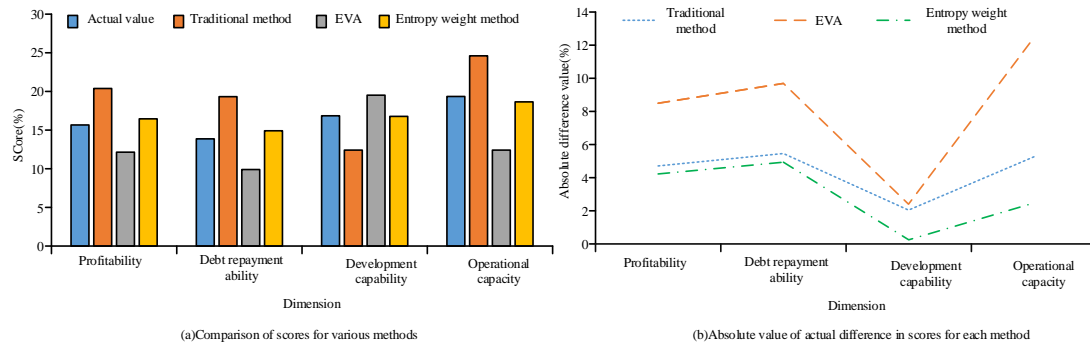


Fig. 11. Performance comparison results of performance evaluation models.

Fig. 11(a) shows the results of the entropy method of evaluating the financial performance of enterprises, which are the actual value, the traditional model and the Economic Value Added (EVA) algorithm model. As can be seen from Fig. 11(a), the actual scores for profitability, solvency, growth and operational capability are 15.7%, 14.8%, 16.2% and 19.8%. The traditional, EVA and entropy models have profitability scores of 20.5%, 12.6% and 16.4%, respectively; debt servicing scores of 18.6%, 10.6% and 15.9%, respectively; development scores of 13.3%, 18.8% and 15.9%, respectively; and operational capacity scores of 26.7%, 12.7% and 18.3%, respectively. Fig. 11(b) shows the absolute error curves of the performance evaluation models and the actual values. As can be seen from Fig. 11(b), the absolute error curve of the entropy method performance evaluation model is lower than that of the other algorithm models, and the absolute error of the three algorithm models is the lowest in the evaluation of development capability. The absolute error of the entropy method performance evaluation model is 0.3%, which is lower than that of the traditional model (2.4%) and the EVA algorithm (2.6%); the absolute error of the entropy method performance evaluation model is 1.1%, which is lower than that of the traditional model (3.8%) and EVA algorithm (4.2%). The entropy method performance evaluation model is the closest to the actual value and has the best performance.

## V. CONCLUSION

Due to the low accuracy of traditional performance evaluation models in assessing enterprise performance, in order to more comprehensively and accurately explore the changes in financial performance of digital enterprises during the period 2012-2022, the study proposes to use a text mining algorithm based on crawler technology to filter the keywords of enterprise annual reports and construct a list of digital enterprises. The financial performance data of the selected enterprises were input into the financial performance evaluation model proposed in the study, and it was found that the digital enterprises had the best growth capacity in 2018, with the annual growth rate of total assets and operating revenue reaching the peak of 15.4% and 23.2%, and the maximum operating capacity in 2012, with the total assets turnover ratio of 1.46% and current assets turnover ratio of 0.78%. A performance comparison experiment of the text mining algorithm revealed that the area under the accuracy-recall line of the algorithm was 0.83 and the mean value of F-value was 0.34, which was better than other

algorithms. The entropy method financial performance evaluation model has a minimum absolute error of 0.3% and a maximum of 1.1% from the actual value, and its absolute error is lower than the traditional model absolute error of 3.8% and the EVA algorithm absolute error of 4.2% at its maximum, and its performance is optimal. The above results indicate that the model proposed in the study has good evaluation effect and has good potential for application in enterprise performance evaluation. The shortcoming of this study is that the model proposed in this study has a narrow scope of application, which can only be applied to the period of enterprise digital transformation, and cannot accurately evaluate the financial status of enterprises before and after the transformation. The subsequent research direction is to improve the scope of application of enterprise financial evaluation model.

## VI. FINDINGS

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# Study of the Drug-related Adverse Events with the Help of Electronic Health Records and Natural Language Processing

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**Abstract**—Surveillance of pharmacovigilance, also known as drug safety surveillance, involves the monitoring and evaluation of drug-related adverse events or side effects to ensure the safe and effective use of medications. Pharmacovigilance is an essential component of healthcare systems worldwide and plays a crucial role in identifying and managing drug safety concerns. Natural language processing (NLP) can play a crucial role in surveillance activities within pharmacovigilance by analyzing and extracting information from various sources, such as clinical trial reports, electronic health records, social media, and scientific literature. It is important to note that while NLP can be a powerful tool in pharmacovigilance surveillance, it should always be used in conjunction with human expertise. NLP algorithms can assist in the identification and extraction of relevant information, but the final assessment and decision-making should involve the knowledge and judgment of trained pharmacovigilance professionals. In this paper, we intend to train and test our models using the dataset from the Medication, Indication, and Adverse Drug Events challenge. This dataset will include patient notes as well as entity categories such as Medication, Indication, and ADE, as well as various sorts of relationships between these entities. Because ADE-related information extraction is a two-stage process, the outcome of the second step (i.e., relation extraction) will be utilized to compare all models. The analysis of drug-related adverse events using electronic health records and automated approaches can considerably increase the effectiveness of ADE-related information extraction, although this depends on the methodology, data, and other aspects. Our findings can help with ADE detection and NLP research.

**Keywords**—Natural language processing; surveillance of pharmacovigilance; drug-related adverse

## I. INTRODUCTION

Adverse drug events are caused by medications, and these forms of injuries are referred to as adverse drug events (ADEs). A few years ago, data mining techniques for identifying adverse drug events (ADEs) by analyzing information were discovered. These data mining tools examine complex data extracted from huge electronic medical databases [1, 2]. The International Standard Organization (ISO) defines electronic health database (EHR) as a repository of patient-related databases in digital form, securely stored and shared, and accessible by various authorized healthcare users. Clinical information such as frequency of drug use, adverse effects, and

so on can be found in electronic databases [3]. Randomized controlled clinical trials (RCTs) are considered the gold standard for investigating the pros and cons of drugs; however, due to limitations such as shorter duration and restricted inclusion criteria, the development of data mining databases and algorithms for Pharmacovigilance tasks has resulted [4]. Since 1960, the most widely available type of medical database for adverse events has been the spontaneous reporting system (SRS) database. The notable SRS databases are the Adverse Event Reporting System (ARRS), the Medicines and Healthcare Products Agency's (MHRA) Yellow card scheme, the European Agency for the Evaluation of Medicinal Products (EMA), and the World Health Organization. The Adverse Event Reporting System (ARRS) and the General Practice Research Database (GPRD) are still operational. ARRS is a well-known adverse event database that supports the FDA's safety program for all approved pharmaceuticals, while the GPRD database (Pharmacoepidemiology database) is a significant database of medical records [5].

The significance of our work is that several phase clinical trials assess the adverse effects of each licensed drug, whereas clinical studies typically target only one drug. The specific effects of multiple-drug administration become harder to analyze. People, on the other hand, take many medications, which creates a chasm between research trials and actual drug use by patients. As a result, information about Adverse Drug Reactions (ADEs) is critical for ensuring patient safety [5]. Clinical information cannot be retrieved from biomedicine literature or narrative clinical reports; consequently, natural language processing (NLP) has been developed expressly for this purpose, which identifies, extracts, and encodes information from biomedicine literature and clinical narratives [4].

The practice of collecting useful information from vast amounts of unstructured text using computational algorithms is known as text mining [6,7]. In the context of pharmacovigilance, "meaningful information" is information that can aid in the detection and assessment of adverse drug events (ADEs). Because text mining provides a technique for converting free text into computable knowledge, it is developing as a method for exploring, analyzing, querying, and managing unused drug safety information. Pharmacovigilance is now based on the analysis of clinical trials and spontaneous reports, as well as a review of biological literature to some

extent. Domain experts often do the study on a case-by-case basis. Statistical approaches have recently been included into standard Pharmacovigilance practice, and these are applied to spontaneous reports [8, 9] and clinical trials [10] to further discover ADE signals. Nonetheless, well-known limitations [11, 12] inherent in the type and range of data sources used in routine Pharmacovigilance, as well as rising public concern about medication safety, have sparked a slew of global research and legislative initiatives [13, 14] aimed at enhancing Pharmacovigilance. It is well acknowledged that development in pharmacovigilance is dependent on a comprehensive methodology that analyses ADE-related data from a diverse range of potentially complementary data sources. With the passage of the Food and Drug Administration Amendments Act (FDAAA) of 2007 [15], Pharmacovigilance research has centered on the expanding secondary use of electronic health records (EHRs) [16]. Other sources, such as biological literature, product labels, social media content, and logs of information seeking activities on the Web, have been explored in recent years to assist holistic Pharmacovigilance. Each source offers a distinct point of view, and each has its own set of advantages and disadvantages.

EHRs contain the promise of active surveillance, the ability to quantify the incidence or risk of ADEs, the ability to identify at-risk patients, and the possibility to deliver more accurate and earlier ADE identification. Unlike the current manual approach, it is conceivable to utilise the biomedical literature computationally for a variety of Pharmacovigilance goals, including signal detection [17]. Product labels offer a wealth of information spanning from adverse medication responses to drug efficacy, risk management, contraindications, drug interactions, and many other topics. Several attempts have evolved to computationally extract information from product labels in order to build a database of known ADEs [18]. The generated knowledgebase can be utilized for additional ADE assessment, determining benchmarks for signal identification, prioritizing and filtering ADEs under research, and detecting class effects. Social media, for example, patients' experiences with pharmaceuticals that are explicitly shared through online health forums and social networks, as well as implicit health information contained in major search engine search logs, are among the potential data sources. Text mining combines a wide range of statistical, machine learning, and linguistic approaches related to natural language processing to address the issues given by unstructured text (NLP). It is helpful to think of text mining as a process that employs tools, methods, and heuristics created by those who study natural language processing. Text-mining workflows can employ varying degrees of sophistication in NLP approaches, depending on the use case. As a result, unlike traditional NLP, which employs sophisticated language models and computationally intensive syntactic and semantic analyses to extract meaning from text, text mining favors the use of simpler but less costly approaches that scale to large data sets.

Typically, a text mining process begins with multiple pipelined NLP subtasks that structure the text in preparation for the statistical analysis or pattern identification phase. A set of foundational low-level syntactic activities and a set of high-

level tasks that build on the low-level tasks and entail semantic processing are among the subtasks.

The primary goal of this study is to use natural language processing technology (NLP) to extract potential adverse events from the notes section of electronic health records, and then to use traditional bio statistical approaches to detect associations with specific medications that patients are taking.

## II. METHODS AND MATERIALS

### A. Population and Study Sample

Patient data from Columbia University Hospital, which contains over free text documents such as correspondence, discharge letters, and events, and are growing at a rate of new documents each month, will be used for research purposes. The Clinical Record Interactive Search System (CRIS) [19], a de-identified version of the EHR, will be implemented to create a research resource, and we are also planning to enhance it with language processing tools to extract information from the vast amount of free text format data stored within our database. The clinical dataset Columbia University EHR Structured and Unstructured ADE corpus, which contains information for all patients at Columbia University Hospital, will be used in this investigation. Data will be extracted from the EHR in Columbia University hospital. The data is gathered from 10th June 2019 to 16th August 2019.

### B. Study Significance

The major goal of medication safety regulators and researchers is to discover and monitor ADEs that have the potential to cause public harm [20]. Many ADEs are discovered after a medicine has been commercialized, when it is taken by a broader and more diverse population than in clinical trials [21]. Because ADEs detected after a drug has been widely used can be a significant cause of morbidity and mortality, good post-marketing drug safety surveillance is crucial for public health protection. Only after a new drug's efficacy and safety have been demonstrated in a series of clinical studies is it granted regulatory approval. Randomized, controlled, phase 3 clinical trials/studies are regarded as the most rigorous method of investigating drug efficacy and safety. However, due to their precise inclusion and exclusion criteria, these clinical studies frequently enroll a relatively small number of patients, which may not always reflect all possible consumers of the therapy. Clinical studies are also undertaken for a short period of time, making ADEs with a lengthy latency difficult to identify. Furthermore, following regulatory clearance, drug labeling and/or prescribing practices may change to incorporate new indications or patient populations, off-label usage, or concurrent use with other pharmaceuticals. Each of these new variables may lead to the development of ADEs that were not previously reported during clinical trials. Even over-the-counter pharmaceuticals, such as nonsteroidal anti-inflammatory drugs and phenylpropanolamine, have been linked to documented adverse drug reactions (ADRs) following regulatory approval, resulting in product withdrawal or labeling modifications [22, 23].

Data mining medication safety record databases, medical literature, and other digital resources could be useful in supplementing information concerning ADEs gathered during

short-term clinical studies. Data mining for Pharmacovigilance may also create an "early warning system" that can discover drug safety risks faster than existing approaches. For these reasons, the FDA, the pharmaceutical industry, and drug safety experts are all interested in data mining these sources for ADEs.

### III. RESULTS

In the first part of the data analysis, we look at six filters that cause the distribution of average age by gender to change the most. Fig. 1 above shows the patients who most affect the distribution of the patients' ages. Patients 737, 1234 and 64 are among the patients who most affect the distribution of age.

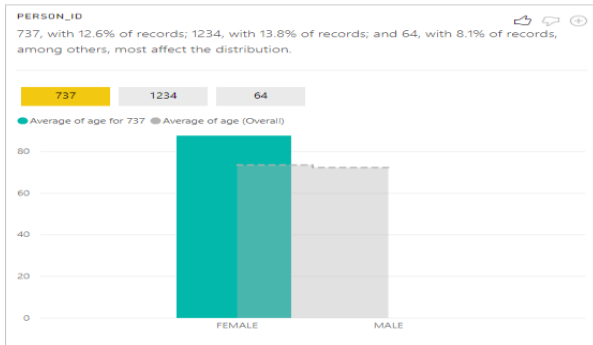


Fig. 1. Affect the distribution of the patients' ages.

The visit derived from HR record, Long Term Care visit and Outpatient visit most affect the distribution of gender versus age at 10.9%, 1.4% and 10.6% of records respectively, as shown in Fig. 2.

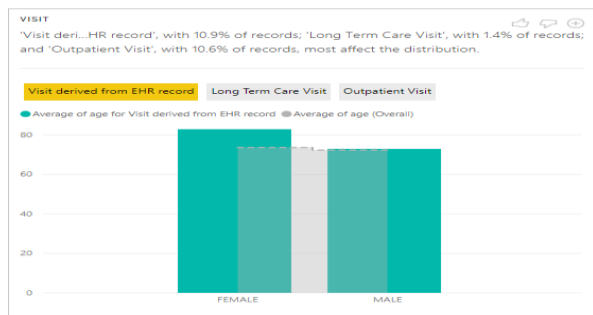


Fig. 2. The distribution of gender versus age.

Among the drug concept names, Dexpanthenol and Atorvastat are the drugs that most affect the distribution of the age and gender, as shown in Fig. 3.

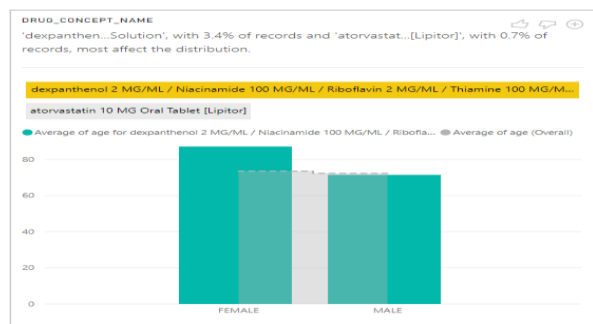


Fig. 3. The distribution of the age and gender.

Among the Cohort start dates, Monday, March 10, 2014, with 12.6% of records; Thursday, August 4, 2016 with 13.8% of records and Saturday, December 27, 2014 with 8.1% of records, among others, most affect the distribution of gender and age, as shown in Fig. 4.

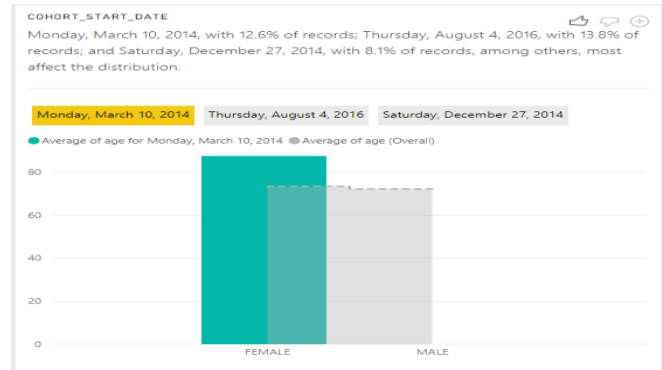


Fig. 4. The distribution of gender and age on March 10, 2014, August 4, 2016 and December 27, 2014.

Among the ingredient concepts, Carvedilol, Furosemide and Atorvastatin most affect the distribution of gender and age comparison at 1.2%, 2.6% and 1.4% respectively, as shown in Fig. 5.

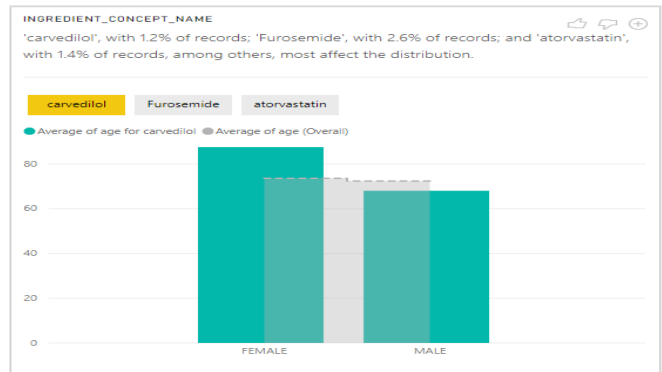


Fig. 5. Effect of the distribution of gender and age.

Among the ingredient concepts, Carvedilol, Furosemide and Atorvastatin most affect the distribution of gender and age comparison at 1.2%, 2.6% and 1.4%, respectively, as shown in Fig. 6.

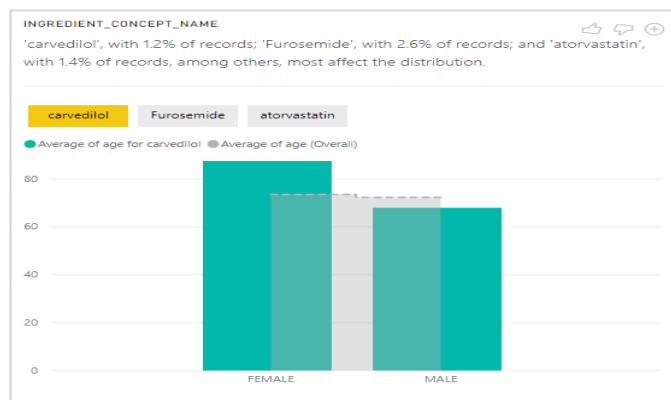


Fig. 6. Distribution of gender versus age comparison.

Among the ingredient concepts, Carvedilol, Furosemide and Atorvastatin most affect the distribution of gender and age comparison at 1.2%, 2.6% and 1.4% respectively, as shown in Fig. 7.

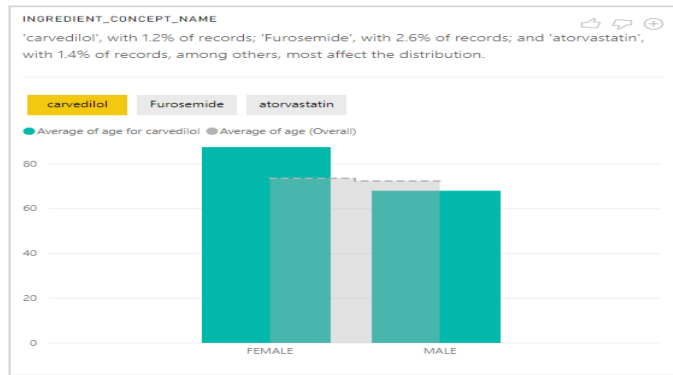


Fig. 7. Ingredient concepts Carvedilol, Furosemide and Atorvastatin.

Among the drug exposure start dates, Saturday, December 19, 2015, with 0.8% of records; Friday, March 3, 2017, with 1.3% of records and Wednesday, April 12, 2017, with 1% of records most affect the distribution, as shown in Fig. 8.

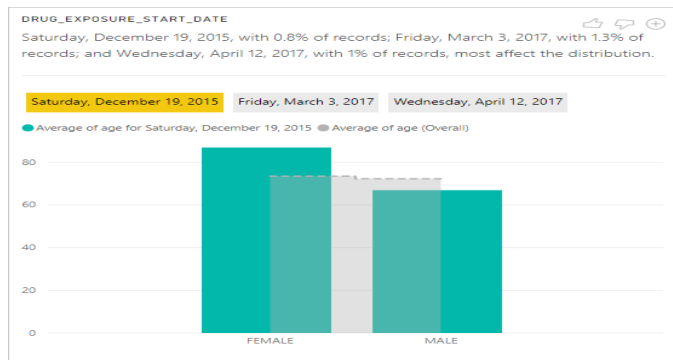


Fig. 8. The drug exposure starts dates.

A. Age of Patients Compared with Drug Exposure End Date

The year 2015 seems to have the oldest patients at the drug exposure end date at an average of 76 years old, as shown in Fig. 9.

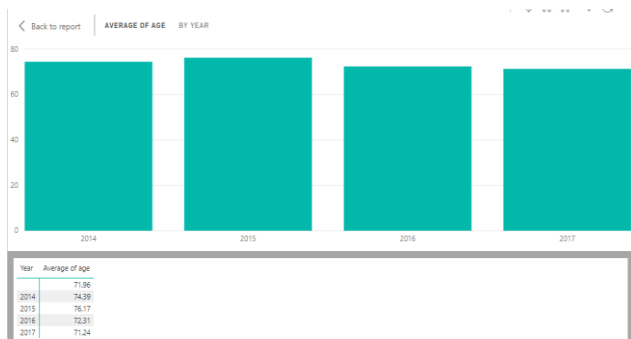


Fig. 9. Age of patients compared with drug exposure end date.

Fig. 10 shows the analysis of the 2.39% increase in average age between 2014 and 2015.

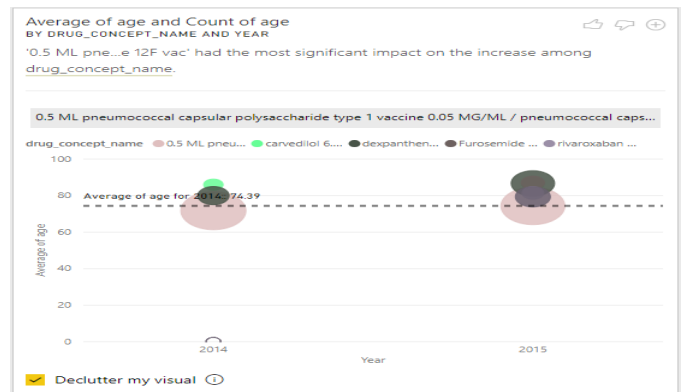


Fig. 10. Average age between 2014 and 2015.

An analysis of drug concept versus age compared by year shows that 0.5 ML pneumococcal had the most significant impact on the increase among drug concept names, as shown in Fig. 11.

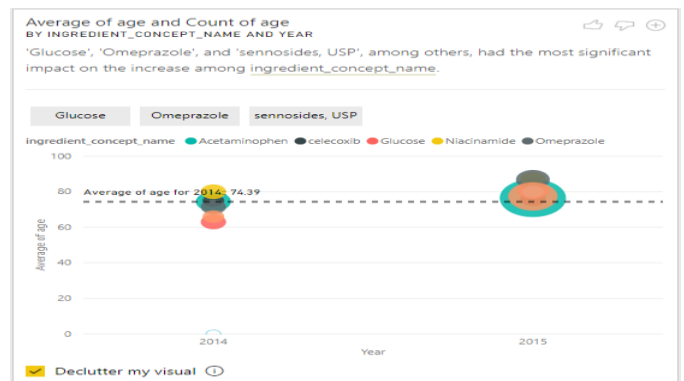


Fig. 11. Analysis of drug concept versus age.

Glucose, Omeprazole and Sennosides had the most significant impact on the increase among ingredient concept names, as shown in Fig. 12.

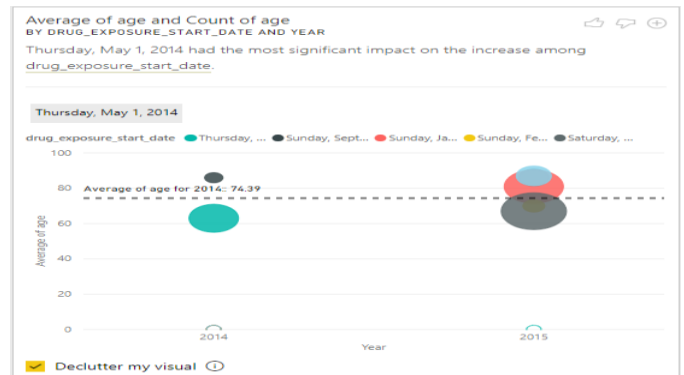


Fig. 12. Effect of the Glucose, Omeprazole and Sennosides.

Thursday, May 1, 2014, had the most significant impact on the increase among drug exposure start date. Table I above shows that visits derived from EHR record make up 10.9% of all patients followed closely by outpatient visits at 10.6%. Women are the majority at 52% of all the patients, as shown in Table II.

TABLE I. VISITS DERIVED FROM EHR RECORD

Type of visit	Frequency	Percent
Missing	1499	75.9
Emergency Room Visit	15	0.8
Inpatient visit	8	0.4
Long term care visit	27	1.4
Outpatient visit	209	10.6
Visit derived from HER record	216	10.9
Total	1974	100

TABLE II. FREQUENCY OF GENDER

Gender	Frequency	Percent
Female	1017	51.5
Male	957	48.5
Total	1974	100

The Cramer's V value measures the strength of the association between two categorical variables. The value of Cramer's V in this test is 0.97 which implies that there is a strong association between the cohort start date and the drug exposure start date, as shown in Table III.

TABLE III. ASSOCIATION BETWEEN THE COHORT START DATE AND THE DRUG EXPOSURE START DATE

Symmetric Measures			
		Value	Approximate Significance
Nominal by Nominal	Phi	6.0627918	0
	Cramer's V	0.9708237	0
N of valid cases		1974	

The Cramer's V value measures the strength of the association between two categorical variables. The value of Cramer's V in this test is 0.74 which implies that there is a strong association between the type of hospital visit and the type of drug administered, as shown in Table IV.

TABLE IV. ASSOCIATION BETWEEN THE TYPE OF HOSPITAL VISIT AND THE TYPE OF DRUG ADMINISTERED

Symmetric Measures			
		Value	Approximate Significance
Nominal by Nominal	Phi	1.6622077	0
	Cramer's V	0.7433619	0
N of valid cases		1974	

The Cramer's V value measures the strength of the association between two categorical variables. The value of Cramer's V in this test is 0.18 which implies that there is a weak association between the gender of a patient and the type of hospital visit, as shown in Table V.

TABLE V. ASSOCIATION BETWEEN THE GENDER OF A PATIENT AND THE TYPE OF HOSPITAL VISIT

Symmetric Measures			
		Value	Approximate Significance
Nominal by Nominal	Phi	0.1789966	0
	Cramer's V	0.1789966	0
N of valid cases		1974	

### B. Discussion

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

Results from the data analysis show that patients 737, 1234 and 64 are among the patients who most affect the distribution of age. When we look at the purpose of the hospital visit, the visits derived from HR record, long term care visit and outpatient visits most affect the distribution of gender versus age at 10.9%, 1.4% and 10.6% of records respectively. Among the drug concept names, Dexpanthenol and Atorvastat are the drugs that most affect the distribution of the age and gender.

As for the Cohort start dates, Monday, March 10, 2014, with 12.6% of records; Thursday, August 4, 2016, with 13.8% of records and Saturday, December 27, 2014, with 8.1% of records, among others, most affect the distribution of gender and age. Among the ingredient concepts, Carvedilol, Furosemide and Atorvastatin most affect the distribution of gender and age comparison at 1.2%, 2.6% and 1.4%, respectively.

The year 2015 seems to have the oldest patients at the drug exposure end date at an average of 76 years old. There was a 2.39% increase in the average age of all patients between 2014 and 2015. An analysis of drug concept versus age compared by year shows that 0.5 ML pneumococcal had the most significant impact on the increase among drug concept names. Glucose, Omeprazole and Sennosides had the most significant impact on the increase among ingredient concept names.

Thursday, May 1, 2014, had the most significant impact on the increase among drug exposure start date. The visits derived from EHR record make up 10.9% of all patients followed closely by outpatient visits at 10.6%. Women are the majority at 52% of all the patients. Most females' visit was derived from EHR record while majority of the males visited the hospital for outpatient services.

There is a statistically significant relationship between the cohort start date and the drug exposure start date. The p-value is less than 0.05 and we therefore reject the null hypothesis and conclude that there is an association between the cohort start date and the drug exposure start date. The Cramer's V value measures the strength of the association between two categorical variables. The value of Cramer's V in this test is 0.97 which implies that there is a strong association between the cohort start date and the drug exposure start date.

There is a statistically significant relationship between the type of hospital visit and the type of drug administered. The p-value is less than 0.05 and we therefore reject the null hypothesis and conclude that there is an association between the type of hospital visit and the type of drug administered. The value of Cramer's V in this test is 0.74 which implies that there is a strong association between the type of hospital visit and the type of drug administered.

There is a statistically significant relationship between the gender of a patient and the type of hospital visit. The p-value is less than 0.05 and we therefore reject the null hypothesis and conclude that there is an association between the gender of a patient and the type of hospital visit. The value of Cramer's V in this test is 0.18 which implies that there is a weak association between the gender of a patient and the type of hospital visit.

#### IV. CONCLUSION

In conclusion, it is clear that there is a statistically significant association between several variables in our sample data. For instance, there is a fairly strong association between the type of hospital visit and the type of drug administered, which could imply that doctors prescribe medicine based on the type of visit to the hospital by the patient. However, it is worth noting that correlation or association between two variables does not imply causality and we recommend further research to delve deeper into the insights garnered by this study.

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