A Systematic Literature Review of Computational Studies in Aquaponic System

Literature Review of Computational Studies in Aquaponic System

Khaoula Taji[1], Ali Sohail[2], Yassine Taleb Ahmad[3], Ilyas Ghanimi[4], Sheeba Ilyas[5], Fadoua Ghanimi[6]
Electronic Systems-Information Processing-Mechanics and Energy laboratory-IBN Tofail University Kenitra Faculty of Sciences, Kenitra, Morocco[1, 4, 6]
Department of Computer Science, Minhaj University Lahore, Lahore, Pakistan[2, 5]
Engineering Science Laboratory, Ibn Tofail University, ENSA, Kenitra, Morocco[3]

Abstract*—The word aquaponics means the growth of aquatic organisms as well as plants in the controlled environment. As the nutrients used for sustainable plant growth is obtained from aquatic organisms and the nutrients that are absorbed by the plants remediate the water for the aquatic life. The advancement in the computational studies plays a vital role in every field of life. The aim of the proposed study is to deeply analyze the computational studies that used IoT, AI, Machine learning and deep learning for aquaponic systems between the years 2019 to 2022. The literature survey deeply discuss the proposed methodology, comprehends the fundamental researches, tool, advantages, limitations, concepts, and results of the recent studies proposed by the researchers in context of aquaponic system. The proposed study extract 41 research articles from these libraries based on year of publication, title, methodology, citation, paper quality and abstract. These articles are collected from seven different research article libraries including Google Scholar, Worldwide Science, IEEE Xplore, Google Books, Refseek, ACM digital Library and Science Direct. This study develops a state of the art research for the next researchers to work on the loopholes of the previous researches in an efficient manner. The results of the proposed study shows that the implementation of IoT based machine learning and deep learning framework shows state of the art results for the nutrients regulation, sensing, monitoring and controlling of the aquaponic environment. It is concluded from the proposed study that there need to be develop ensemble learning model with an efficient dataset in context of aquaponic environment.

Keywords—Aquaponics; machine learning; internet of thing (IoT); message queue telemetry transport; sensors; SMART aquaculture

I. Introduction

The growth of the human population is expected to cross 10 billion till 2062. This increase in the population will create the challenge of energy, food and water for human. Computational field has a huge impact in every field of life [1] [2]. Agriculture is suffering from many problems including consumption of water, lack of land, lack of workforce etc. It is the most water consuming field that uses about 70% of water in different contexts. The word aquaponic refers to two words "Aquaculture" means to grow the water culture organisms in controlled environment and "Ponics" means growth of soil less media. The word aquaponics means the growth of aquatic organisms as well as plants in the controlled environment [3]. It is a combined production system of plant and aquatic animals in which most of the nutrient used for the development are obtained from each other. As the nutrients used for sustainable plant growth is obtained from aquatic organisms and the nutrients that are absorbed by the plants remediate the water for the aquatic life. This technology was firstly developed by the scientist in United States of America in early 1970's. The aim of this process is to create a sustainable and economic environment by efficient usage of water and nutrients, increase the profitability, Farm diversification, use of wastage, lowered the environmental impact and increasing the production to agricultural fish and plant production [4] [5] [6]. This is one of the main methods to solve the food and environmental crisis of the nature adopted by many countries worldwide. The Nutrient flow in the aquaponic system is measured constantly for the regulating the growth of the plants as the nutrients generated by the fishes is not sufficient for the growth of the plants. There are hundreds of studies proposed by the researchers for the identification and regulation of the flow of the nutrients in the aquaponic system. Fig. 1 describes the all-time interaction of the aquaponic system with computational industry [7].

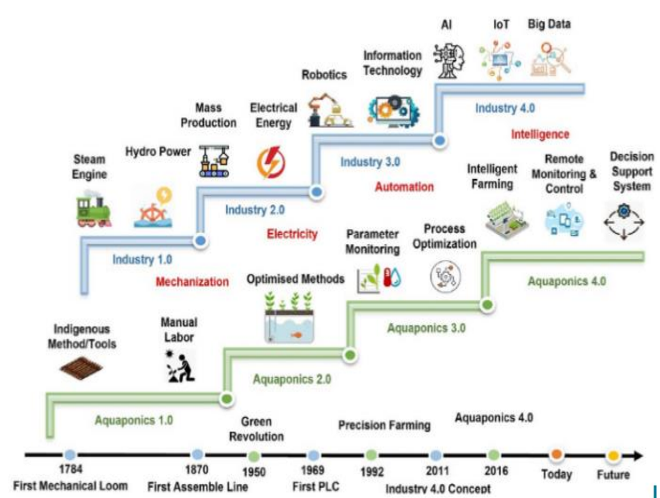

Fig. 1. Industrial revolution in the aquaponic system.

To find the best design, implementation of that design with management and maintenance is the key factor for the success of an aquaponic environment [8]. Many researcher in past focus on different computational, statistical and mathematical tools and techniques to ensure the efficient working of an aquaponic system. The smart working of an aquaponic system based on different factors including the water quality, temperature, pH level, air flow, predictors, light intensity, humidity, Air quality, IoT sensors etc. The aim of the study is to develop a systematic survey on the latest researches proposed by different researchers for aquaponic environment. This study provides the deep analysis of the methodology, advantages and limits of the study that will create a benchmark for the new researchers in this field. A total of 41 quality research articles are deeply reviewed in this research.

The list of abbreviations used in the proposed study is illustrated in Table I

TABLE I. LIST OF ABBREVIATIONS

Word	Abbreviation
RFE	Recursive Feature Elimination
IoT	Internet of things
XGBoost	Extreme Gradient Boosting
PA	Precision Agriculture
SAR	Sodium Absorption Ratio
LDA	Linear Discrimination Analysis
BLOO	Bolstered leave one out
DTC	Decision Tree Classifier
WSN	Wireless Sensor Network
DCNNs	Deep convolutional neural networks
DB-SMOTE	Density Based Synthetic monitoring over sampling technique
SDC	Stochastic Gradient Descent
R-CNN	Regional Convolutional Neural Network
LR	Logistic Regression
SMR	Standard Metabolic
ADC	Analogue to digital convertor
US	Univariate Selection
FI	Feature importance
GNB	Gaussian Naïve Bayes
CPS	Cyber-Physical Systems
MQTT	Message Queue Telemetry Transport
NGSI	Next Generation Service Interface
ANFIS	Adaptive Neuro Fuzzy Inference System

II. RESEARCH PLANNING

The aim of this study is to presents the latest IoT based machine learning and deep learning presented by different researcher in advancement of aquaponic system. The review method developed by Brereton et al. [9] is used in this research for reviewing the articles. This is one of the most widely used approaches for systematic literature review. This process includes five steps which are [10] discussed here in the below section.

The first phase of the research survey is planning a systematic model for work. The process of research planning include identification of the research questions, the include exclude criteria of selection, quality measurements, identification of relevant studies and analysis of these studies. Fig. 2 explain the selection criteria of research for the proposed study [11].

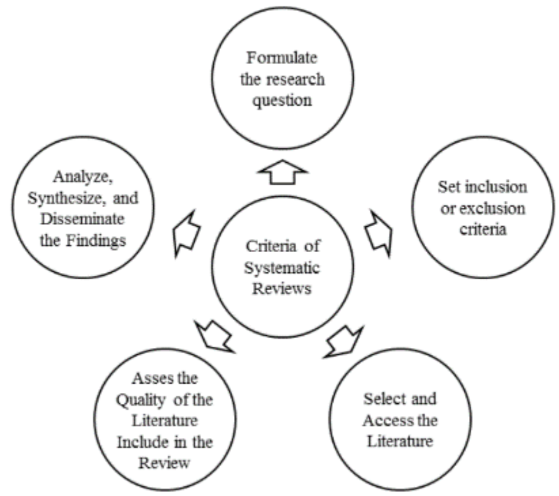

Fig. 2. Selected criteria for systematic literature review.

The first thing is to generate the research questions. The research questions for the proposed study are

RQ1: What is an Aquaponic culture?

RQ2: How the aquaponic environment works?

RQ3: What is the purpose of the proposed study?

RQ4: What are the advantages of aquaponic system?

RQ5: What are the computational studies proposed for the aquaponic system?

RQ6: What are different IoT based studies using machine learning and deep learning for aquaponics?

RQ7: What are the methodologies, advantages and loopholes of those studies?

RQ8: Comparison of the results of the previous studies?

RQ9: What are the research possibilities?

RQ10: What is the conclusion of this study?

RQ11: What are the research questions raised for the new researchers regarding aquaponic system?

The quality of the systematic literature reviews completely depend upon the selection of the related articles. In context of this, the proposed study extracts the research articles from most of the authentic and widely used article database sources. The articles are selected from seven different articles websites including Google Scholar, Worldwide Science, IEEE Xplore, Google Books, Refseek, ACM digital Library and Science Direct.

The selection is based on the quality of the research article. For searching articles from these sites different combination of words used including "Aquaculture, Aquaponics, SMART Aquaponics, IoT Based Aquaponic, Machine learning for aquaponic system, Deep learning for aquaponic system, Nutrients regulation in Aquaponic system, Monitoring and sensing in aquaponic system, Accurate segmentation, Real time semantic, Neural network for aquaponic systems". After applying these keywords on database libraries hundreds of articles appear. The articles are included on the basis of the relevant studies that are proposed for systematic review. This includes, excluded criteria of these articles as given below:

- Language must be English.
- Authentic Journal papers, Conference papers, Books etc.
- Papers using IoT based SMART technology
- The paper with ML and DL methods of aquaponic culture
- Papers after year 2019

The papers chosen for the proposed study are between the years 2019 and 2022. The paper published in English language and use IoT, ML, AI and DL methods are accepted for processing.

Exclude:

- Paper in language other than English
- Papers published before 2019
- Paper with method other than AI, IoT, ML and DL.

In the proposed study a total of 2,002 articles are screened from the article databases. From the selected papers 1,106 are rejected due to the publication year was before 2019. Rest of 896 articles is processed and 602 articles are rejected because of their irrelevancy of the subject. 294 selected articles are further processed and 79 out of them are selected based on IoT, ML, AI and DL methods used by the studies. 38 papers are rejected due to the low quality of paper. After the overall selection process overall 41 articles are processed for systematic literature review.

Fig. 3 explains the study flow of different phases using PRISMA [12] diagram for the article selection.

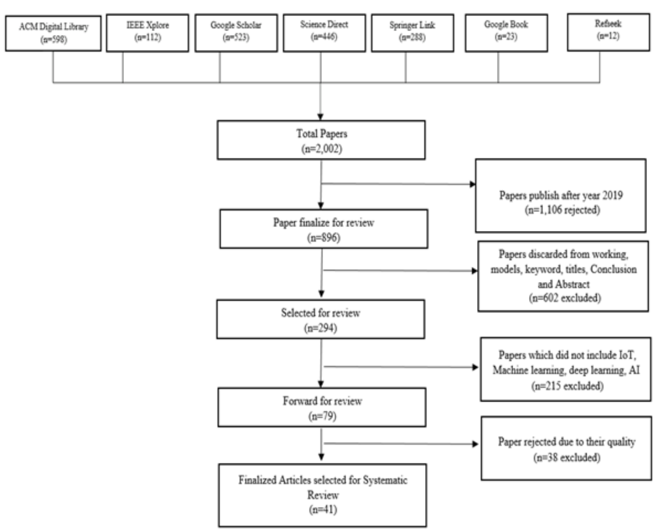

Fig. 3. Article selection criteria for systematic literature review.

III. Literature Review

There are a number of computational studies developed by different researchers for the development of smart aquaponic system. In this section of the research the latest studies developed by the researchers based on IoT, Machine learning, deep learning and AI based methods between the years 2019 and 2023 are discussed. This paper deeply analyzes the advantages and disadvantages of the proposed models developed by the recent researchers.

Commercial aquaponic system helps to increase the profitability and sales revenue of aquaponic system by increasing the production. The most revenue is generated by the aquatic animals including tilapia, catfish, ornamental fish, perch, bass, trout, and bluegill [13]. The regulation of the nutrients in the aquaponic environment is one of the most discussed topic in recent years. S. B. Dhal *et al* [14] presents an IoT based system used for nutrient supply in the commercial aquaponic environment. The dataset for the study is taken from three different farms at Southeast Texas (Aquatic Greens Farm, Wolff Family Farms and Texas US Farms). This data was generated from the farms weekly over a year. From the dataset 12 predictors (Ca, Mg, Na, K, B, $NaHCO_3$, HCO_3 , SO_4 , Cl, NO_3, NH_4, PO_4) and 211 observations are generated. On this dataset the features are extracting using pairwise correlation matrix and Recursive Feature Elimination (RFE). Machine learning algorithm XGBoost is used for generating F-score of the features and ExtraTreesClassifier is used for RFE [15]. The experiment was carried out in the cycle of 21 days. Two predictor calcium and ammonium is identified and regulate by using this system. The cost of the proposed model is decreased by 75% as compared to the existing models that are used for nutrient regulation [14].

M. A. Zamora-Izquierdo, J. Santa, J. A. Martínez, V. Martínez, and A. F. Skarmeta presents [16] IoT based on edge computing system to enhance PA. The model works on three tiers. The local plans the CPS system connects with the aquaponic crops to collect the data and perform atomic control actions. The Edge plane used for monitoring and managing the PA task and cloud plane host and record the data in FIWARE deployment. MQTT and NSGI protocols are used communicating and accessing with the cloud. The working of this system is shown in Fig. 4 [16].

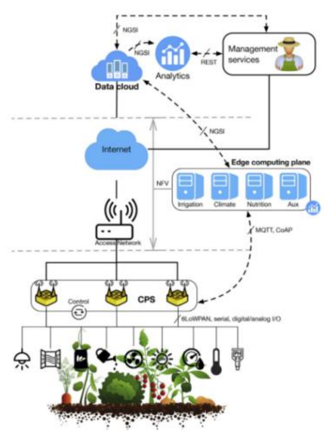

Fig. 4. Precision Agriculture based on IoT and edge computing.

The experiment is carried in Greenhouse of CEBAS-CSIC, Spain. Nutrient solution unit, irrigation unit, disinfection unit, purification unit and climate unit is used to facilitate the greenhouse environment. This research provides the water saving of more than 30% with upto 80% nutrients. This study provides the new path for the researcher to implement the PA platform in future crops. R. Barosa, S. I. S. Hassen, and L. Nagowah [17] combine hydroponic with conventional agriculture system to develop Plantabo Aevum system. The IoT devices are used for continue monitoring the environmental factor and providing the real time feedback. Live cameras are used for continue image capturing that is used for image processing. With the detection of the main features of the plant leaf the system detect the disease in it and generated the report on mobile application. The dataset is taken from the 50 leafs of four different type of plants including chilli, eggplant, mandarin and citrus. Machine learning algorithm decision tree is used for the classification. The working is implemented on OpenCV toolbox. This study detect the leafs of different species of plants accurately using machine learning system. The implementation of deep learning on the method was the loophole of that study. A researcher developed a web based monitoring system of pH, temperature and dissolved oxygen in aquaponic system [18]. Arduino microprocessor is used for measuring the environmental factors that send the measurements to local host server. Raspberry Pi is use as a network backbone of this process that transmit the information and display the live sensor data to the website on every half second [19]. In another research [20] statistical tools with machine learning algorithms are used for the nutrient regulation for the optimal growth of plants. The dataset for that study is taken from aquaponic farms of Bryan, Caldwell, and Grimes counties in Texas. The data is collected from the plant bed and fish tanks of the farms. From the collected dataset 143 observations are collected for 24 predictors out of which 11 are chemical predictors, eight are solutions, two of them measure the hardness, and other are SAR, Alkalinity and total dissolved salt. Different dimension reduction techniques [21] i.e. XGBoost and pairwise correlation matrix applied on the dataset for defining the nutrient concentration of the solution. The working of the model is explained in the Fig. 5 [20].

The predicators with less importance in the dataset are removed. Error calculation techniques including Bolstered resubstituting error estimation, BLOO error estimation and Semi-bolstered Resubstitution error estimation [22] are applied on the dataset for selecting the best methods. The results show that Semi-Bolstered Resubstitution Error estimation technique gives best result for Linear Support Vector Machine. A CNN based model using machine vision is also proposed to measure the fish length [23]. This study uses the dataset of European sea buss using camera. R-CNN gives the mIoU value of 93% for fish detection. Reduction of precision bias and increasing the precision using machine vision was the loophole of that study.

A. Taufiqurrahman, A. G. Putrada, and F. Dawani [24] proposed DT regression based model for stabilizing the water temperature for trees and fishes in an aquaponic environment. Adaptive Boosting [25] algorithm is applied with DT to avoid the model over fitting. Swirl filter and bioball filter is installed in the fish tank for extracting the waste and nitrification of bacteria from the water. Temperature sensor is installed to detect the water temperature, water heater use to heat the water when the temperature get down, fans are used to lower the water temperature if the temperature goes high. The results of the model show that the DTR model with AdaBoost shows MSE value of 0.0045 and R-square value of 0.92.

Researcher [26] proposed a deep learning model with ResNet, SegNet18 and Inceptionv3 [27][28] for monitoring and diagnosis of the nutrient deficiency in lettuce plant of aquaponic system. The dataset used by the study consists of 3000 images that are classified into four groups. These groups are based on the images with full nutrients, Phosphate deficiency, nitrogen deficiency and potassium deficiency group. The images of the dataset are divided into training, testing and validation dataset and passed through image segmentation method for labeling the images [29]. Different features are extracted from the segmented images. These features include texture features (entropy, contrast, correlation, energy), morphological features (area, parameter) and color features are extracted. The results shows the accuracies of 98.30%, 98.90%, and 97.70% of SegNet, Inceptionv3, and ResNet18 for training set and 99.29%, 98.00% and 92.5% for validation set respectively.

S. B. Dhal, M. Bagavathiannan, U. Braga-Neto, and S. Kalafatis [30] present a comparitive analysis of nutrient control in aquaponic system. The dataset of this study consists of 32 predictors taken from 201 observations. DB-SMOTE algorithm applied on the dataset for balancing the dataset values [31]. RFE with ExtraTreeClassifier shows more than 90% correlation between the predictors. M. F. Taha *et al.* [32] present machine learning model for the content detection of based on spectral data. The experiment for the study was proposed at Zhejiang University china. The working of this model is completely explained in Fig. 6.

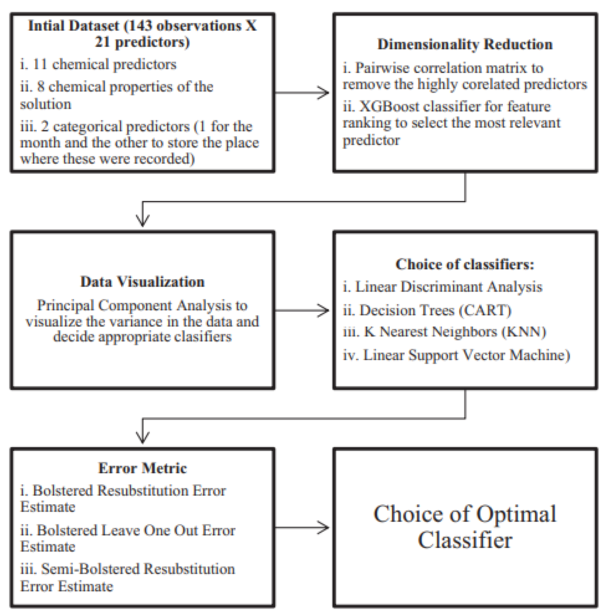

Fig. 5. The process of decision support system for nutrients regulation in aquaponic system.

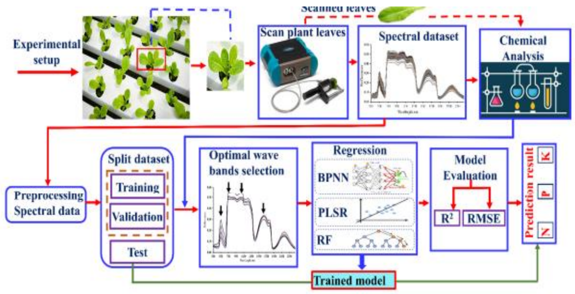

Fig. 6. The working of machine learning based Nutrient content detection model.

The spectral reflectance of the leaf [33] is measure by FieldSpec4, Pro FR portable spectroradiometer. Three machine learning models including Random Forest (RF), partial least square regression (PLSR) and backpropagation neural network (BNN) is used to classify the nutrients. The BNN algorithm shows the highest predictive accuracy of 97.2 for nitrogen content. While the highest predictive value of 0.94 and 0.96 for phosphate and potassium is obtained by RF algorithm.

In aonther research machine learning vision based system is employed for the lettuce growth classification. The process of lettuce development took around 45-55 days for the growth in vegetative, development and hardvest cycle. The dataset of lettuce images for the study contains 300 images taken from the aquaponic system developed by Rizal, Philippines. The data extractions from these images are done by using different machine learning based feature extraction techniques in MATLAB. This classification is perfomed by three machine learning algorithms KNN, L-SVM and LR. The model gives the classification accuracy of 91.67% by KNN algorithm, 80% with L-SVM and 66.7% with LR algorithm [34].

Wireless technology also have a vital role in the aquaponic farming. In the latest researches the researchers presented an IoT Based system for the monitoring, regulating and controllingof the aquaponic systems [35]. T. Khaoula, R. A. Abdelouahid, I. Ezzahoui, and A. Marzak [36] presents AI and IoT based system for controling the water quality of aquaponic system using different sensors and actuators. The system consists physical layer that consists of sensors, gateway layer that includes NodeMCU for data collection, the middleware layer that is responsible for publishing the semantics done by MQTT and the application layer use for providing the interface. There are different types of sensors including pH sensor, water level sensor, humidity sensor, temperature sensor, EC sensor, soil measure etc. used in the study for collecting the data. Haryanto, M. Ulum, A. F. Ibadillah, R. Alfita, K. Aji, and R. Rizkyandi, presents smart IoT-based system for controlling the nutrients in aquaponic system. The working of this model is explained in Fig. 7 [25].

The results of this model shows the accuracy value of 99.94% for ultrasonic sensor and 92.53% for pH sensor. In IoT based deep learning approach use edge computing for aquaponic monitoring system. The system contain four subsystems for greenhouse sensors form plant growth, aquaponic control, growth monitoring and data uploading. DHT11 sensor is used for temperature sensing, BH1750 is used for light sensing, HC-SR04 is used for ultrasonic sensing, and SEN0161 is used for sensing pH in the current scenario. Mask-RCNN architecture is used for instance segmentation from the 250 images of fish dataset. The model shows the precision, recall and F1 score of 0.94, 0.96 and 0.95, respectively [38].

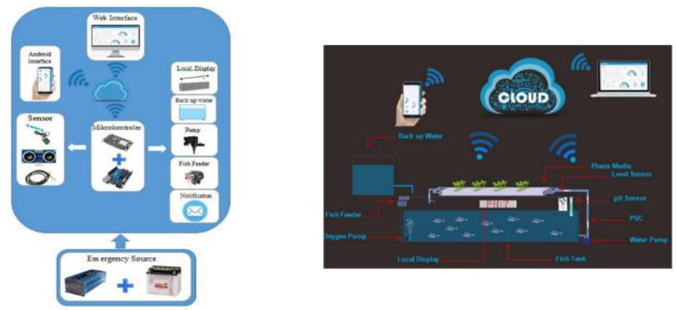

Fig. 7. System design of smart IoT based aquaponic system.

C. Lee and Y. J. [39] also present the cloud system for fish based IoT metabolism in aquaponic system through oxygen transfer rate model. IR distance sensor in used in the fish tank for finding the locomotion of the fishes in water tank. ADC is used to convert the IR signals to integer value. The dataset used in the study obtained from 27 fishes of different types in the water tank. The fish metabolic rate is used to determine the oxygen consumption level of fishes. The study shows that the pH, temperature of water and dissolved oxygen affect the metabolic activity of fishes in aquaponic system. The periodic regression of the model is carried out on ThingSpeak cloud computing platform [40]. Wang P. Mpofu, S. H. Kembo, S. Jacques, and N. Chitiyo [41] suggest IoT based household aquaponic system for food production. This was an offline-First system for overcoming the challenges of cloud computing systems in low budget household scenarios by using the Edge and Fog computing [42]. This system is deployed using LAN connection to remove the dependency of active internet connection. Edge computing is utilized to constantly check the water flow in the water pumps. This detection was based on the sound detection scenario of water in the water pumps. Raspberry Pi network is used for Fog computing. This research shows that the Edge and Fog computing system shows the cheap and efficient results in household aquaponic system.

S. C. Lauguico, R. I. S. Concepcion, J. D. Alejandrino, R. R. Tobias, and E. P. Dadios [43] classify the lettuce life in aquaponic system using machine learning for texture classification. The dataset used for the study is taken from Morong, Rizal, Philippines aquaponic farms. Haralick Texture Feature is used to extract the features from RGB images [44]. RFE, US and F1 feature extraction methods are used for extracting the features from the texture attributes. The extracted features are classifies using machine learning algorithms GNB, SGD, LDA and DTC. Hold-Out validation and cross validation is applied on these algorithms for generating the results in the form of accuracy and F1 score. The best accuracy classification accuracy of 87.9% is obtained from DTC.

A. Reyes-Yanes, P. Martinez, and R. Ahmad [45] present computer vision based system to determine weight and growth rate of the fish and crops of little gem romaine lettuce the aquaponic environment. There are three basic methodology used in the model as model building for image preprocessing, image training and model training, prediction- correlation for image segmentation and parameter estimation for feature extraction. A total of 3150 instances of data is obtained from 1350 image dataset. The results of this system show the overall error of 18.7% mm for size of crop and 8.3% for weight of the fish. R. Abbasi, P. Martinez, and R. Ahmad [46] present ontology model for aquaponic grow beds. This knowledge modelling system automatically detects the required characteristics for an aquaponic crop. The AquaONT system is developed for decision making, GUI developed used inferred, and the design parameters are obtained by mathematical equations. The results of this research shows that the correct grow bed design gives the high crop yield and quality. In one of the latest research, industry 4.0 [47] method is implemented on the aquaponic environment. This method combines the latest computational studies including big data analysis, deep learning, robotics, IoT, AI and cloud computing for aquaponic environment. This research use the methontology model [48] to evaluate the AquaONT. The overall working of this whole process is shown in Fig. 8 [7].

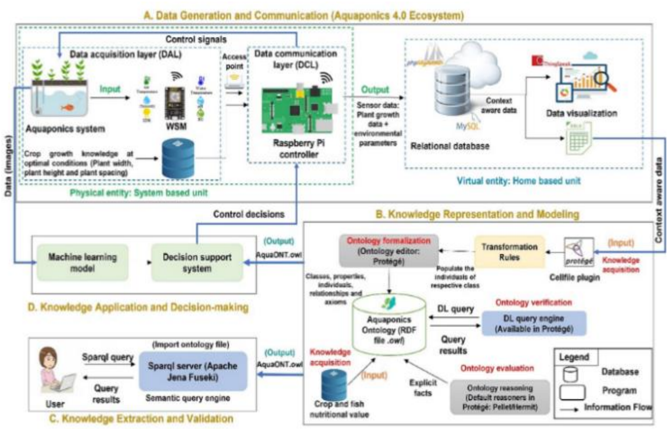

Fig. 8. An overview of AquaONT system.

This model gives the information about optimal operation of IoT devices, taking required actions on qualitative issues of fish and crops in aquaponic environment, and design configuration of grow beds based on crop characteristics while merging them with a suitable interface. These results helps the farmers to control the system of aquaponic environment in efficient manners.

A research is designed IoT based model to monitor modularization, miniaturization, and low-cost features of aquaponic system. The architecture of the model is shown in Fig. 9 [49].

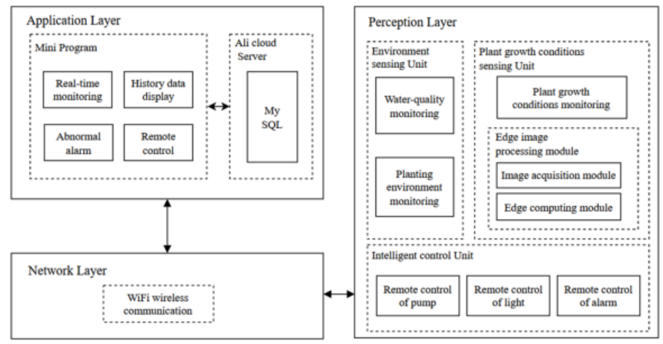

Fig. 9. Architecture of Embedded Edge computing based in IoT monitoring for aquaponic system.

The IoT based sensing consists of three layers including Application, Network and Perception layer allow the system to communicate and pass information without human interaction [50]. For this study there are three units of environment sensing, plant growth sensing, and intelligent control unit in perception layer. The model shows the environmental error rate of 5%. This system works on the edge computing using monitoring nodes, that provides the base line for the next reseachers to use more nodes with strong edge sensing for the aquaponic modularization. P. Debroy and L. Seban [51] presented machine learning based study for the prediction of fruit biomass for enhancing the profit and production. The mathematical model is used to generate the dataset consists of parameters and weight of tomato in aquaponic system. Machine learning algorithm ANN and ANFSI is used for the classification. The model shows the MAE value of 0.1079 and RMSE value of 0.4582 with ANN model.

In one of the latest research AI based surrogate models [52] are implied with IoT for smart aquaponic to overcome the labor problem. This system provides the real time monitoring of water quality, temperature, pH and other parameters in aquaponic system. Fig. 10 explain the whole setup of IoT based smart pound with automatic control [53].

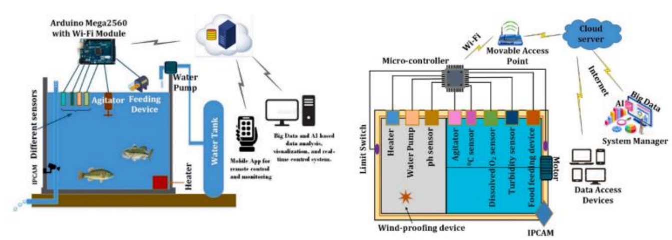

Fig. 10. IoT based smart aquaponic system.

Five sensors, five actuators along with Arduino Mega2560 are used in the system for sensing and monitoring the data. The result of the research shows R^2 value of 0.94 and a MSE value of 0.0015. The comparison of latest models for the studies is explained in Table II.

TABLE II. LITERATURE REVIEW TABLE

Paper Title	Year of Publication	Methods	Dataset	Result
Smart aquaponic system based Internet of Things (IoT) [37]	2019	IoT cloud based system	Live sensors for collecting the data.	The accuracy of 99.94% for Ultrasonic sensor and 92.35% for pH sensor.
Smart Aquaponics with Disease Detection [17]	2019	IoT based system with machine learning classifier	Real time Firebase database	Detect leafs of different species for disease detection.
Smart farming IoT platform based on edge and cloud computing [16]	2019	IoT based Edge computing	Greenhouse of CEBAS-CSIC	Saving more than 30% and 80% nutrients.
Using Machine Vision to Estimate Fish Length from Images using Regional Convolutional Neural Networks [23]	2019	Machine vision using R-CNN	European sea bass image dataset	mIoU value of 93%
Lettuce life stage classification from texture attributes using machine learning estimators and feature selection processes [43]	2020	REF, US and F1 feature extraction model with GNB, LDA, DTC and SGD algorithms	Data instances from Morongo, Rizal, Philippines aquaponic farms	DTC shows the classification accuracy of 87.9%
Real-time growth rate and fresh weight estimation for little gem romaine lettuce in aquaponic grow beds [45]	2020	Computer vision based system including image processing, deep learning and regression analysis	Image dataset created by Department of environmental science of University of Alberta	The overall error of18.7% mm for size of crop and 8.3% for weight of the fish
A Comparative Analysis of Machine Learning Algorithms Modeled from Machine Vision-Based Lettuce Growth Stage Classification in Smart Aquaponics [34]	2020	KNN, L-SVM with LR	Images dataset developed by Rizal, Philippines	Classification accuracy 91.67%
Decision Tree Regression with AdaBoost Ensemble Learning for Water Temperature Forecasting in Aquaponic Ecosystem [24]	2022	DT Regression with AdaBoost Ensemble learning	Experimental based aquaponic system at Telkom University lab	DTR model with AdaBoost shows MSE value of 0.0045 and R-square value of 0.92.
Edge Computing Based Smart Aquaponics Monitoring System Using Deep Learning in IoT Environment [38]	2020	AutoML model with gradient boost Machine learning algorithm	Images of fish dataset from Singapore Bioimaging Consortium, Singapore,	Precision, recall and F1 score of 0.94, 0.96 and 0.95 respectively.
Development of a Cloud-based IoT Monitoring System for Fish Metabolism and Activity in Aquaponics [40]	2020	Cloud based IoT monitoring system using ThingCloud Computing	Data from 27 fishes in the aquaponic environment from National Sun Yat-sen University	The pH, temperature of water and dissolved oxygen effect the metabolic activity of fishes in aquaponic system.
Utilizing a Privacy-Preserving IoT Edge and Fog Architecture in Automated Household Aquaponics [41]	2021	Edge and Fog computing based IoT system	St Peters Mbare IoT Maker space	Edge and Fog computing serve best for household aquaponic system
An Ontology model to support the automated design of aquaponic grow beds [46]	2021	Knowledge modeling approach AquaONT	LIMDA, University of Alberta	The correct grow bed design gives the high crop yield and quality.
A Machine-Learning Based IoT System for Optimizing Nutrient Supply in Commercial Aquaponic Operations [14]	2022	XGBoost and ExtraTreesClassifier With pairwise correlation matrix and Recursive Feature Elimination	Aquatic Greens Farm , Wolff Family Farms and Texas US Farms	Calcium and Ammonium predicators are identified and cost is decreased by 75%.
Nutrient optimization for plant growth in Aquaponic irrigation using Machine Learning for small training datasets [20]	2022	XGBoost and pairwise correlation matrix for dimension reduction and LDA, CART, KNN, SVM for the classification	Bryan, Caldwell, and Grimes counties	semi-Bolstered Resubstitution shows the error values of zero

Using Deep Convolutional Neural Network for Image-Based Diagnosis of Nutrient Deficiencies in Plants Grown in Aquaponics [26]	2022	Deep convolutional neural networks	3000 images of lettuce plant captured by camera (PowerShot SX720 HS)	Accuracy of 96.5%
Can Machine Learning classifiers be used to regulate nutrients using small training datasets for aquaponic irrigation? A comparative analysis [30]	2022	XGBoost and ExtraTreesClassifier	Farms in Texas	More than 90% correlation between the predictors
Using Machine Learning for Nutrient Content Detection of Aquaponics-Grown Plants Based on Spectral Data [32]	2022	Random Forest, Partial least square regression and Back propagation neural network	Spectral data self-obtained from the plant leaves.	The predictive value of R^2p = 0.97 for nitrogen is obtained by BNN. While RF gives R^2p = 0.94 for phosphate and R^2p = 0.96 for potassium
An ontology model to represent aquaponics 4.0 system's knowledge [7]	2022	AquaONT model with methontology approach following deep learning, computer vision and machine learning approaches	Data taken from different farms of Canada	The model show best results for optimal operation of IoT devices, qualitative issues of fish and crops, and design configuration of crop beds grow beds
Tomato Fruit Biomass Prediction Model for Aquaponics System Using Machine Learning Algorithms [51]	2022	ANN with AFNIS		MAE value of 0.1079 and RMSE value of 0.4582
A Modularized IoT Monitoring System with Edge-Computing for Aquaponics [49]	2022	Embedded Edge computing based in IoT monitoring	Real time data collection	Environmental error rate 5%.
Development of smart aquaculture farm management system using IoT and AI-based surrogate models [53]	2022	AI based surrogate model with deep CNN and IoT	Real time monitoring and collecting data	R^2 value of 0.94 and a MSE value of 0.0015,

IV. Analysis and Discussion

Fig. 11 explain the overall working of systematic literature review for the proposed study.

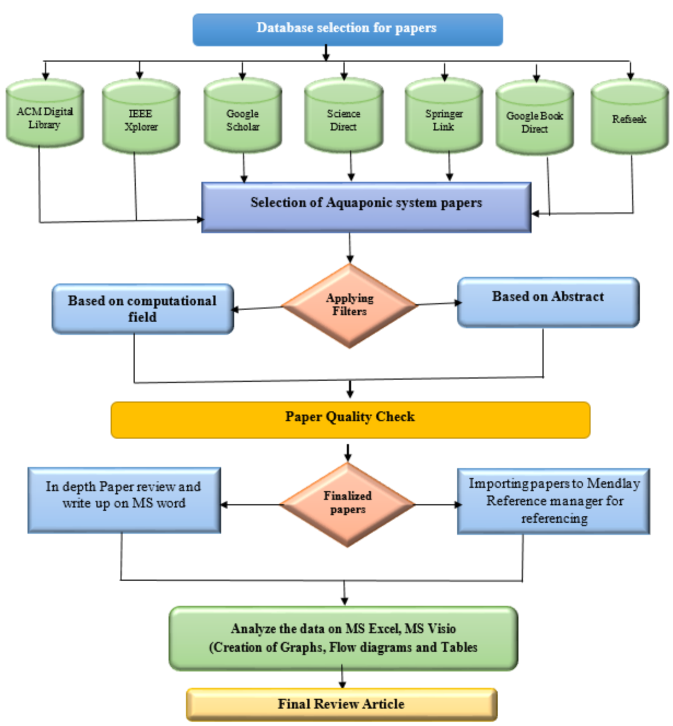

Fig. 11. Workflow of the proposed model.

In the very first step, the papers are selected from seven different known article databases. After applying different queries on these articles only 41 articles are future processed for systematic literature review. These papers are reviewed deeply as discussed in the Literature review section and the methodology, pros and cons of this study are extracted. The final draft of the study present a state of the art article for the new researchers in field of aquaponic culture to analyze the latest methods deeply and find a new direction in context of their working. All the papers that are selected are between years 2019 to 2022. The frequency distributions of the papers are shown in Fig. 12.

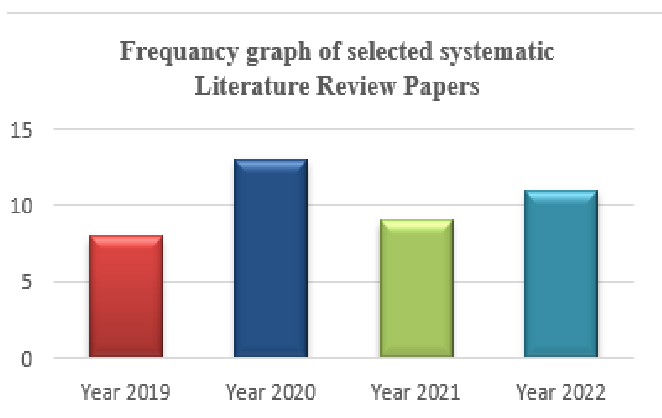

Fig. 12. Workflow graph of the proposed model.

All of the selected study gives an efficient result for aquaponic environments. Each study has its own benefits as well as drawback for the upcoming researchers. All the papers are chosen for the study are collected from high source journals and conferences with maximum citations are used in this study for maintaining the quality of the research. The heatmap diagram of the proposed study is illustrated in Fig. 13.

Figure illustrates the publication in context of year with the proposed algorithm. The selected papers are taken from different journal or conferences. The most citied papers among all along with the publishing source are explained in Table III.

In the table from 2019, it may be observed that,till date the most cited research article was IoT based edge detecting system that is published on biosystem engineering journal. Following this [23] [45] [34] has 47, 34, 31 citations respectively considered as best research articles regarding to the field.

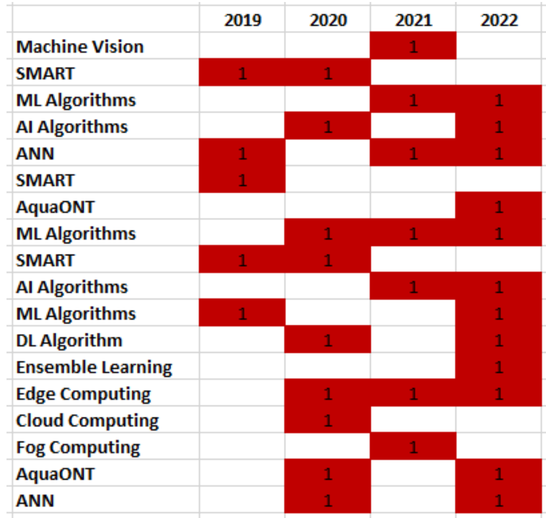

Fig. 13. Heatmap diagram of the proposed selected studies.

TABLE III. ARTICLES WITH MOST CITATIONS AND THEIR PUBLICATION JOURNALS

Author	Paper Title	Year of Publication	Methods	Journal Conference
M. A. Zamora-Izquierdo, J. Santa, J. A. Martínez, V. Martínez, and A. F. Skarmeta [16]	Smart farming IoT platform based on edge and cloud computing	2019	IoT based Edge computing	biosystems engineering
G. G. Monkman, K. Hyder, M. J. Kaiser, and F. P. Vidal [23]	Using Machine Vision to Estimate Fish Length from Images using Regional Convolutional Neural Networks	2019	Machine vision using R-CNN	Methods in Ecology and Evolution
A. Reyes-Yanes, P. Martinez, and R. Ahmad [45]	REAL-TIME GROWTH RATE AND FRESH WEIGHT ESTIMATION FOR LITTLE GEM ROMAINE LETTUCE IN AQUAPONIC GROW BEDS	2020	Computer vision based system including image processing, deep learning and regression analysis	Computer and Engineering in Agriculture
S. C. Lauguico, R. S. Concepcion, J. D. Alejandrino, R. R. Tobias, D. D. Macasaet, and E. P. Dadios [34]	A Comparative Analysis of Machine Learning Algorithms Modeled from Machine Vision-Based Lettuce Growth Stage Classification in Smart Aquaponics	2020	KNN, L-SVM with LR	International Journal of Environmental Science and Technology
C. Lee and Y. J. [40]	Development of a Cloud-based IoT Monitoring System for Fish Metabolism and Activity in Aquaponics	2020	Cloud based IoT monitoring system using ThingCloud Computing	International Journal of Environmental Science and Technology
S. C. Lauguico, R. I. S. Concepcion, J. D. Alejandrino, R. R. Tobias, and E. P. Dadios [43]	Lettuce life stage classification from texture attributes using machine learning estimators and feature selection processes	2020	REF, US and F1 feature extraction model with GNB, LDA, DTC and SGD algorithms	Methods in Ecology Evolution

V. CONCLUSION

Aquaponic system is the growth of aquatic organisms as well as plants in the controlled environment to overcome the problem of nutrients regulation, consumption of water, lack of land, lack of workforce etc. It is one of the major discussed topics in the current scenario. This study is proposed for review the latest computational studies proposed by different researchers in aquaponic system providing the baseline for the next researchers. A total of 41 high quality research articles are choose from seven different articles database to review for the study. After deeply analyzing these researches the aim, objectives, limitations and future work of these articles are generated as illustrated in Tables II and III of the research.

It is seen in the proposed study that the most of the researchers use different IoT sensors including water quality sensor, temperature sensor, pH sensor, air flow, predictor's sensor, light sensor, humidity sensor for constant monitoring of the aquaponic environment. There are different machine learning and deep learning models proposed by the researchers for regulating the predictors in aquaponic system.

The results of the proposed study stated that the highest sensor accuracy 99.4% for IoT ultrasonic sensor is obtained by research presented by Haryanto, M. Ulum, A. F. Ibadillah, R. Alfita, K. Aji, and R. Rizkyandi [37]. The highest classification accuracy of 96.5% is obtained by paper titled Using Deep Convolutional Neural Network for Image-Based

Diagnosis of Nutrient Deficiencies in Plants Grown in Aquaponics [26]. Paper presented by S. C. Lauguico, R. S. Concepcion, J. D. Alejandrino, R. R. Tobias, D. D. Macasaet, and E. P. Dadios [34] and S. C. Lauguico, R. I. S. Concepcion, J. D. Alejandrino, R. R. Tobias, and E. P. Dadios [43] gives the detection accuracy of 91.67% and 87.9% respectively. Smart farming IoT platform based on edge and cloud computing [12] shows the mostly cited research article use IOT based edge computing system for nutrients regulation and save upto 80% nutrients. The study [51] give the MAE value of 0.10 while [53] gives the MSE value of 0.005.

VI. Future Work

It is seen from the proposed study that most of the researchers used real time IoT sensors for continue capturing the data and process. A few of them uses a dataset to train the ML and DL model. So to develop and use an efficient dataset in context of aquaponic environment is one of the major needs of the aquaponic study. It was also seen from the literature review that none of the research use ensemble learning method implemented on different deep learning and machine learning algorithms for aquaponic system. Deep learning algorithms with different RNN methods are not implemented by any researcher for all time in aquaponic environment.

This is the guideline for the new researcher to develop a more secure IoT based model that can use either of the ensemble learning or deep learning with RNN and CNN models to make aquaponic system more secure and sustainable.

References

[1] S. Ilyas, A. A. Shah, and A. Sohail, "Order Management System for Time and Quantity Saving of Recipes Ingredients Using GPS Tracking Systems," IEEE Access, vol. 9, pp. 100490–100497, 2021, doi: 10.1109/ACCESS.2021.3090808.

[2] A. A. Shah, M. K. Ehsan, A. Sohail, and S. Ilyas, "Analysis of Machine Learning techniques for identification of post translation modification in protein sequencing: A Review," in 4th International Conference on Innovative Computing, ICIC 2021, 2021, pp. 1–6. doi: 10.1109/ICIC53490.2021.9693020.

[3] B. Yep and Y. Zheng, "Aquaponic trends and challenges – A review," J. Clean. Prod., vol. 228, pp. 1586–1599, 2019, doi: 10.1016/j.jclepro.2019.04.290.

[4] W. Lennard and S. Goddek, Aquaponics Food Production Systems, no. June. 2019. doi: 10.1007/978-3-030-15943-6.

[5] S. Goddek et al., Decoupled Aquaponics Systems. 2019. doi: 10.1007/978-3-030-15943-6_8.

[6] A. J. Van Der Goot et al., "Concepts for further sustainable production of foods," J. Food Eng., vol. 168, no. November 2018, pp. 42–51, 2016, doi: 10.1016/j.jfoodeng.2015.07.010.

[7] R. Abbasi, P. Martinez, and R. Ahmad, "An ontology model to represent aquaponics 4.0 system's knowledge," Inf. Process. Agric., vol. 9, no. 4, pp. 514–532, 2022, doi: 10.1016/j.inpa.2021.12.001.

[8] M. F. Taha et al., "Recent Advances of Smart Systems and Internet of Things (IoT) for Aquaponics Automation: A Comprehensive Overview," Chemosensors, vol. 10, no. 8, 2022, doi: 10.3390/chemosensors10080303.

[9] P. Brereton, B. A. Kitchenham, D. Budgen, M. Turner, and M. Khalil, "Lessons from applying the systematic literature review process within the software engineering domain," J. Syst. Softw., vol. 80, no. 4, pp. 571–583, 2007, doi: 10.1016/j.jss.2006.07.009.

[10] K. S. Khan, R. Kunz, J. Kleijnen, and G. Antes, "Five steps to conducting a systematic review," J. R. Soc. Med., vol. 96, no. 3, pp. 118–121, 2003, doi: 10.1258/jrsm.96.3.118.

[11] A. Ramdhani, M. A. Ramdhani, and A. S. Amin, "Writing a Literature Review Research Paper: A step-by-step approach," Int. J. Basic Appl. Sci., vol. 03, no. 01, pp. 47–56, 2014.

[12] L. A. Kahale et al., "PRISMA flow diagrams for living systematic reviews: a methodological survey and a proposal," F1000Research, vol. 10, no. March, p. 192, 2021, doi: 10.12688/f1000research.51723.1.

[13] D. C. Love et al., "Commercial aquaponics production and profitability: Findings from an international survey," Aquaculture, vol. 435, pp. 67–74, 2015, doi: 10.1016/j.aquaculture.2014.09.023.

[14] S. B. Dhal et al., "A Machine-Learning-Based IoT System for Optimizing Nutrient Supply in Commercial Aquaponic Operations," Sensors, vol. 22, no. 9, pp. 1–14, 2022, doi: 10.3390/s22093510.

[15] A. Mariot, S. Sgoifo, and M. Sauli, "I gozzi endotoracici: contributo casistico-clinico (20 casi)," Friuli Med., vol. 19, no. 6, 1964.

[16] M. A. Zamora-Izquierdo, J. Santa, J. A. Martínez, V. Martínez, and A. F. Skarmeta, "Smart farming IoT platform based on edge and cloud computing," Biosyst. Eng., vol. 177, no. xxxx, pp. 4–17, 2019, doi: 10.1016/j.biosystemseng.2018.10.014.

[17] R. Barosa, S. I. S. Hassen, and L. Nagowah, "Smart Aquaponics with Disease Detection," 2nd Int. Conf. Next Gener. Comput. Appl. 2019, NextComp 2019 - Proc., pp. 1–6, 2019, doi: 10.1109/NEXTCOMP.2019.8883437.

[18] J. P. Mandap, D. Sze, G. N. Reyes, S. Matthew Dumlao, R. Reyes, and W. Y. Danny Chung, "Aquaponics pH Level, Temperature, and Dissolved Oxygen Monitoring and Control System Using Raspberry Pi as Network Backbone," IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON, vol. 2018-Octob, no. 1, pp. 1381–1386, 2019, doi: 10.1109/TENCON.2018.8650469.

[19] A. Nayyar and V. Puri, "Raspberry Pi-A Small, Powerful, Cost Effective and Efficient Form Factor Computer: A Review," Int. J. Adv. Res. Comput. Sci. Softw. Eng., vol. 5, no. July, pp. 720–737, 2015, [Online]. Available: https://www.researchgate.net/publication/305668622

[20] S. B. Dhal, M. Bagavathiannan, U. Braga-Neto, and S. Kalafatis, "Nutrient optimization for plant growth in Aquaponic irrigation using Machine Learning for small training datasets," Artif. Intell. Agric., vol. 6, pp. 68–76, 2022, doi: 10.1016/j.aiia.2022.05.001.

[21] K. Muhi and Z. C. Johanyák, "Dimensionality Reduction Methods Used in Machine Learning," Műszaki Tudományos Közlemények, vol. 13, no. 1, pp. 148–151, 2020, doi: 10.33894/mtk-2020.13.27.

[22] U. Braga-Neto and E. Dougherty, "Bolstered error estimation," Pattern Recognit., vol. 37, no. 6, pp. 1267–1281, 2004, doi: 10.1016/j.patcog.2003.08.017.

[23] G. G. Monkman, K. Hyder, M. J. Kaiser, and F. P. Vidal, "Using machine vision to estimate fish length from images using regional convolutional neural networks," Methods Ecol. Evol., vol. 10, no. 12, pp. 2045–2056, 2019, doi: 10.1111/2041-210X.13282.

[24] A. Taufiqurrahman, A. G. Putrada, and F. Dawani, "Decision Tree Regression with AdaBoost Ensemble Learning for Water Temperature Forecasting in Aquaponic Ecosystem," 6th Int. Conf. Interact. Digit. Media, ICIDM 2020, no. Icidm, 2020, doi: 10.1109/ICIDM51048.2020.9339669.

[25] Y.-Q. Wang, "An Analysis of the Viola-Jones Face Detection Algorithm," Image Process. Line, vol. 4, pp. 128–148, 2014, doi: 10.5201/ipol.2014.104.

[26] M. F. Taha et al., "Using Deep Convolutional Neural Network for Image-Based Diagnosis of Nutrient Deficiencies in Plants Grown in Aquaponics," Chemosensors, vol. 10, no. 2, pp. 1–23, 2022, doi: 10.3390/chemosensors10020045.

[27] V. Badrinarayanan, A. Kendall, and R. Cipolla, "SegNet: A Deep Convolutional Encoder-Decoder Architecture for Image Segmentation," IEEE Trans. Pattern Anal. Mach. Intell., vol. 39, no. 12, pp. 2481–2495, 2017, doi: 10.1109/TPAMI.2016.2644615.

[28] S. I. and M. K. E. A. Sohail, N. A. Nawaz, A. A. Shah, S. Rasheed, "A Systematic Literature Review on Machine Learning and Deep Learning Methods for Semantic Segmentation," IEEE Access, vol. 10, pp. 134557–134570, 2022, doi: 10.1109/ACCESS.2022.3230983.

[29] G. Lin and W. Shen, "Research on convolutional neural network based

on improved Relu piecewise activation function," Procedia Comput. Sci., vol. 131, pp. 977–984, 2018, doi: 10.1016/j.procs.2018.04.239.

[30] S. B. Dhal, M. Bagavathiannan, U. Braga-Neto, and S. Kalafatis, "Can Machine Learning classifiers be used to regulate nutrients using small training datasets for aquaponic irrigation?: A comparative analysis," PLoS One, vol. 17, no. 8 August, pp. 1–15, 2022, doi: 10.1371/journal.pone.0269401.

[31] N. V. Chawla, K. W. Bowyer, L. O. Hall, and W. P. Kegelmeyer, "SMOTE: Synthetic minority over-sampling technique," J. Artif. Intell. Res., vol. 16, no. February 2017, pp. 321–357, 2002, doi: 10.1613/jair.953.

[32] M. F. Taha et al., "Using Machine Learning for Nutrient Content Detection of Aquaponics-Grown Plants Based on Spectral Data," Sustain., vol. 14, no. 19, 2022, doi: 10.3390/su141912318.

[33] C. Buschmann, S. Lenk, and H. K. Lichtenthaler, "Reflectance spectra and images of green leaves with different tissue structure and chlorophyll content," Isr. J. Plant Sci., vol. 60, no. 1–2, pp. 49–64, 2012, doi: 10.1560/IJPS.60.1-2.49.

[34] S. C. Lauguico, R. S. Concepcion, J. D. Alejandrino, R. R. Tobias, D. D. Macasaet, and E. P. Dadios, "A comparative analysis of machine learning algorithms modeled from machine vision-based lettuce growth stage classification in smart aquaponics," Int. J. Environ. Sci. Dev., vol. 11, no. 9, pp. 442–449, 2020, doi: 10.18178/ijesd.2020.11.9.1288.

[35] A. R. Yanes, P. Martinez, and R. Ahmad, "Towards automated aquaponics: A review on monitoring, IoT, and smart systems," J. Clean. Prod., vol. 263, no. April, 2020, doi: 10.1016/j.jclepro.2020.121571.

[36] T. Khaoula, R. A. Abdelouahid, I. Ezzahoui, and A. Marzak, "Architecture design of monitoring and controlling of IoT-based aquaponics system powered by solar energy," Procedia Comput. Sci., vol. 191, no. September, pp. 493–498, 2021, doi: 10.1016/j.procs.2021.07.063.

[37] Haryanto, M. Ulum, A. F. Ibadillah, R. Alfita, K. Aji, and R. Rizkyandi, "Smart aquaponic system based Internet of Things (IoT)," J. Phys. Conf. Ser., vol. 1211, no. 1, 2019, doi: 10.1088/1742-6596/1211/1/012047.

[38] C. S. Arvind, R. Jyothi, K. Kaushal, G. Girish, R. Saurav, and G. Chetankumar, "Edge Computing Based Smart Aquaponics Monitoring System Using Deep Learning in IoT Environment," 2020 IEEE Symp. Ser. Comput. Intell. SSCI 2020, no. November 2021, pp. 1485–1491, 2020, doi: 10.1109/SSCI47803.2020.9308395.

[39] C. Lee and Y. J. Wang, "Development of a cloud-based IoT monitoring system for Fish metabolism and activity in aquaponics," Aquac. Eng., vol. 90, p. 102067, 2020, doi: 10.1016/j.aquaeng.2020.102067.

[40] A. A. H. Mohamad, N. K. Jumaa, and S. H. Majeed, "ThingSpeak cloud computing platform based ECG diagnose system," Int. J. Comput. Digit. Syst., vol. 8, no. 1, pp. 11–18, 2019, doi: 10.12785/ijcds/080102.

[41] P. Mpofu, S. H. Kembo, S. Jacques, and N. Chitiyo, "Utilizing a privacy-preserving iot edge and fog architecture in automated household aquaponics.," Proc. Int. Conf. Ind. Eng. Oper. Manag., vol. 59, no. November, pp. 2281–2288, 2020.

[42] A. Sunyaev, "Fog and Edge Computing," Internet Comput., no. September, pp. 237–264, 2020, doi: 10.1007/978-3-030-34957-8_8.

[43] S. C. Lauguico, R. I. S. Concepcion, J. D. Alejandrino, R. R. Tobias, and E. P. Dadios, "Lettuce life stage classification from texture attributes using machine learning estimators and feature selection processes," Int. J. Adv. Intell. Informatics, vol. 6, no. 2, pp. 173–184, 2020, doi: 10.26555/ijain.v6i2.466.

[44] P. Brynolfsson et al., "Haralick texture features from apparent diffusion coefficient (ADC) MRI images depend on imaging and pre-processing parameters," Sci. Rep., vol. 7, no. 1, 2017, doi: 10.1038/s41598-017-04151-4.

[45] A. Reyes-Yanes, P. Martinez, and R. Ahmad, "Real-time growth rate and fresh weight estimation for little gem romaine lettuce in aquaponic grow beds," Comput. Electron. Agric., vol. 179, no. September, p. 105827, 2020, doi: 10.1016/j.compag.2020.105827.

[46] R. Abbasi, P. Martinez, and R. Ahmad, "An ontology model to support the automated design of aquaponic grow beds," Procedia CIRP, vol. 100, pp. 55–60, 2021, doi: 10.1016/j.procir.2021.05.009.

[47] L. Thames and D. Schaefer, Industry 4.0: An Overview of Key Benefits, Technologies, and Challenges, no. April 2019. 2017. doi: 10.1007/978-3-319-50660-9_1.

[48] M. Fernandez, A. Gómez-Pérez, and N. Juristo, "Methontology: from ontological art towards ontological engineering," Proc. AAAI97 Spring Symp. Ser. Ontol. Eng., no. May 2014, pp. 33–40, 1997, [Online]. Available: http://speech.inesc.pt/~joana/prc/artigos/06c METHONTOLOGY from Ontological Art towards Ontological Engineering - Fernandez, Perez, Juristo - AAAI - 1997.pdf

[49] S. Wan, K. Zhao, Z. Lu, J. Li, T. Lu, and H. Wang, "A Modularized IoT Monitoring System with Edge-Computing for Aquaponics," Sensors, vol. 22, no. 23, 2022, doi: 10.3390/s22239260.

[50] P. Sethi and S. R. Sarangi, "Internet of Things: Architectures, Protocols, and Applications," J. Electr. Comput. Eng., vol. 2017, 2017, doi: 10.1155/2017/9324035.

[51] P. Debroy and L. Seban, "A Tomato Fruit Biomass Prediction Model for Aquaponics System Using Machine Learning Algorithms," IFAC-PapersOnLine, vol. 55, no. 1, pp. 709–714, 2022, doi: 10.1016/j.ifacol.2022.04.116.

[52] M. Frangos, Y. Marzouk, K. Willcox, and B. van B. Waanders, "Surrogate and reduced-order modeling: A comparison of approaches for large-scale statistical inverse problems," Large-Scale Inverse Probl. Quantif. Uncertain., pp. 123–149, 2010, doi: 10.1002/9780470685853.ch7.

[53] M. C. Chiu, W. M. Yan, S. A. Bhat, and N. F. Huang, "Development of smart aquaculture farm management system using IoT and AI-based surrogate models," J. Agric. Food Res., vol. 9, no. August, p. 100357, 2022, doi: 10.1016/j.jafr.2022.100357.