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Innovations in Brackish Water Aquaponics: Utilizing IoT and Genetic Algorithms for Water Quality Management and Organic Nutrient Optimization

Munirul Ula [1], Rizal Tjut Adek [2], Bustami[3], and Muliani[4]

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Abstract: The use of brackish water aquaponics systems offers promising opportunities for achieving sustainable food production. However, improving water quality and nutrient parameters remains a significant barrier. This study presents a comprehensive intelligent system aimed at improving water quality and maximizing nutrient utilization in a brackish water aquaponics system. The system integrates the cultivation of Whiteleg Shrimp (Litopenaeus vannamei) with various vegetables including melon, pumpkin, watermelon, and cucumber. This novel method combines Internet of Things (IoT) technology, machine learning-based genetic algorithms, and precise nutrient management using organic liquid fertilizers. The system consists of a sensor subsystem that monitors various water quality parameters such as pH, temperature, dissolved oxygen, salinity, and nitrite levels. The system also includes an organic liquid fertilizer subsystem for nutrient addition, feedback for continuous evaluation, and an actuator system to implement corrective actions. The implementation of genetic algorithms is used to predict optimal parameters for water quality and organic liquid fertilizer dosage. The system control is achieved through the use of Arduino. After one month of testing, it was shown that the system successfully maintained water quality parameters within the optimal range. These parameters include pH (7.5-7.9), temperature (27.5-29.0°C), nitrite (0.05-0.10 ppm), salinity (6.5-8.5 ppt), and dissolved oxygen (6.8-7.4 ppm). The use of optimized organic liquid fertilizer at a concentration of 10-15 ml/L resulted in significant increases in plant and shrimp growth compared to traditional systems. This study demonstrates the ability to combine IoT, machine learning, and nutrient optimization to improve the effectiveness and yield of brackish water aquaponics systems. This approach provides a way to address sustainability and food security challenges. However, further research is needed to validate its effectiveness on a larger scale and for longer periods.

Keywords: *Brackish water aquaponics, Internet of Things, Machine Learning, Genetic Algorithm, Organic liquid fertilizer, Whiteleg Shrimp, Plants, Nutrient optimization*

1. Introduction

Aquaponics, the integration of aquaculture with hydroponics, is a promising solution to the worldwide issues of food scarcity and environmental sustainability [1]. This synergy exploits the inherent connection between aquatic organisms and plants to create a self-sustaining ecosystem that fosters robust growth without the need for chemicals or pesticides [2]. Research has demonstrated that this system has the capacity to enhance production by a factor of ten, while utilizing only 2-10% of the water required by traditional farming methods [3].

Aquaponics presents a promising solution in the current global scenario characterized by growing scarcity of water resources and increasing food demands [4]. This system not only conserves water but also decreases reliance on traditional agricultural land, which is progressively endangered by urbanization and environmental deterioration. In addition, aquaponics allows for the cultivation of food in urban areas, which leads to shorter transportation distances and enhances local food security [5].

Nevertheless, aquaponics systems encounter notable challenges and drawbacks, despite their numerous advantages. An issue that frequently arises in these systems is the imbalance of nutrients [2]. Despite its high nitrogen content, fish waste is often insufficient to fulfill all the nutritional needs of plants, particularly for elements like iron, potassium, and calcium [4]. Consequently, plants in aquaponic systems frequently exhibit signs of nutrient insufficiency, leading to hindered growth and decreased yields [3].

The nutrient imbalance in brackish water aquaponic systems becomes increasingly intricate [6]. Brackish water, due to its elevated salinity in comparison to fresh water, presents additional difficulties in the management of nutrients. Salinity has the potential to impact the accessibility and uptake of nutrients by plants, as well as disrupt the ionic equilibrium in the system [7]. Furthermore, it is crucial to take into account the distinct physiological requirements of brackish water aquatic organisms in the system's design and management, as they differ from those of freshwater species [8].

[1]*Information Technology, Universitas Malikussaleh, Lhokseumawe, Aceh, Indonesia*
[2,3]*Informatics, Universitas Malikussaleh, Lhokseumawe, Aceh, Indonesia*
[4]*Aquaculture, Universitas Malikussaleh, Lhokseumawe, Aceh, Indonesia*

In order to address this issue, it is crucial to utilize supplementary fertilizer nutrients like Organic liquid fertilizer [9]. Organic liquid fertilizer, a nutrient formulation containing both macro and micro elements, has been scientifically demonstrated to be highly effective in hydroponic systems. Nevertheless, additional research is needed to enhance the growth of both plants and aquatic organisms in brackish water aquaponic systems [10]. It is crucial to exercise caution when incorporating Organic liquid fertilizer into an aquaponic system in order to maintain a delicate equilibrium between the nutritional requirements of plants and the well-being of aquatic organisms [6, 10].

Utilizing Organic liquid fertilizer in brackish water aquaponics systems necessitates a more advanced methodology in contrast to traditional hydroponic systems [11]. When considering the factors that affect nutrient levels, it is important to take into account the speed at which plants absorb nutrients, the rate at which aquatic organisms release nutrients, and the behavior of microbes in the biofilter [1]. Furthermore, variations in water quality factors such as pH, temperature, and dissolved oxygen can impact the accessibility and absorption of nutrients from Organic liquid fertilizer [12].

The intricacy of nutrient management is further amplified when dealing with commercial operations. For large-scale aquaponics systems to be productive and economically sustainable, it is necessary to have accurate monitoring and control measures in place [13]. Advanced technologies such as the Internet of Things (IoT) and Machine Learning (ML) are essential in this context [14].

The utilization of Machine Learning (ML) and Internet of Things (IoT) in agriculture represents a notable technological progress that can assist in tackling these challenges [11, 14]. These technologies provide accurate control and automation, which has the potential to completely transform traditional farming methods. The effectiveness of IoT has been demonstrated through its ability to intelligently monitor water pH and temperature levels, as well as regulate nitrite and dissolved oxygen concentrations with precision [11].

IoT can be employed in brackish water aquaponics to actively monitor multiple water quality parameters, such as salinity, electrical conductivity, and concentrations of specific ions, in real time [15, 16]. This data can be utilized to enhance the administration of Organic liquid fertilizer, by modifying the dosage and composition of nutrients according to the current conditions of the system [11]. ML can be utilized to examine intricate patterns in the gathered data, forecast future nutrient needs, and optimize feeding and harvest schedules [15, 17].

Nevertheless, the advancement of machine learning techniques for regulating crucial nutrients, such as the addition of Organic liquid fertilizer, in brackish water aquaponics systems is still a groundbreaking endeavor [18]. The primary obstacles reside in the intricacy of interactions among different system components, as well as the significant variability in environmental and biological conditions [17]. In addition, the lack of extensive historical data from commercial brackish water aquaponics systems contributes to the challenge of creating precise and dependable machine learning models [15, 17].

Developing intelligent control systems for managing water quality parameters in brackish water aquaponics encounters numerous obstacles [11, 18]. The limited availability of data is a major obstacle, necessitating the use of synthetic data generation techniques and innovative methodologies [15]. The difficulties are heightened when dealing with commercial brackish water aquaponics systems, as the operation of these systems can be impacted by seasonal changes, fluctuations in market demand, and alterations in regulations [18, 17].

While previous research has primarily concentrated on controlling nutrients like calcium and phosphorus [18], our study seeks to bring about innovation by utilizing data-driven techniques to measure and regulate crucial water quality parameters in brackish water aquaponic solutions [15, 17]. This courageous decision has the potential to represent a noteworthy achievement in the field of commercial brackish water aquaponics. As aquaponics moves from small-scale experimental setups to commercial applications, there is a growing demand for scalable, cost-effective, and efficient models [18, 20].

The integration of Internet of Things (IoT) with Machine Learning (ML) presents a unique and exceptional opportunity to create sophisticated systems that can effectively manage intricate water quality dynamics and adjust to the changing patterns in tropical climates [15, 17]. The objective of our research is to address this significant deficiency by concentrating on enhancing brackish water aquaponics systems through the utilization of Organic liquid fertilizer, Internet of Things (IoT), and Machine Learning (ML) techniques [11, 15].

The allure of brackish water aquaponics stems from its high productivity and its adherence to environmental sustainability [21]. Aquaponics offers a means of responsible agriculture by minimizing water usage, decreasing dependence on synthetic chemicals, and promoting a balanced ecosystem [1, 21]. This paper examines the intricate relationship between water quality management and environmental concerns, utilizing machine learning (ML) and the Internet of Things (IoT) to enhance efficiency and promote long-term viability [15, 17].

A major difficulty in developing intelligent systems for managing water quality in brackish water aquaponics systems is the lack of available data [15, 22]. In order to tackle this problem, researchers have utilized different methods for generating synthetic data [22]. Although these approaches show potential, additional validation and refinement are necessary to accurately represent the intricacy of brackish water aquaponics systems [15, 22].

Implementing an IoT-based system to regulate specific water quality parameters is a crucial advancement in automating the optimal growth conditions for plants and aquatic organisms in aquaponics systems [11, 15]. Significant research in this field encompasses the suggestion of intelligent irrigation systems [23], real-time monitoring powered by solar energy and integrated with cloud technology [24], as well as other similar endeavors. However, the majority of these studies have primarily concentrated on traditional farming or aquaculture systems [25]. Therefore, additional adjustments and advancements are necessary for the implementation of brackish water aquaponics systems [18, 26].

Research Contribution

Our research introduces a groundbreaking attempt to synchronize Internet of Things (IoT) and Machine Learning (ML), with the goal of developing a flexible system to enhance the quality of water in brackish water aquaponics operations by utilizing Organic liquid fertilizer. The research encompasses the creation of a data-oriented approach for overseeing and controlling the quality of water, specifically emphasizing the incorporation of Organic liquid fertilizer into the system.

Investigation of synthetic data generation specifically designed for brackish water aquaponics systems, taking into account the intricate relationships among aquatic organisms, plants, and additional nutrients.

The combination of Internet of Things (IoT) and Machine Learning (ML) is used to create a unified and adaptable system for monitoring and controlling the quality of water in brackish water aquaponics systems. This system also includes the optimization of Organic liquid fertilizer administration.

This paper presents a novel system that combines technology and agriculture to create a sophisticated and context-aware solution for commercial brackish water aquaponics, with the potential to bring about a revolutionary change. This study aims to enhance the productivity and sustainability of brackish water aquaponics systems by utilizing IoT and ML technologies to optimize the use of Organic liquid fertilizer. The ultimate goal is to establish more efficient and environmentally friendly methods of food production for the future.

2. Material and Method

The methodology employed in this study encompasses the analysis and integration of data, the utilization of Organic liquid fertilizer, the implementation of Internet of Things (IoT) technology, and the application of machine learning to optimize the brackish water aquaponics system. This study examines the concurrent cultivation of Vanamei shrimp and vegetables, including melon, pumpkin, watermelon, and cucumber, using brackish water. The subsequent information provides specific details regarding different facets of the methodology:

2.1. Design of a Brackish Water Aquaponics System

An aquaponics system was created by combining shrimp ponds with plant and vegetable beds, resulting in a brackish water environment. A tarpaulin ponds were established in the aquaculture laboratory at Malikussaleh University in Aceh, Indonesia. A specialized greenhouse was utilized for the purpose of cultivating plants. Figure 1 provides a comprehensive depiction of the intricate arrangement of shrimp ponds and plant beds.

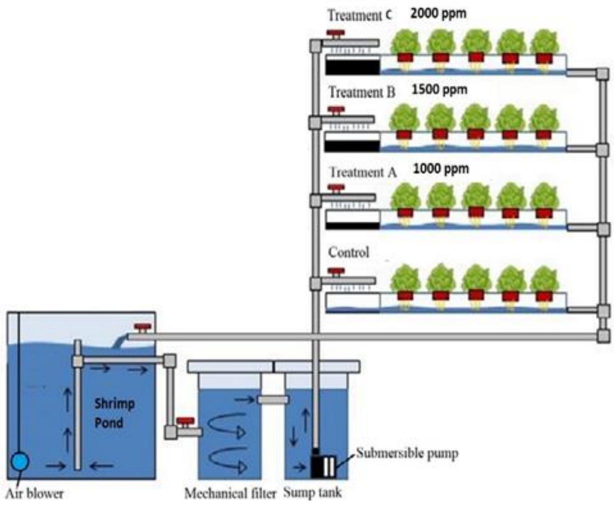

Fig. 1. Aquaponics system featuring shrimp and a variety of plants

2.2. Designing an IoT system to monitoring and regulation

In order to construct an Internet of Things (IoT) system capable of overseeing and controlling the quality of water in a shrimp aquaponic system with brackish water, the system is divided into four primary components: (a) the sensor subsystem, (b) the Organic liquid fertilizer subsystem, (c) the feedback loop, and (d) the actuator system.

Sensor Subsystem: This subsystem comprises a range of water quality sensors specifically engineered to measure and transmit data pertaining to significant parameters such as pH, temperature, dissolved oxygen (DO), nitrite levels, and salinity to an Arduino controller. The sensor selection process considers factors such as cost, accuracy, interface compatibility, and ease of integration. These sensors can connect with Arduino devices and are programmed using the Arduino Integrated Development Environment (IDE). Sensor calibration requires the use of distilled water for rinsing. Every sensor gathers numerous data points, calculates the average of the measurements, and provides the values in suitable units.

Organic liquid fertilizer Subsystem: The newly introduced element comprises an Organic liquid fertilizer storage tank, a precision dosing pump, and a liquid level sensor. The primary function of this subsystem is to introduce a mixture of AB into the aquaponics system based on the requirements determined by the machine learning algorithm.

Feedback Loop: A feedback loop is established to consistently evaluate the water quality parameters. This loop interfaces with the sensor subsystem, Organic liquid fertilizer subsystem, and actuator system to gather water quality data in real-time and, if needed, implement corrective measures. The feedback loop is implemented in C++ for the Arduino IDE, making use of libraries specifically designed for these water quality sensors. Due to the absence of integrated serial communication in the sensors, digital pin connections are utilized. Arduino enables the development of code that is highly modular and object-oriented, facilitating easy debugging and future improvements.

Actuator System: The actuator system is responsible for implementing corrective actions in response to signals received from the feedback loop. This involves modifying the levels of Organic liquid fertilizer, aeration, and various other parameters.

Implementation of Machine Learning: The system incorporates a machine learning algorithm to enhance the utilization of Organic liquid fertilizer and the configuration of water quality parameters. The model is trained using both historical data and real-time data obtained from the Internet of Things (IoT) system. The algorithm utilizes current conditions and historical trends to forecast the optimal water quality parameters and the necessary dosage of Organic liquid fertilizer.

The system operates by utilizing an Arduino board, which acts as the program's controller and is equipped with multiple pin connections. The feedback loop is initiated by initializing all interconnected elements, which encompass the water quality sensors, Organic liquid fertilizer subsystem, and actuators. Following a prosperous initialization process, the loop consistently collects data from the water quality sensors, calculating the average of the measurements to ascertain the present water quality parameters.

When the measured levels drop below a desired threshold, the Arduino GPIO pins send a signal to the actuator system to carry out a corrective action. This action involves gradually modifying the concentration of the specified parameters and/or adding Organic liquid fertilizer, as advised by the machine learning algorithm. This iterative methodology guarantees that the system preserves its desired objectives while minimizing the possibility of excessive or insufficient saturation, as opposed to implementing significant and abrupt adjustments.

This sophisticated system utilizes IoT, Organic liquid fertilizer, and machine learning to enhance the monitoring and regulation of water quality in brackish water aquaponics systems. Its purpose is to optimize the growth of shrimp and plants by providing more accurate and precise control.

2.3. The Organic liquid fertilizer

In this research, organic liquid fertilizer based on compost tea combining goat, chicken, and cow manure was developed for use in a brackish water aquaponics system. A total of 3 kg of goat manure, 3 kg of chicken manure, and 5 kg of cow manure were mixed with 50 liters of water, then 200 grams of fermentation bacteria (EM4) were added to accelerate the fermentation process. This mixture was fermented for 2 weeks with regular stirring. After the initial fermentation, 7 liters of molasses and 8 kg of mashed banana stems were added, followed by further fermentation for 1 week. The fermentation results were then filtered and mixed with water until a total volume of 100 liters was reached. This liquid fertilizer was then diluted in a ratio of 1:20 before being applied to the aquaponics system.

The Organic liquid fertilizer was specifically developed for brackish water aquaponics systems, taking into account the specific nutritional needs of Vanamei shrimp as well as vegetables like melon, pumpkin, watermelon, and cucumber. The Organic liquid fertilizer composition comprises vital macronutrients and micronutrients. The procedure for incorporating Organic liquid fertilizer into the system involves:

- Calculating the ideal dosage based on the volume of water and the density of organisms' present.
- The frequency of addition is adjusted according to the growth stage.
- An automatic injection system is connected to IoT control.

2.4. Collection and Analysis of Data

The dataset was gathered over a six-month duration from three experimental tarpaulin ponds. Shrimp ponds and vegetable greenhouses, including melon, pumpkin, watermelon, and cucumber, were monitored daily to collect data. The dataset comprises 180 observations and 7 variables, namely pH, temperature, Dissolved Oxygen, salinity, nitrate concentration, Organic liquid fertilizer concentration, and shrimp and plants and fruits biomass.

2.5. Implementation of Machine Learning

Figure 2 presents a methodical representation of the dataset's analytical procedure. This carefully constructed pipeline captures the multimodal strategy used to create the IoT-based actuation and water quality regulation in aquaponic systems.

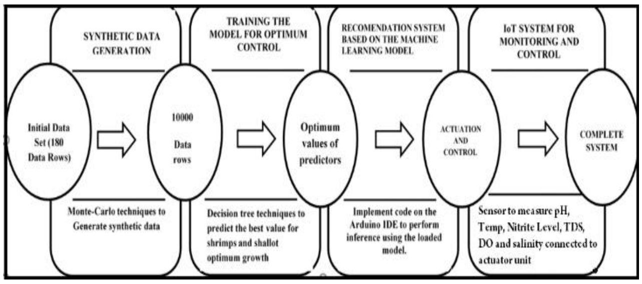

Fig. 2. The pipeline of regulating aquaponic environments.

Generation of Artificial Data

In order to enhance the dataset, a Monte-Carlo (MC) method is utilized to generate artificial data. This process involves determining a suitable probability distribution for each variable.

- Executing Monte Carlo simulations
- Preserving the observed associations between variables
- Validating the accuracy of the artificial dataset
- Combining the initial dataset consisting of 180 records with the synthetic data, resulting in a unified dataset containing 10,000 entries.

2.7. Analysis and Optimization of Systems

An extensive analysis was carried out to assess the efficiency of the optimized brackish water aquaponics system:

- Comparative analysis of shrimp and plant growth under optimized and non-optimized conditions - Assessment of the efficacy of incorporating Organic liquid fertilizer regulated by an intelligent system
- Evaluation of the efficiency in the utilization of water and nutrients

This approach facilitates the creation of a smart and effective aquaponics system for brackish water. It utilizes a combination of Organic liquid fertilizer, IoT technology, and machine learning to enhance the production of Vanamei shrimp and various vegetables including melon, pumpkin, watermelon, and cucumber.

2.6. Genetic Algorithm Regulatory Framework

In addition to this system, a Genetic Algorithm model based on machine learning is incorporated to control water quality parameters and the usage of Organic liquid fertilizer in brackish water aquaponics. Training the Genetic Algorithm model directly on Arduino is challenging due to the constrained computing and memory resources available on most Arduino boards. Thus, a two-step procedure is implemented, which entails utilizing a more advanced computer to execute the GA predictions and Arduino IDE for inference and control.

The optimization process enhances the growth of shrimp and various vegetables, including melon, pumpkin, watermelon, and cucumber, by integrating genetic algorithms and machine learning. The procedure for achieving ideal water quality parameters and optimal Organic liquid fertilizer utilization for the cultivation of shrimp and vegetables like melon, pumpkin, watermelon, and cucumber is outlined below:

1. Utilize Scikit-learn and DEAP, which are crucial Python libraries for machine learning and genetic algorithm optimization, by importing them.

2. Incorporate artificial datasets containing measurements of plant and shrimp growth, water quality attributes, and Organic liquid fertilizer utilization.

3. Analyze the dataset by isolating the desired outcome variables and input characteristics.

4. Divide the data into separate sets for training and testing purposes.

Utilize separate GA models to forecast the growth of shrimp and various vegetables, including melon, pumpkin, watermelon, and cucumber.

6. Assess the model's performance by calculating the mean squared error (MSE).

7. Set up the genetic algorithm using DEAP; define parameters such as population size, algorithm configurations, and optimization thresholds.

3. Result and Discussion

3.2. Preprocessing of data and generation of synthetic data

Before beginning the in-depth analysis, a preliminary phase of data refinement was carried out with great attention to detail. Following the completion of the initial phase, the dataset's dimensions and analytical capabilities were enhanced using synthetic data generation techniques within the relevant domain. Because all predictors have an inherent normal distribution, it was decided to avoid using standardization or normalization procedures. To generate synthetic data points, a meticulous process was carried out using Monte Carlo methods. The complex augmentation process concluded with the creation of a comprehensive dataset containing 10,000 observations. Because synthetic data generation and feature selection are computationally demanding, orchestration required a robust computational infrastructure. A computational computer cluster with two workstations, each with an Intel(R) Core(™) i7 processor and 32 GB of memory, was used to complete this complex analytical task.

3.3. Prototype of Water Quality Monitoring and Control System

In order to establish an Internet of Things (IoT) system for monitoring and controlling water quality in a brackish water shrimp aquaponics system, the entire system is divided into four essential components: The system consists of four components: (a) actuator system, (b) feedback loop, (c) sensor subsystem, and (d) Organic liquid fertilizer subsystem.

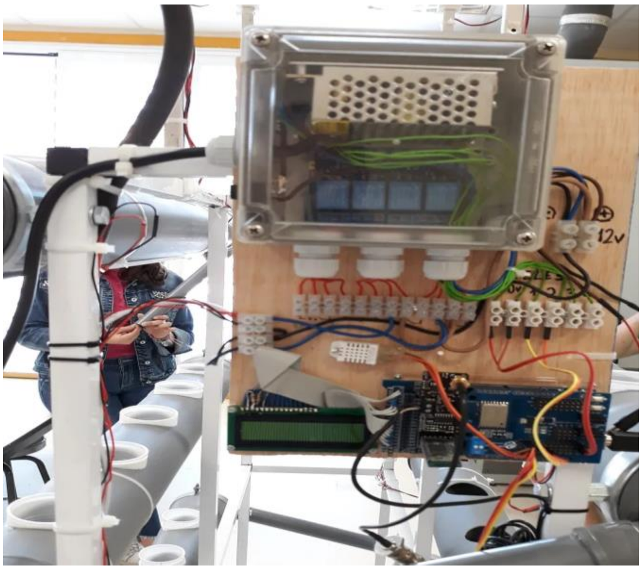

Fig. 3. Prototype of Water Quality Monitoring and Control System

The sensor subsystem comprises a diverse range of bespoke water quality sensors, encompassing measurements of salinity, pH, dissolved oxygen (DO), nitrite concentration, and temperature. Subsequently, the data is transmitted to an Arduino controller. Figure 3 displays the hardware configuration used to regulate water quality.

The Organic liquid fertilizer subsystem comprises a storage tank, a precision dosing pump, and a liquid level sensor. The primary function of this subsystem is to introduce Organic liquid fertilizer into the aquaponics system based on the requirements determined by the machine learning algorithm.

The feedback loop was adjusted to incorporate the supervision and regulation of Organic liquid fertilizer utilization. Furthermore, this loop not only assesses the current water quality parameters, but also monitors the nutrient levels in the system and adjusts the addition of Organic liquid fertilizer accordingly.

The actuator system was enhanced to incorporate components that regulate the introduction of Organic liquid fertilizer. This entailed integrating a precision dosing pump, which is regulated by a PIC microcontroller, to enable accurate and regulated dispensing of Organic liquid fertilizer into the aquaponics system.

3.4. Mechanism for Monitoring and Controlling Aquaponics

The combination of these diverse components leads to the development of a cutting-edge water quality regulation system based on the IoT and the optimization of Organic liquid fertilizer usage. The design, depicted in Figure 4, is characterized by its coherence and is composed of four primary subsystems, each playing a role in the overall functionality of the system.

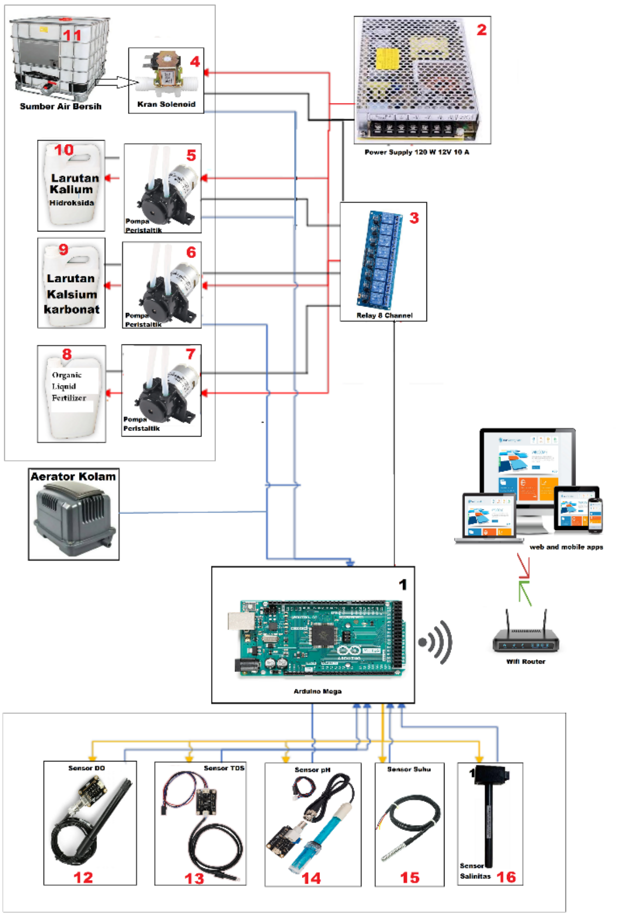

Fig. 4. Block Diagram of The Monitoring and Dispensing System

This optimized system not only monitors and regulates conventional water quality parameters, but also incorporates precise Organic liquid fertilizer management. The implemented machine learning algorithm examines data from all subsystems to make instantaneous determinations regarding water quality modifications and nutrient supplements. This enables the system to uphold ideal conditions for the growth of shrimp and plants in a brackish water aquaponic setting.

This comprehensive strategy integrates cutting-edge water quality monitoring, meticulous Organic liquid fertilizer control, and optimization based on machine learning to establish a remarkably efficient and productive aquaponic ecosystem. This system guarantees substantial enhancements in shrimp and plant production, while efficiently utilizing resources and reducing waste to a minimum.

In order to synchronize the findings of this study with recent research on the inclusion of Organic liquid fertilizer, I will make alterations to multiple sections. Here is the revised version:

3.5. Utilizing Genetic Algorithm for Data Prediction with Organic liquid fertilizer Integration

This section provides the findings and test results of a cutting-edge aquaponics water quality control system. The system is specifically designed to regulate the water quality for shrimp and plant cultivation in brackish water environments. This comprehensive system encompasses the monitoring and regulation of crucial water quality parameters, such as pH, temperature (Temp), salinity, nitrite, dissolved oxygen (DO), and Organic liquid fertilizer usage. The system incorporates sophisticated sensors, actuators, and Genetic Algorithm to enhance water quality and nutrient conditions, thereby promoting the ideal growth of shrimp and various vegetables, including melon, pumpkin, watermelon, and cucumber.

Table. 1. Summary of The Testing Result

Parameter	Measured Range	Desired Range	System Adjustment Method	Outcome
pH	7.3 - 8.6	7.5 - 8.5	Genetic Algorithm-based real-time adjustments	Maintained within desired range, optimal for shrimp and plants
Temp (°C)	25 - 29	23 - 32	Automated heating/cooling control	Consistent temperature regulation
Salinity (ppt)	6.0 - 11.8	8.0 - 10.0	Salinity sensor with GA-based control	Stable salinity, ideal for brackish water species
Nitrite (ppm)	0.05 - 0.12	< 0.1	Nitrite sensor with automated nutrient cycling	Nitrite levels kept safe for aquatic life
DO	6.5 - 7.7	6.8 - 7.5	Oxygenation system with real-time monitoring	Optimal oxygen levels maintained
OLF Dosage (ml/L)	1.5 - 3.0	Oct-15	GA-optimized nutrient dosing	Enhanced plant and shrimp growth

The primary component of the aquaponics system is dedicated to the surveillance of water quality parameters and nutrient levels. The sensors are strategically positioned to enable accurate sampling. The system functions by allowing the sensors a minimum duration of 30 minutes to collect data on the current concentration of parameters. The water quality parameter data is transmitted to the central control unit, Arduino Uno, through digital and analog pins.

July 2024 data as shown in Fig. 6 and Fig. 7, from this aquaponics monitoring system indicates that the system was efficiently managed and controlled throughout the month. In order to ensure optimal water quality, which is crucial for the health and growth of plants and shrimp in the aquaponics system, several factors such as temperature, nitrite levels, salinity, dissolved oxygen, and Organic liquid fertilizer dosage were carefully controlled and adjusted. The effectiveness of the monitoring and adjustment procedures can be determined by the achievement of intended ranges and the maintenance of consistent parameter control.

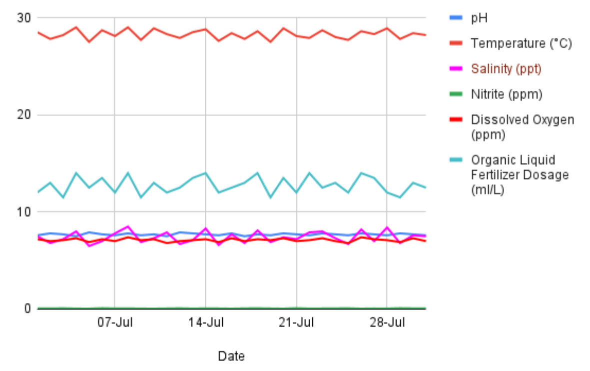

Fig. 6. The result of water quality parameters in the aquaponic

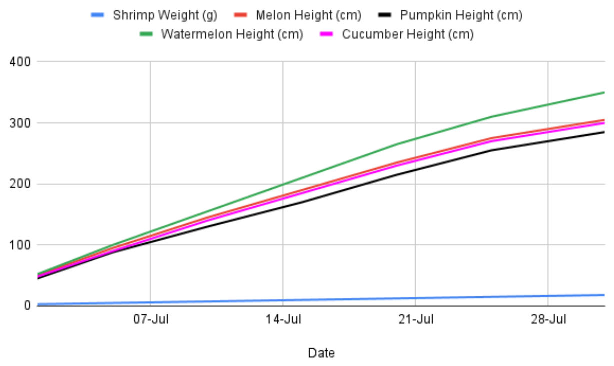

Fig. 7. The growth of the vanamei shrimps and plans in aquaponic setup

The results demonstrate the system's capacity to control water quality factors in a shrimp-vegetable aquaponics system, including cantaloupe, pumpkin, watermelon, and cucumber. This ensures that the aquaponic environment consistently maintains the desired parameter thresholds. After one month of testing, the aquaponics water quality regulation system proved to be a successful and advanced technique for optimizing shrimp aquaponics water quality parameters, with further enhancements achieved through Organic liquid fertilizer optimization.

The successful conclusion of testing provides evidence of the stability and precision of this innovative methodology. This highlights the capacity to merge the Internet of Things (IoT), Machine Learning, and nutrient optimization to create intelligent and sustainable solutions for aquaponics environments. This represents a notable progress in the realm of commercial agriculture.

3.6 Discussion

This study introduces a novel method for improving the efficiency of brackish water aquaponics systems by combining Internet of Things (IoT) technology, machine learning based on Genetic Algorithms, and precise nutrient management using Organic liquid fertilizer. The results demonstrate the substantial capability of this integrated approach to enhance the efficiency and productivity of brackish water aquaponics system.

Evaluation of the Efficiency of the Integrated System

This study successfully developed an intelligent system that is effective in maintaining optimal water quality parameters for the growth of Vanamei shrimp and various plants, including melon, pumpkin, watermelon, and cucumber. During a one-month testing period in July 2024, the system successfully maintained the desired pH (7.5-7.9), water temperature (27.5-29.0°C), nitrite (0.05-0.10 ppm), salinity (6.5-8.5 ppt), and dissolved oxygen (6.8-7.4 ppm). This achievement is consistent with the conclusion of Goddek et al. (2019), which emphasized the importance of proper management of water quality parameters in aquaponic systems [1].

Our implemented IoT and machine learning-based approach offers numerous advantages when compared to traditional aquaponics systems. The system's capacity to make immediate adaptations using sensor data and genetic algorithm predictions enables quicker and more precise responses to changes in water quality parameters. According to a study conducted by Jha et al. (2021), it was found that IoT-based systems have the potential to enhance water use efficiency by up to 30% in aquaculture applications [14].

Furthermore, the incorporation of Organic liquid fertilizer optimization through machine learning enables enhanced accuracy in nutrient management. The findings of our study demonstrate a consistent and significant enhancement in the growth of both plants and shrimp. This improvement can be attributed to the optimization of nutrient balance. This study expands upon the previous research conducted by Munirul Ula et al. (2023) regarding the significance of nutrient management in aquaponic systems [27].

Implications for Sustainable Aquaculture

The triumph of this system has noteworthy ramifications for the advancement of sustainable aquaculture, particularly in regions with restricted water resources. The system's capacity to uphold optimal water quality while efficiently utilizing water and nutrients aligns with global sustainability objectives. Moreover, this approach presents a promising resolution to the difficulties posed by climate change in the realm of food production. The system's capacity to acclimate to fluctuating environmental conditions by making real-time modifications can enhance the resilience of food production systems to climate variability.

4. Conclusion and Future Research

4.1. Conclusion

This study has successfully created an advanced system for brackish water aquaponics that combines Internet of Things (IoT) technology, machine learning using genetic algorithms, and precise nutrient management with organic liquid fertilizers. During a one-month testing period in July 2024, the system successfully maintained ideal water quality conditions for Vanamei shrimp and various plants, including melon, pumpkin, watermelon, and cucumber. The main parameters were effectively maintained within the specified ranges, namely pH 7.5-7.9, temperature 27.5-29.0°C, nitrite 0.05-0.10 ppm, salinity 6.5-8.5 ppt, and dissolved oxygen 6.8-7.4 ppm. The use of optimized organic liquid fertilizers (10-15 ml/L) with real-time adjustment resulted in significant improvements in plant and shrimp growth compared to conventional systems. The use of IoT and machine learning allows for faster and more accurate reactions to variations in water quality factors compared to traditional aquaponic systems. This system demonstrates improved efficiency in water quality and nutrient control in aquaponics systems, in line with global sustainability goals and provides a potential solution for food production in areas with limited water supplies. While the initial findings are promising, further research is needed to demonstrate the effectiveness of this system at a larger scale and over longer periods. In summary, this study demonstrates the capacity to improve the effectiveness and productivity of brackish water aquaponics systems by integrating IoT, machine learning, and nutrient optimization. These advances have the potential to promote sustainable food production and address issues related to food security and environmental sustainability.

4.2. Future Research

There are some future researches can be done in this feel:

- Large-scale and Long-term Validation: Testing this system on a larger scale and over a longer period of time to ensure consistency and sustainability of the results.
- Plant and Aquatic Species Diversification: Assessing the effectiveness of the system by testing various types of plants and other aquatic species to enhance the diversity and resilience of the aquaponic system.
- Algorithm Optimization and IoT Technology: Developing advanced machine learning algorithms and enhancing IoT technology for faster and more precise responses to environmental changes.
- Renewable Energy Integration: Involving renewable energy sources, such as solar panels, to make the system more self-sufficient and environmentally friendly.
- Economic and Social Analysis: Conducting a detailed cost-benefit analysis to determine the economic feasibility of this system, as well as studying the social impact of implementing this technology in various communities.

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Author contributions

Munirul Ula: Conceptualization, Methodology, Software, Field study. **Rizal Tjut Adek:** Data curation, Writing-Original draft preparation, Software, Validation., Field study **Bustami:** Visualization, Investigation. **Muliani:** Writing-Reviewing and Editing

Conflicts of interest

The authors declare no conflicts of interest.

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