International Journal on Perceptive and Cognitive Computing (IJPCC) Vol 10, Issue 2 (2024)
https://doi.org/10.31436/ijpcc.v10i2.479

Selective of IoT Applications for Water Quality Monitoring in Malaysia

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(Received: 29th May 2024; Accepted: 2nd June 2024; Published on-line: 30th July 2024)

Abstract— The aquaculture industry in Malaysia relies predominantly on Recirculating Aquaculture Systems (RAS), which are susceptible to infections, leading to disease outbreaks and significant economic repercussions. The frequent need for manual interventions makes RAS labor-intensive and inefficient. To address these challenges, this study advocates a shift towards disease prevention and proactive water quality management. The proactive approach entails modern water treatment methods, stringent biosecurity measures, and the integration of IoT (Internet of Things) technology to anticipate and prevent disease outbreaks. Our disease detection system utilizes real-time sensors, machine learning algorithms, and IoT technology to swiftly identify pathogen indicators. Simultaneously, the IoT-enabled water quality monitoring system consistently delivers crucial data, eliminating the need for on-site monitoring. The adoption of disease prevention and control strategies, including probiotics, vaccinations, and biosecurity measures, plays a pivotal role in fostering sustainable advancements within the aquaculture sector. By incorporating effective water quality management, optimizing fish stocking density, ensuring proper nutrition, adhering to hygienic practices, and deploying fish vaccines, with the aim to mitigate the occurrence of fish diseases, ultimately bolstering the resilience and sustainability of Malaysia's aquaculture industry. Overall, this paper proposes a comprehensive overview of IoT-based applications for water quality monitoring in Malaysia's aquaculture with the advancements in IoT technology and its potential impact on improving water quality management practices.

Keywords— Aquaculture, RAS, practices.

I. Introduction

The practice of aquaculture in Malaysia began in the 1920s, employing large polyculture in ex-mining pools with introduced Chinese carps like the bighead, silver, and grass carp [1]. Malaysian aquaculture includes both food and non-food sectors, such as brackish water fish, freshwater fish, seaweed, decorative fish, and aquatic plants. In 2019, Malaysia's fisheries industry contributed about 1.1% to global output, with aquaculture accounting for 0.4% [2]. Recognized as essential for food security in the Seventh Malaysia Plan (1996-2000) and a catalyst for economic growth in the Eighth Malaysia Plan (2001-2005) [1], the industry faces high land costs, feed, labor, and pollution challenges, with land costs posing the most significant obstacle [2].

The fisheries sector is currently confronted with environmental challenges, particularly in relation to water pollution, despite its significant role in driving the country's economic development [3]. The release of untreated effluent from aquaculture ponds into the surrounding environment has the potential to result in water contamination, hence contributing to the deterioration of aquatic ecosystems [4]. Fortunately, the Malaysian government has implemented several policies and plans to address those issues including:

1. National Agrofood Policy 2021-2030 (NAP 2.0): This policy aims to ensure adequate food safety and security, increase the contribution of the agro-food industry, empower human capital, and promote sustainable agriculture [5].
2. Malaysian Aquaculture Farm Certification Scheme (SPLAM): This certification scheme is

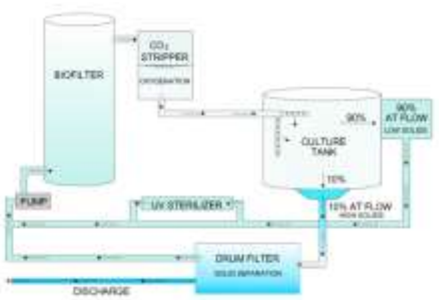

Fig. 1. Recirculating Aquaculture System Components showing the path water takes through major components within one type of a recirculating system [15]

https://doi.org/10.31436/ijpcc.v10i2.479

aimed at promoting sustainable aquaculture practices in Malaysia. It covers areas such as environmental management, animal health, and welfare, and food safety [4].

3. **Good Aquaculture Practices (GAqP)**: This initiative aims to promote sustainable aquaculture practices among Malaysian aquaculture farmers. It covers areas such as site selection, water quality management, and disease control [4].

4. **Technical support services and good regulatory frameworks**: The government provides technical support services and good regulatory frameworks for the industry [4].

5. **Aquaculture Master Plan**: This plan aims to promote the development of the aquaculture industry in Malaysia. It covers areas such as research and development, infrastructure development, and marketing [4].

6. **Effective governance:** Effective governance of modern aquaculture must reconcile ecological and human well-being so that the industry is sustainable over time. The government has implemented policies and plans to ensure effective governance of the aquaculture industry in Malaysia [6].

One solution to the challenges of high land cost and environmental pollution in the aquaculture industry in Malaysia is the use of Recirculating Aquaculture Systems (RAS). RAS is a technology that allows for the efficient use of water and reduces the environmental impact of aquaculture. The system works by recirculating water through a closed system, which reduces the amount of water needed for aquaculture production. RAS also allows for the efficient removal of waste products, which reduces the environmental impact of aquaculture. Figure 1 shows RAS water flow schematic.

Yet RAS offer several advantages, there are also some challenges associated with its use for instance:

1. Poor designs of the systems: Many RAS systems have been modified after a previous approach was unsuitable, leading to poor designs [7].

2. High investment costs: RAS technology is expensive to set up, and the recirculation technology consumes vast amounts of energy, which can be costly [8].

3. Vulnerable to disease: Parasites with direct life cycles are more common and dangerous in an RAS, because RASs used in production tend to have greater fish densities and by definition recycle water, which results in closer fish-to-fish contact and greater buildup of parasite numbers within the system. Once a parasite infects a fish within an RAS, it becomes magnified, and disease can spread rapidly [9].

It can be seen that water quality management is very important in RAS frameworks. The quality of water directly affects the health and well-being of the aquatic organisms being cultivated. Fish, shrimp, and other species are highly sensitive to changes in water parameters such as temperature, pH, dissolved oxygen levels, and ammonia concentration. Maintaining optimal water quality ensures that these organisms thrive, grow, and remain disease-free. Water quality management can be conducted at aquaculture ponds or water tanks by monitoring their inlet water quality, performing on-site monitoring and using biofiltration systems to manage ammonia and nitrite levels in RAS. Monitoring water quality is a continuous process that must adapt to changing conditions. Seasonal variations, weather events, and industrial activities can significantly influence water quality. Timely monitoring and data analysis are essential for early detection of contamination, ensuring the safety of water supplies, and taking appropriate remedial actions. Therefore, determining the optimal frequency and timing of water quality assessments is a critical aspect of effective management.

Integrating the Internet of Things (IoT) with RAS can enhance efficiency and sustainability. IoT sensors provide real-time data on water quality, temperature, and oxygen levels, enabling farmers to monitor and adjust conditions promptly [10, 11].

Section 1 introduces the enhancement of aquaculture practices in Malaysia through RAS and IoT and outlines related work on water quality, environmental factors, IoT technology, and disease prevention as well as the details objectives related to RAS operational efficiency, framework development, and substantiation of RAS efficacy as a sustainable methodology. Section 2 describes the research methodology, Section 3 shows the practical applications and real-world benefits, and Section 4 presents the results. Section 5 includes a Gantt chart of milestones, and Section 6 summarizes and concludes the work.

1.1 RELATED WORK

In this section, a set of questions that drive the investigation into the challenges and possibilities within Malaysia's aquaculture industry. These questions touch on vital topics, such as water quality, environmental factors, IoT technology, and disease prevention. By exploring these questions, the aim is to uncover practical insights and solutions to improve and sustain aquaculture practices in Malaysia.

A. Optimal Water Quality Parameters

What are the species-specific optimal water quality parameters for different aquaculture organisms in Malaysia, and how do these parameters vary across different stages of growth?

B. Impact of Environmental Factors

How do environmental factors, such as climate change and seasonal variations, affect water quality in aquaculture systems in Malaysia, and what strategies can be employed to mitigate these impacts?

C. Optimal Water Quality Parameters

What are the species-specific optimal water quality parameters for different aquaculture organisms in Malaysia, and how do these parameters vary across different stages of growth?

D. Optimal Water Quality Parameters

How can the integration of Internet of Things (IoT) technology enhance water quality management in Malaysian aquaculture, and what are the economic and environmental benefits of such integration?

1.2 Objective

In this study, there are a few specific goals to tackle the problems in the aquaculture industry, especially in how Recirculating Aquaculture Systems (RAS) are used in Malaysia. These objectives aim to investigate, develop solutions, and confirm improvements that can make RAS more efficient, resilient to diseases, and sustainable. Together, these objectives help to work towards improving aquaculture practices in Malaysia as such:

A. To investigate Operational Efficiency and Susceptibility of Recirculating Aquaculture Systems (RAS)

The first objective of this study is to conduct a comprehensive investigation into the operational efficiency and susceptibility of Recirculating Aquaculture Systems (RAS) within the Malaysian aquaculture industry. As previously stated, Malaysia's aquaculture sector heavily relies on RAS as a method of cultivating aquatic species [12]. However, the inherent sensitivity of RAS to diseases and other operational challenges has raised concerns regarding its efficiency and sustainability [13].

B. To Develop a Comprehensive Framework to Address RAS Weaknesses and Enhance Operational Efficiency

Building upon the identified vulnerabilities and inefficiencies, the second objective is to develop a robust framework designed to counter these weaknesses and elevate the operational efficiency of RAS. It is necessary to shift from reactive disease management to proactive disease prevention and water quality control.

This objective seeks to address this need by proposing innovative strategies and solutions. It aims to design a comprehensive system that not only mitigates the identified vulnerabilities but also optimizes resource utilization within the aquaculture facilities. This aligns closely with the solution proposed in the abstract, where advanced water treatment processes and stringent biosecurity measures are recommended to prevent disease outbreaks and enhance overall efficiency.

C. To Substantiating the Enhanced Efficacy of RAS as a Sustainable Aquaculture Methodology

The final objective is to empirically validate the effectiveness of the proposed enhancements to the RAS methodology. The objective is to demonstrate that the improved RAS approach is more operationally efficient, economically viable, and sustainable compared to its current state [14].

To achieve this, rigorous experimentation and in-depth data analysis will be undertaken. This process aims to provide substantial evidence supporting the benefits of the proposed modifications, reinforcing the idea that RAS can indeed serve as a more efficient and resilient method for sustainable aquaculture in Malaysia.

II. Research Methodology

This section touches on the detailed methodology employed in this research endeavor. Figure 2 provides an insightful flowchart that visualizes the step-by-step approach guiding this investigation. This methodology encompasses a multifaceted strategy designed to comprehensively address our research objectives and culminate in meaningful outcomes.

Month 2-4: Work Initiation and Planning

- Define research objectives, questions, and scope.
- Develop a detailed research proposal.
- Identify research team members and assign roles.
- Secure necessary approvals and funding.

Month 6-8: Literature Review and Data Collection

- Conduct an extensive literature review.
- Collect historical data on disease outbreaks in Malaysian aquaculture systems.
- Gather information on water quality parameters during outbreaks.
- Compile data on aquaculture species, stocking density, and environmental factors during outbreaks.

Month 10-12: Data Analysis and Protocol Development

- Analyze historical data to identify patterns and correlations.
- Identify critical factors contributing to disease susceptibility.
- Determine optimal water quality parameters for different aquaculture species.
- Consult with experts and stakeholders to refine protocols.

Month 14-16: Protocol Implementation and Monitoring

- Implement water quality management protocols in selected aquaculture systems.
- Set up on-site testing equipment and IoT technology.
- Establish a routine for proactive monitoring and data collection.

Month 18-20: Response and Mitigation

- Respond to parameter deviations by initiating corrective actions.

- Implement disease prevention measures (biosecurity, vaccination, probiotics).
- Monitor the effectiveness of these measures.

Month 22-24: Data Analysis, Reporting and Conclusion
- Analyze data collected over the research period.
- Evaluate trends and the effectiveness of disease prevention measures.
- Adjust protocols and strategies as necessary.
- Prepare research paper, including abstract, introduction, methodology, results, discussion, and conclusion.
- Complete final revisions, proofreading, and formatting.

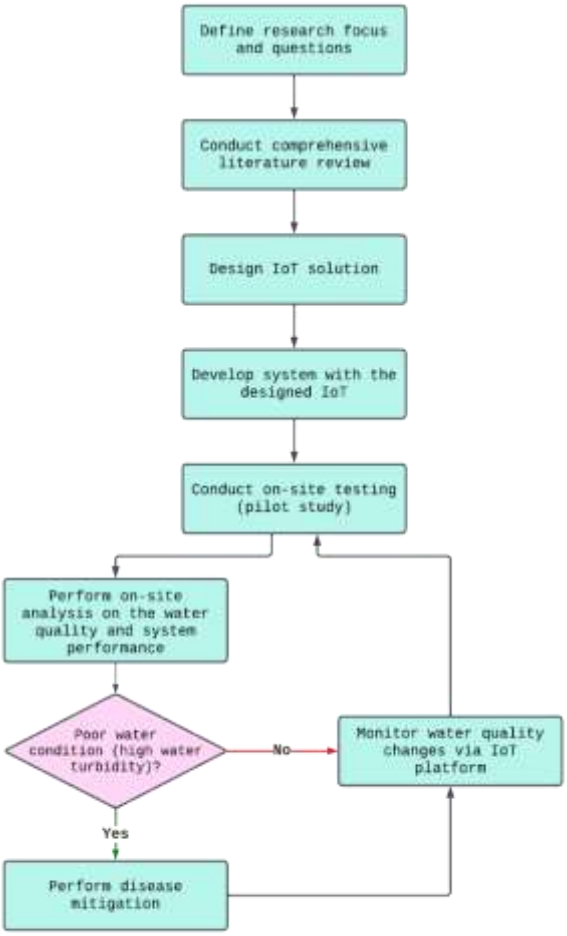

Fig. 2. IoT-integrated aquaculture solution flow

2.1 Description of Methodology

A. *Table Captions*

At an early phase, a comprehensive literature review needs to be conducted. In aquaculture, there are numbers of parameters that should be concerned which can affect the water quality. The variation of water quality parameters across different stages of growth can affect the behaviour, physiology, and cell biology of aquatic organisms [15]. But these three parameters are chosen to be enough for controlling water quality and inexpensive to be applied [16].

TABLE I
WATER QUALITY PARAMETERS

Parameters	Factors that can affect the parameter	Optimal water condition
pH	CO_2 concentration Organic materials	pH 6.5 - pH 8.5
Temperature	Solar radiation Climate Aquaculture system design (eg. exposed piping)	Coldwater species: Coldwater species such as trout and salmon prefer water temperatures between 10-18°C [17] Warmwater species: Warmwater species such as catfish, carp, and tilapia thrive in water temperatures between 22-32°C [17] Tropical species: Tropical species such as shrimp prefer water temperatures between 26-30°C [18] Hard clams: Hard clams prefer water temperatures between 16-27°C [19]
Turbidity	Small floating organisms suspended in the water column (e.g. plankton, algae, cyanobacteria) Pelleted food	Intense culture systems: In intense culture systems such as recirculation systems, it is recommended that suspended solids levels should not go above 15 mg/l (dry weight) [18] Aquaculture systems: The amount of total suspended solids (TSS) in aquaculture systems determines the level of mineral turbidity. If there is less than 25 TSS (mg/l), the mineral turbidity is considered low. The mineral turbidity is medium if it falls between 25-100 TSS (mg/l) [20]

B. *Impact of Environmental Factors*

Obviously, Environmental pollution can affect water quality in aquaculture systems. Malaysian coastal waters are mainly contaminated with oil and grease, faecal matter, and other

https://doi.org/10.31436/ijpcc.v10i2.479

pollutants [21]. The presence of pollutants can affect the health and growth of aquatic organisms, as well as the quality of aquaculture products [21-23]. Climate change can also affect water availability, with changes in precipitation patterns and water flow affecting the amount of water available for aquaculture operations [24].

There are several strategies that can be applied to mitigate environmental impacts in aquaculture. These strategies include:

- Farm design and layout: The design and layout of aquaculture systems can also affect environmental impacts. Factors to consider include the use of recirculating systems, the use of appropriate cage design and orientation, and the control of stocking densities [25]–[27].
- Feeding practices: Managing feeding practices can help to reduce pollution and improve water quality. Overfeeding can lead to excessive waste and pollution, while underfeeding can lead to poor growth rates and weakened immune systems in farmed fish [26].
- Reducing chemical use: Minimizing the use of chemicals and veterinary drugs can help to reduce environmental impacts. Natural alternatives can be used to control diseases and parasites, and careful monitoring can help to prevent the overuse of chemicals [26], [27].

C. *IoT Integration*

Assessing environmental impacts: Assessing the environmental impacts of aquaculture operations can help to identify potential issues and develop appropriate mitigation strategies (see Figure 3 to 6). This can include monitoring water quality, assessing the cumulative impacts of multiple aquaculture farms, and seeking professional advice [25], [28].


Fig. 3. pH Sensor


Fig. 4. Temperature Sensor


Fig. 5. Turbidity Sensor

Moreover, IoT-based systems can collect and analyse large amounts of data on water quality parameters, allowing for more accurate and precise monitoring of water quality. There are many IoT platforms available on the Internet which enable users to monitor and analyse data from IoT sensors remotely like Blynk. Blynk is a comprehensive software suite that enables the prototyping, deployment, and remote management of connected electronic devices at any scale [29]. The integration of IoT technology in water quality management in aquaculture can provide both economic and environmental benefits:

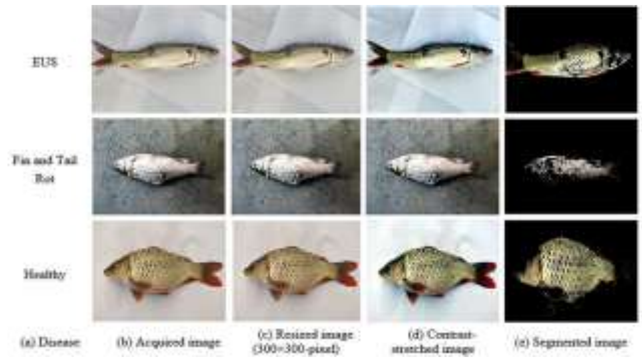

Fig. 6. Classification using multi-SVM's [36]

i. Economic

- Increase in productivity: IoT-based systems can provide aquaculture operators with more accurate and timely information on water quality, allowing for better decision-making and improved management of aquaculture operations [30]–[32]
- Cost savings: IoT-based systems can reduce the need for manual labour and improve efficiency, leading to cost savings for aquaculture operators [32], [33].

ii. Environmental

- Reduced environmental footprint: IoT-based systems can help to reduce the environmental footprint of aquaculture operations by improving water quality management and reducing pollution.

https://doi.org/10.31436/ijpcc.v10i2.479

- Improved sustainability: IoT-based systems can help to improve the sustainability of aquaculture operations by reducing waste and improving resource management [34].

D. *Disease Prevention*

Disease prevention in Malaysia aquaculture is designed to reduce the incidence of diseases and enhance the overall health and sustainability of aquaculture systems. The methodology spans several key phases over the course of the work, aiming to proactively manage water quality parameters and mitigate disease outbreaks.

- **Species-Specific Monitoring:** The early disease detection system is tailored to the specific aquaculture species being cultivated. As seen in Figure 6, different species have varying sensitivities to changes in water quality [35], [36]. Species-specific parameter ranges are defined, ensuring that the system's alerts are customized to the needs and vulnerabilities of the aquatic organisms in question.
- **Internet of Things (IoT) Connectivity:** A robust IoT infrastructure that facilitates the seamless transmission of sensor data to a central monitoring platform is established [37]. Its connectivity allows for remote monitoring and
- **Early Warning Signs and Biomarkers:** The monitoring of early warning signs, such as abrupt shifts in temperature, pH, or dissolved oxygen levels, which are often associated with disease onset are prioritized [38]. The integration of disease-specific biomarkers or genetic markers that can be detected through molecular techniques, providing precise and early indications of disease presence.

2.2 Detailed Implementation Framework

A. Adopting Disease Prevention Methods and Advanced Water Quality Management Practices

To effectively adopt disease prevention methods and advanced water quality management practices in Malaysian aquaculture, the following step-by-step framework is recommended for industry stakeholders:

i. Assessment of Current Practices:
- Conduct a thorough evaluation of existing disease prevention and water quality management practices in the facility.
- Identify gaps and areas for improvement in current methodologies.

ii. Selection of Appropriate Technologies:
- Choose suitable IoT sensors and water treatment technologies based on the specific needs of the aquaculture operation.
- Consider factors such as farm size, species cultivated, and local environmental conditions.

iii. Integration of IoT Technologies:
- Install IoT sensors to monitor key water quality parameters such as temperature, pH, dissolved oxygen, and ammonia levels.
- Ensure real-time data transmission to a centralized monitoring system for continuous oversight.

iv. Implementation of Disease Prevention Protocols:
- Develop and implement standard operating procedures (SOPs) for disease prevention, including regular health checks, vaccination programs, and biosecurity measures.
- Utilize IoT data to predict and prevent outbreaks by identifying early warning signs of disease.

v. Training and Capacity Building:
- Provide comprehensive training for staff on the use of IoT technologies and new water management practices.
- Conduct regular workshops and refresher courses to keep the workforce updated on the latest advancements and protocols.

vi. Continuous Monitoring and Evaluation:
- Establish a continuous monitoring system to track the effectiveness of implemented practices.
- Use collected data to make informed decisions and adjustments to enhance the overall efficiency of the aquaculture operation.

III. Practical Applications and Real-World Benefits

Incorporating advanced technologies such as IoT and RAS in Malaysian aquaculture offers numerous practical applications and real-world benefits, enhancing both efficiency and sustainability.

3.1 Enhancing Aquaculture Efficiency and Sustainability

i. Increased Productivity

Implementing IoT technologies allows for increased productivity by enabling precise monitoring and control of water quality parameters, ensuring optimal conditions for aquaculture. This real-time data facilitates immediate corrective actions, significantly reducing the risk of crop losses due to poor water conditions or disease outbreaks.

ii. Cost-Effective Management

Advanced water quality management practices reduce the need for frequent water changes and chemical treatments, leading to cost savings. Automated monitoring systems further decrease labour costs by reducing the necessity for manual checks.

iii. Improve Fish Health and Yield

Healthier fish populations and higher yields are achieved through early detection and prevention of diseases, made

https://doi.org/10.31436/ijpcc.v10i2.479

possible by IoT sensors. This proactive water quality management results in optimal growth conditions, enhancing the overall quality and market value of the produce.

iv. Sustainability and Environmental Protection

Additionally, adopting RAS and IoT technologies minimizes water usage and waste discharge, contributing to environmental sustainability. Effective governance and adherence to sustainable practices reduce the ecological footprint of aquaculture operations, ensuring long-term viability and environmental protection.

IV. Presentation of the Results

This research work holds substantial significance for the Malaysian Aquaculture sector. These worked outcomes represent pivotal advancements and benefits for the industry, fostering a more efficient, sustainable and environmentally conscious framework such as:

E. *Enhanced Water Quality Management Practices*

The research efforts outlined in this study, encompassing the exploration of optimal water quality parameters and strategies to mitigate environmental impacts, are assured to achieve improved water quality management practices within Malaysian aquaculture systems. The practical implementation of contemporary water treatment methodologies and proactive water quality oversight is anticipated to elevate overall water conditions in these systems.

F. *Increase Operational Efficiency and Effectiveness*

The integration of IoT technology into aquaculture operation is expected to boost the efficiency and effectiveness of water quality management significantly. By providing real-time data and facilitating swift responses to any changes from optimal conditions, IoT technology has the potential to streamline operations and minimize resource wastage, thus optimizing the use of water resources.

G. *Reduced Disease Outbreaks*

One of the paramount objectives of this research is to tailor water quality management practices for disease prevention. Consequently, a reduction in the incidence of disease outbreaks within Malaysian aquaculture systems is a expected outcome. The proactive measures recommended, including stringent biosecurity measures and the early disease detection system, are designed to pre-empt pathogen proliferation, thereby minimizing losses attributed to disease-related incidents.

H. *Economic and Environmental Sustainability*

The adoption of best practices in water quality management is anticipated to bolster both economic and environmental sustainability within Malaysian aquaculture. By optimizing resource utilization and reducing disease-related losses, aquaculture businesses can expect improved profitability and productivity. Simultaneously, the implementation of sustainable practices and the reduction of environmental impacts contribute to a more environmentally friendly industry.

I. *Reinforcement of RAS with IoT*

The integration of IoT technology is poised to bolster the capabilities of Recirculating Aquaculture Systems (RAS). By providing real-time insights into water quality parameters and facilitating immediate responses, IoT technology is set to empower RAS, rendering it more resilient and adaptable to dynamic conditions. This technological fortification holds the potential to transform RAS into a more robust and resource-efficient aquaculture method.

Through the implementation of proactive disease prevention strategies, the seamless integration of IoT technology, and the optimization of water quality management practices, the sector stands to reap the benefits of heightened productivity, profitability, and sustainability. These outcomes collectively contribute to the cultivation of a more prosperous, resilient, and ecologically attuned aquaculture industry that harmonizes with the evolving demands and expectations of the nation.

V. Milestone and Gantt Chart

Phase 1: System Setup and Data Collection

In this initial phase, the focus is on establishing the foundation of the early disease detection system. Key activities include the deployment of specialized sensors designed to monitor critical water quality parameters in selected aquaculture systems. These sensors are strategically placed to ensure comprehensive coverage. Simultaneously, the team acquires and configures data analysis software and tools, laying the groundwork for data processing and interpretation. To facilitate effective operation, research personnel undergo thorough training in sensor operation and data collection techniques. A crucial aspect of this phase is the allocation of the initial budget, which covers sensor procurement, installation, and other essential setup expenses. Additionally, preliminary data collection begins, serving as the baseline for subsequent monitoring and analysis.

Phase 2: System Implementation and Monitoring

With the infrastructure in place, Phase 2 focuses on the full-scale implementation and continuous monitoring of the early disease detection system. Sensors, deployed across aquaculture sites, provide real-time data on water quality parameters. This continuous data stream is subject to real-time analysis, enabling the rapid identification of any deviations from optimal conditions that could signal early disease indicators. To enhance data transmission and accessibility, an Internet of Things (IoT) infrastructure is developed and seamlessly integrated into the system. Ongoing budget allocation ensures sensor maintenance, data storage, and any necessary adjustments. A critical milestone is the implementation of a real-time alert system, enabling immediate notifications to aquaculture personnel when potential disease indicators are detected. This phase also involves the establishment of response protocols, outlining the actions to be taken in the event of an alert, such as isolation measures and disease mitigation efforts.

Phase 3: Evaluation and Optimization

In the final phase, the research work shifts its focus to evaluation and optimization. Extensive data analysis is conducted, delving into the collected data to refine algorithms and enhance the system's accuracy in detecting early disease indicators. Simultaneously, the response protocols are continually assessed and improved to ensure efficient and effective actions in response to alerts. A critical aspect of this phase is reporting, where research findings are compiled and synthesized into a comprehensive research report. Budget allocation for final evaluations, reporting, and dissemination is essential to ensure the work's outcomes reach relevant stakeholders. The research work also emphasizes a commitment to continuous improvement, maintaining an open dialogue with industry stakeholders to refine the system based on evaluation results and emerging disease patterns.

VI. Conclusion

In conclusion, the imperative for a more efficient, sustainable, and resilient aquaculture industry in Malaysia necessitates the concerted embrace of disease prevention, advanced water quality management, and cutting-edge technologies such as RAS. These concerted efforts bear the potential to significantly contribute to the realms of food security, economic prosperity, and environmental preservation. It suggests a focused approach to exploring specific IoT applications tailored for water quality monitoring in Malaysian aquaculture settings. Furthermore, it underscores the importance of customization and adaptation of IoT solutions to suit the unique needs and challenges of Malaysian aquaculture.

Acknowledgement

AgriNXT, a collaborative initiative involving the Malaysian Communications and Multimedia Commission (MCMC), the Ministry of Agricultural and Food Security, and Bioeconomy Corporation, serves as a platform for young innovators to present their ideas in agricultural technology. This competition seeks to foster innovation and address challenges within the agricultural sector. In the highly anticipated AgriNXT competition 2023, a team of ambitious and creative students from the Department of Computer Science, Kulliyyah of Information Communication and Technology, IIUM, showcased their talent and emerged victorious on 28 December 2023, with their innovative solutions to real-world agricultural challenges.

Conflict of Interest

The authors declare that there is no conflict of interest

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