Implementing IoT-Based Water Quality Monitoring for Enhanced Cultivation Practices: I-AQUAS Aquaculture

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Abstract

Aquaculture plays a vital role in global food security, necessitating advanced methodologies for water quality monitoring to ensure the sustainable and healthy growth of aquatic organisms. Conventional monitoring methods have proven labour-intensive, time-consuming, and lacking real-time data acquisition. To address these challenges, our research integrates popular IoT platforms, such as ThingSpeak, along with Virtuino, Arduino, and an array of sensors measuring temperature, dissolved oxygen (DO), pH, salinity, and ammonia levels. This comprehensive sensor array provides a thorough overview of the aquatic environment. By harnessing IoT technology, our system enables continuous and remote monitoring, offering real-time data access via the internet. This not only reduces the need for physical presence but also allows for immediate responses to deviations from optimal water quality parameters. The integration of IoT technology significantly enhances the reliability and accuracy of water quality measurements, achieving over 89% accuracy. The implementation of this IoT-based system presents a groundbreaking approach to aquaculture water quality management, providing a sustainable solution that promotes the well-being of aquatic organisms and supports the growth of the aquaculture industry. This research offers a practical and implementable solution to overcome the shortcomings of traditional monitoring methods. This technological framework aligns with the demands of modern aquaculture, contributing to the ongoing discourse on sustainable aquaculture practices.

Keywords: IoT, Water Quality, Real-Time Monitoring, Aquaculture, Sea Bass

INTRODUCTION

The Asian Sea bass, also known as the barramundi or giant perch, commands widespread popularity as a culinary delicacy in numerous Southeast Asian countries, with Malaysia being a notable enthusiast (Idris et al., 2022). As a perciform fish species indigenous to the rivers and estuaries of Southeast Asia, it has evolved into a globally significant aquaculture commodity, cherished for its exquisite white flesh. Renowned for its culinary versatility, the Asian sea bass can be masterfully prepared through grilling, baking, frying, and steaming, earning it a distinguished place as the centrepiece in seafood restaurants and a preferred choice for both home cooking and catering.

Its nutritional richness and high demand have propelled its economic value, rendering it comparatively more expensive than other fish species. Furthermore, its rapid growth and adaptability to various environments contribute to its appeal. However, despite these desirable attributes, a precipitous decline in production surfaced in 2019, with reports indicating a staggering over 50% reduction in the total annual yield (Insivitawati et al., 2022). The primary culprit identified was the inconsistency in water quality and the use of outdated traditional management techniques, leading to a significant downturn in production. The accumulation of contaminants, a byproduct of the traditional treatment method, exposed the fish to diseases, stunted growth, and elevated mortality rates, reflecting the dire state of sea bass production in 2019. The indiscriminate discharge of contaminated wastewater into the environment posed a severe threat, potentially leading to environmental degradation and the depletion of water oxygen levels, further underscoring the urgency of timely water quality monitoring and management (Tom et al., 2021).

Recognizing the pivotal role of water quality in the success of the aquaculture sector, particularly in a fish tank, becomes apparent (Chiu et al., 2022). Factors such as water temperature, pH levels, ammonia concentration, dissolved oxygen, and salinity significantly impact the health and productivity of fish. Maintaining optimal conditions is crucial, as deviations can lead to stress, disease, and reduced productivity (Taha et al., 2022).

The conventional method of monitoring water quality relies heavily on manual labour, often resulting in inconsistent measurements due to staffing issues and timing irregularities (Tsai et al., 2022). Untimely and inadequate management exacerbates the spread of diseases among fish. Hence, a pressing need exists for a more efficient and timely system to monitor water quality, ensuring anticipated higher productivity and effective management. In this context, the integration of technology, such as the Internet of Things (IoT), emerges as a pertinent solution. Leveraging IoT enables continuous monitoring of water quality parameters, minimizing losses, mitigating disease risks, and averting eutrophication (Danh et al., 2020; Taha et al., 2022).

While previous studies have applied IoT for water quality monitoring in fish farming, comprehensive approaches that encompass all crucial parameters, including salinity and ammonia, remain limited. Against this backdrop, an interactive IoT water quality system has been developed for monitoring pH, dissolved oxygen (DO), temperature, ammonia, and salinity in aquaculture water (seabass fish). Utilizing cost-effective sensors, this system aims to empower aqua farmers with real-time information, guiding them in maintaining optimal conditions for Asian seabass cultivation.

In response to these challenges, our project takes a proactive stance by introducing an interactive Internet of Things (IoT) water quality system specifically tailored for sea bass cultivation. By employing low-cost sensors and leveraging IoT technology, this system aims to empower aqua farmers with real-time data, enhancing their ability to monitor and manage critical parameters such as pH, dissolved oxygen, temperature, ammonia, and salinity. This holistic approach not only addresses the challenges faced by traditional aquaculture methods but also contributes to the sustainable development of aquaculture in Nigeria, fostering economic growth and ensuring the production of high-quality seafood for local and regional consumption.

METHODOLOGY

Project Location

This initiative was conceived and implemented within the parameters of the Sea Bass tank at the Fish Hatchery International Institute of Aquaculture and Aquatic Sciences (I-AQUAS). Notably, the project's design allows for its potential implementation in diverse contexts, including regions like Nigeria. The project was executed in three stages: required devices and software used, IoT development and IoT performance validation.

Devices and Software

Table 1 details the devices and sensors incorporated into this project, chosen meticulously to ensure seamless integration and optimal performance. The selection was made with a focus on key parameters, namely pH, dissolved oxygen (DO), and electrical conductivity (EC) sensors. These components were specifically chosen for their compatibility with the Arduino microcontroller, aligning with the manufacturer's specifications.

The pH sensor, as the name suggests, provides real-time measurements of acidity-alkalinity, while the DO sensor gauges dissolved oxygen levels. Simultaneously, the EC sensor contributes by detecting salinity levels in real time. This deliberate selection ensures that each sensor harmoniously interfaces with the Arduino microcontroller, facilitating efficient data acquisition and processing.

Furthermore, to house the IoT circuits and sensors, a compartment was constructed using 3 mm thick acrylic material. This design choice guarantees the durability and structural integrity of the enclosure, providing a robust environment for the proper functioning of the IoT components within the system.

Table 1. Sensors and Devices Specifications

Sensors/Device	Manufacturer	Specification
Arduino Uno R2	Arduino	Input Voltage 7-12V
pH Sensor (SKU SEN0161)	DF Robot	Range: 0 to 14; Temperature 5 to 60°C
Temperature Sensor (DS18B20)	DF Robot	Waterproof + stainless steel, -55°C to+125°C
DO Sensor Kit (SKU SEN0237)	DF Robot	Detection Range: 0 to 20 mg/L
Salinity sensor (SKU DFR0300)	DF Robot	Detection Range: 0 to 20 ms/cm
Ammonia Gas Sensor MQ-137 (MQ137)	Hanwei Electronic Co. Ltd	Detection Range: 5 to 500 ppm
WIFI module (ESP 8266)	Spark Fun	ESP 8266 Wi-Fi connectivity
DS3231 RTC Module (IIC / I2C)	OEM	AT24C32 32Kbit Serial I2C

IoT Development

Sensors calibration

The Internet of Things (IoT)-based water quality monitoring system designed for Asian sea bass utilizes small, embedded devices, specifically Arduino microcontrollers, alongside multiple water quality sensors and Wi-Fi modules. Prior to integrating the various water quality sensors into the microprocessor, a crucial step involves calibrating each sensor to enhance performance, ensure accuracy, and establish monitoring threshold limits suitable for Asian Sea Bass cultivation. The calibration process adhered to the guidelines provided by the respective sensor manufacturers.

The pH sensor underwent calibration using different buffer solutions, dissolved oxygen levels were calibrated through a single-point calibration method, and the electrical conductivity sensor (measuring salinity) was calibrated using a two-point calibration approach. Subsequently, the determined threshold range limit for Asian Sea Bass farming was established, drawing insights from prior studies to ensure optimal conditions for cultivation.

Setting monitoring threshold

The Asian Sea bass is a warm-water species that thrives within a temperature range of 18°C to 29°C (Idris et al., 2022). It is evident that the ambient temperature significantly impacts the internal body temperature of the fish, establishing it as a critical parameter requiring continuous monitoring. Furthermore, maintaining the pH within a specific range is essential. Episodic fluctuations in pH can impede the growth of the Asian sea bass and make them susceptible to diseases (Tsai et al., 2022). The recommended pH level for optimal cultivation of Asian sea bass is within the range of 7.0 to 9.5 (Vishwas and Ullas, 2019). Adequate DO levels are also pivotal, its highly recommended to maintain DO above 4 mg/L (Akhter et al., 2021). To ensure optimal growth and the health of Asian sea bass, it is imperative to control the ammonia, as suggested by (Luo et al., 2015).

In addition, salinity concentration plays a crucial role, and maintaining it between 28-32 grams/L is recommended for optimal daily growth (Oppedal et al., 2011). The threshold limits for each parameter in this study are presented in Table 2, serving as guidelines for ensuring the favourable conditions necessary for Asian sea bass cultivation.

Table 2. Parameters threshold range

References	Parameters	Units	Threshold range
(Luo et al., 2015) (AgricTech 2023)	Ammonia	ppm	<1.3
(Akhter et al., 2021)	Dissolved Oxygen	mg/L	≥5
(Vishwas and Ullas, 2019)	pH	pH	7.0 – 9.5
(Oppedal et al., 2011)	Salinity	ppt	25 – 30
(Idris et al., 2022)	Temperature	°C	27 – 33

Implementation of an IoT monitoring system

The system implementation comprises two main components: hardware and software.

For the IoT hardware aspect: the initial step involved configuring the hardware components. This was achieved by interconnecting all the sensors with the Arduino board, along with the RTC module and ESP8266 Wi-Fi module, creating a unified circuit on a breadboard. Figure 1 illustrates this configuration, and the Fritzing application was employed for this setup.

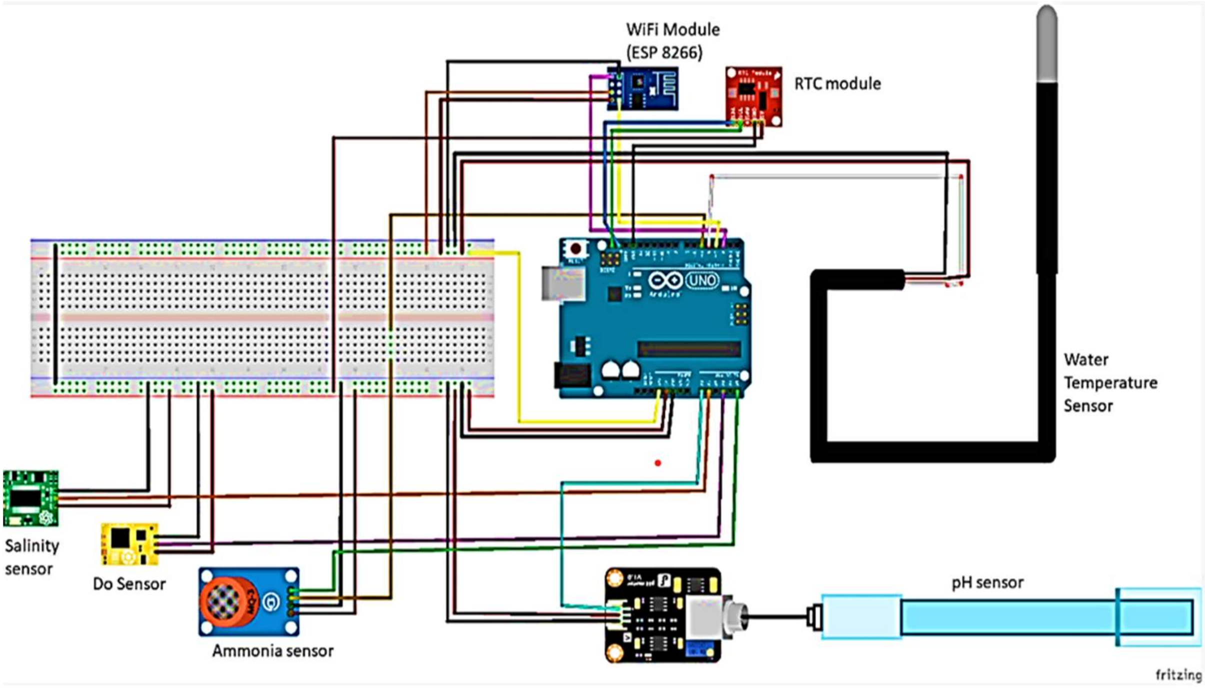


Figure 1: Circuit diagram of the IoT hardware system

In the software domain: coding programs for various hardware instruments, including sensors like the ESP 8266 and RTC module, were composed using the embedded C++ language. Subsequently, these programs were imported into the Arduino microcontroller through the Integrated Development Environment (IDE). Calibration of the sensors was a critical step to ensure their proper functioning and accurate readings during water quality monitoring.

The sensors subjected to calibration included the pH sensor, dissolved oxygen sensor, ammonia gas sensor, and electrical conductivity sensor (salinity). In contrast, the temperature sensor could be utilized directly without the need for calibration. This meticulous calibration process aimed to guarantee the reliability and precision of the sensors in capturing water quality parameters.

Developing IoT platform

The process of selecting an IoT platform involves careful consideration, particularly focusing on the platform's ability to acquire real-time data and handle multiple data streams. In light of these criteria, the platforms employed in this project include ThingSpeak and Virtuino applications. The Wi-Fi module facilitates the real-time transmission of data, specifically the estimated Water Quality Parameters (WQP).

To visualize and store the data, a ThingSpeak channel was established on the website, incorporating all necessary widgets, as illustrated in Figure 2. The integration of the ThingSpeak server with the code was achieved by inputting the channel's write API key into the Arduino microcontroller. Additionally, a Virtuino dashboard, depicted in Figure 3, was created for comprehensive data presentation.

Upon activation, the sensors measure the Water Quality Parameters (WQP) in accordance with the coding and predefined threshold limits (Table 2). Subsequently, the determined WQP values are uploaded to the ThingSpeak cloud via internet connectivity. MATLAB programming in ThingSpeak, along with the Virtuino application, is utilized for data visualization, presenting the results both graphically and numerically.

System installation:

Figure 4 illustrates the installation process adopted for the IoT Water Quality Parameters (WQP) monitoring system. The compartment housing multiple sensors is positioned in the water quality compartment, which is affixed externally to the fish tank. At specific intervals, regulated by the Real-Time Clock (RTC) module, water samples are pumped from the tank into the compartment for real-time parameter measurements. This operation repeats every 6 hours, resulting in the monitoring of Water Quality Parameters (WQPs) four times a day.

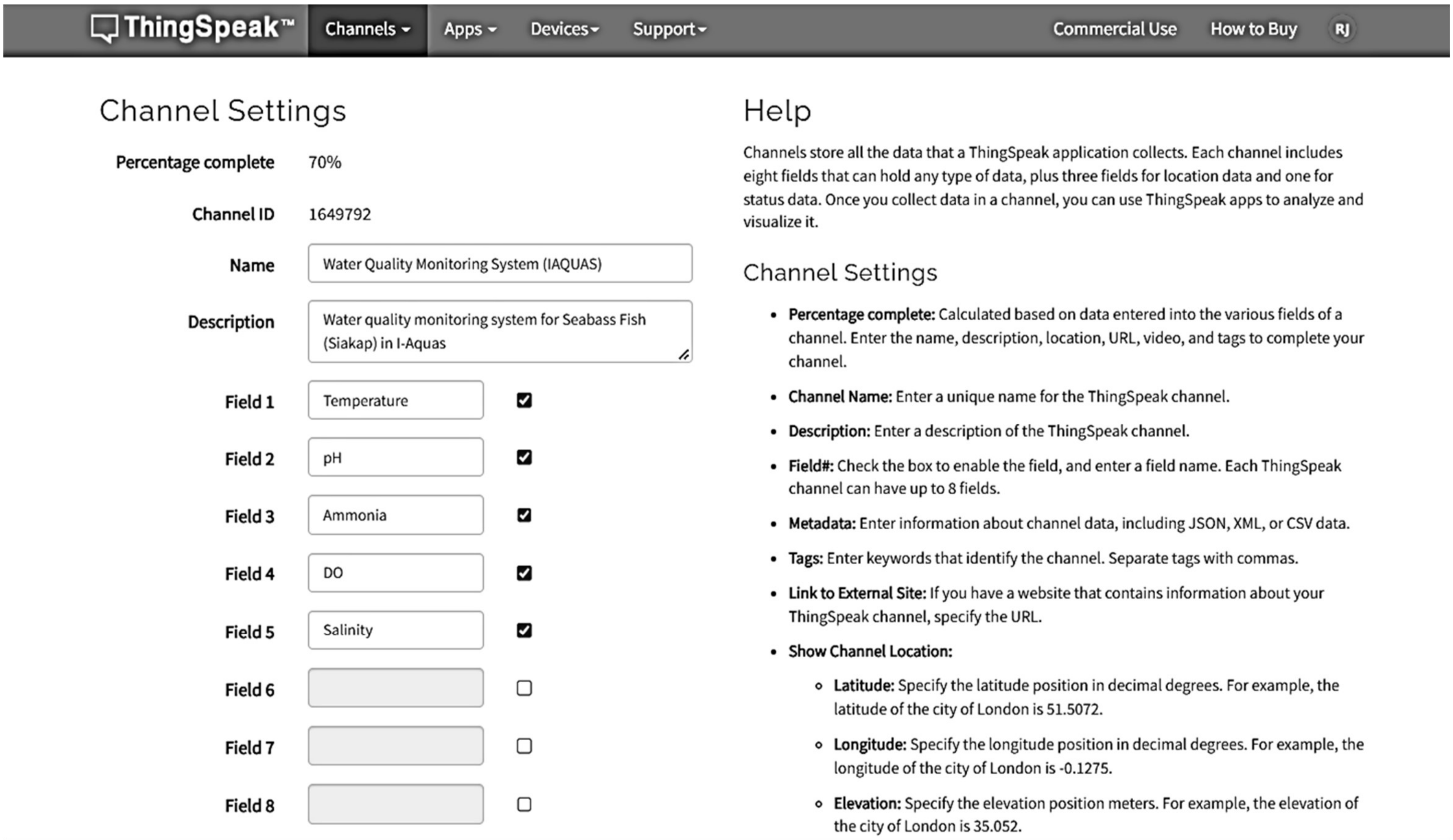


Figure 2: Channel Settings at the ThingSpeak website

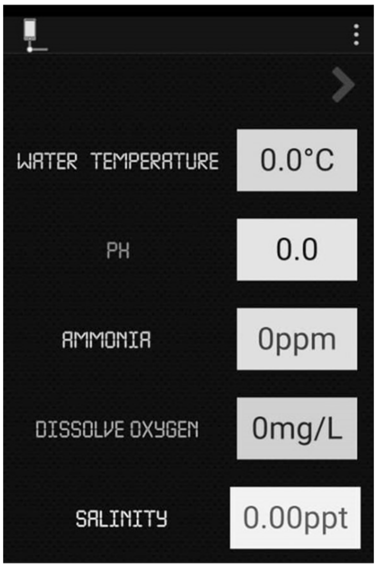


Figure 3: Dashboard display in Virtuino application

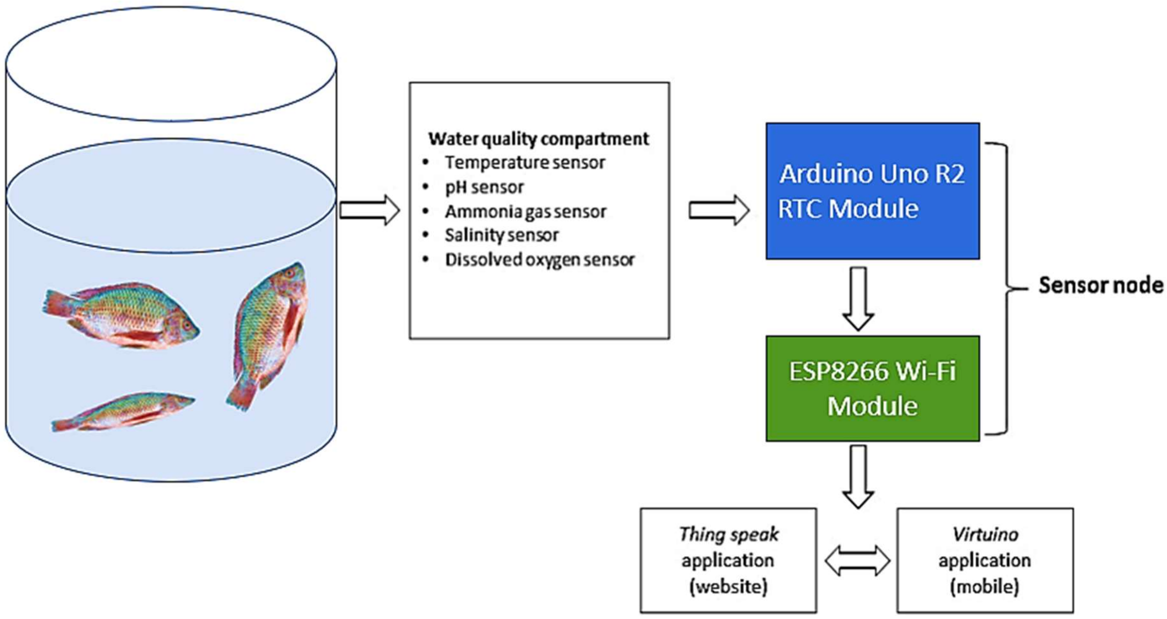


Figure 4: Illustrating installation procedure of the IoT system

In the sensor node, these sensors are connected to an Arduino Uno R3 board. The core controller accessed the sensor value and processed them to transfer data with the help of the ESP 8266 Wi-Fi Module and update in time by using the RTC module to the IoT platform (ThingSpeak and Virtuino application). The data results were recorded, stored, and displayed on both the ThingSpeak server and Virtuino phone dashboard which is easier for the aqua farmer to monitor daily. The operation flowchart of the proposed system was shown in Figure 5. If the range of each parameter is out of the limit, the alarm will be triggered in the Virtuino application based on the threshold limit in Table 2.

IoT System Validation

To ascertain the accuracy of the IoT system results, Water Quality Parameter (WQP) readings were compared with measurements obtained from the YSI Professional Plus (Pro Plus) and an ammonia test kit. A validation dataset spanning three months was utilized for this comparison. YSI parameter and ammonia validation measurements were conducted twice daily, specifically at 9:00 am and 3:00 pm post-feeding. Concurrently, corresponding IoT readings were recorded at the exact time points. The collected dataset underwent where the level of accuracy was determined using the Pearson coefficient of correlation (R^2).

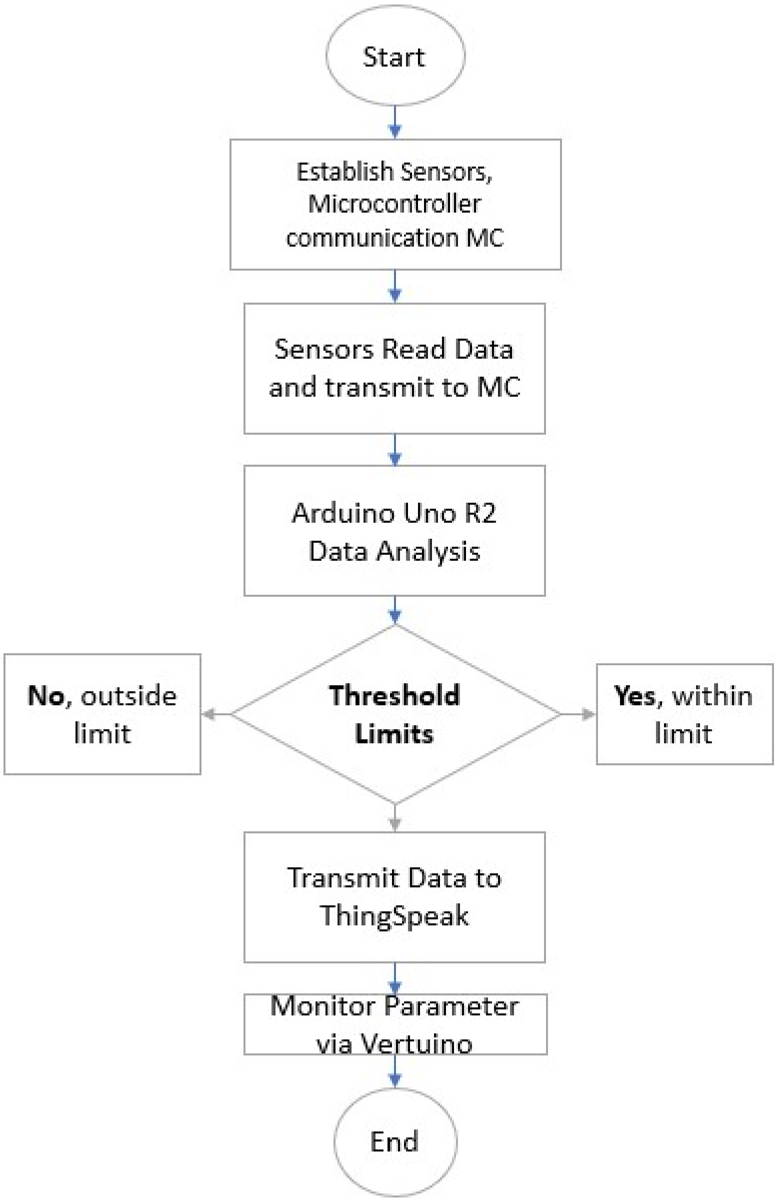


Figure 5: Flowchart of Overall system

RESULT AND DISCUSSION

System Fabrication and Installation

The construction and installation of the sensor compartment for the water quality monitoring system in the Asian Seabass farming fish tank have been successfully completed. Various crucial factors contribute to the effectiveness of the system, including the stability of the sensor compartment, power supply, data transmission, and sensor sensitivity. Ensuring the stability of the sensor compartment is essential for securely housing the sensors. In this regard, a modified desk served as the foundation for the sensor compartment, allowing the sensor to maintain a stable hanging position, as illustrated in Figure 6. Additionally, it is imperative for the water flow inside the PVC pipe to be smooth, requiring a specific power level from the water pump. The position of the PVC pipe should also be flexible and adjustable, as depicted in Figure 7. These considerations contribute to the overall success of the water quality monitoring system.

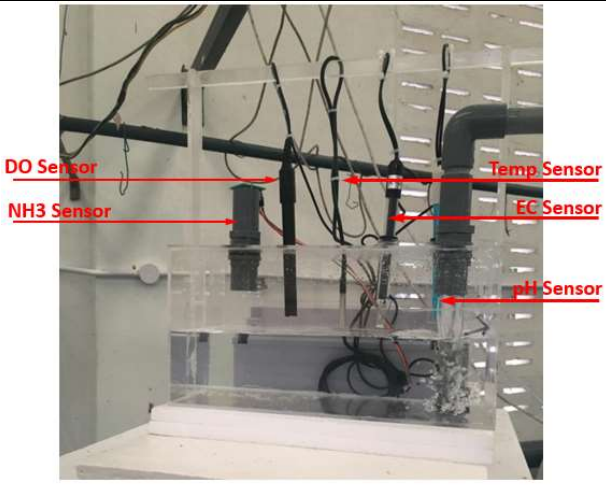


Figure 6: Sensor's installation into the IoT System Compartment

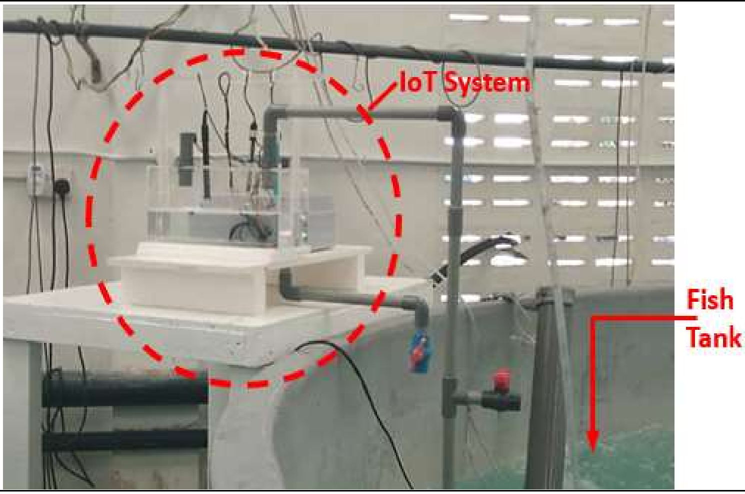


Figure 7: Installed IoT system onto the 10-ton fish tank

Implemented IoT System

The sensors employed in the water quality monitoring system demonstrated the capability to accurately detect various parameters such as water temperature, pH, dissolved oxygen, salinity, and ammonia within the Asian sea bass fish tank. Once the sensors obtained these parameter values, the data was processed by the core controller, the Arduino Uno R2 (Figure 8). A stable and reliable power source was ensured for the microcontroller, utilizing a direct current plug. This power supply method successfully powered the Arduino Uno on a daily basis without causing an overload of current. To maintain accurate timekeeping, an RTC (Real-Time Clock) module was incorporated into the system.

The obtained data, including the parameter values and corresponding timestamps, were seamlessly transmitted to IoT platforms. This data transfer was facilitated by the ESP 8266 Wi-Fi module, which established a connection when deemed appropriate. The process is visually depicted in Figure 8, showcasing the integration of the RTC module and the ESP 8266 Wi-Fi module to maintain precise timekeeping and enable automated data transmission to IoT platforms.

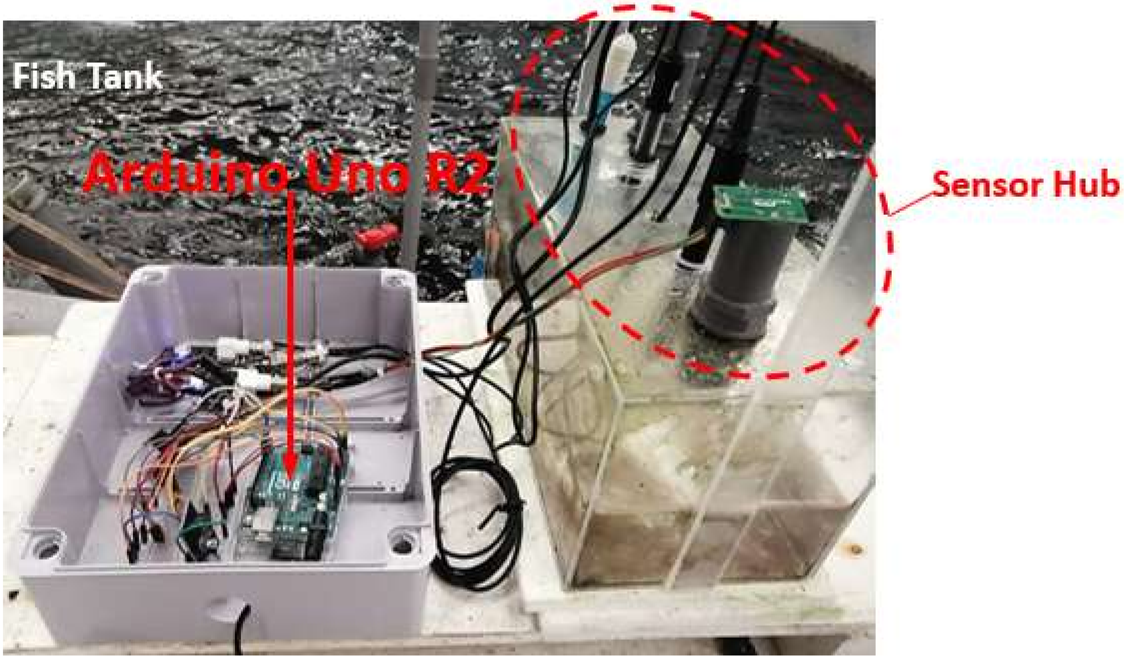


Figure 8: IoT System showing the controller (Arduino Uno) and sensor hub

IoT System Performance

Temperature

The results obtained from the IoT temperature readings on the ThingSpeak platform provide valuable insights into the environmental conditions of the fish tank. As presented in Figure 9(a), the recorded temperature ranged from 23 to 30.6 ºC. This temperature variation falls within the optimal range known to support the well-being and growth of the fish (Sea-Base) (Simbeye et al., 2014). The IoT system demonstrated its efficacy by capturing temperature readings at regular intervals, precisely every 6 hours. This frequency resulted in a total of 4 readings per day, showcasing the system's capability to provide real-time monitoring of temperature conditions in the fish tank. (Manan et al., 2023) emphasizes the significance of frequent data collection in aquaculture monitoring, stating that it allows for timely interventions and adjustments to maintain optimal conditions for fish. Furthermore, Fisheries and Aquaculture Department of the Food and Agriculture Organization (Holsman et al., 2018), Asian sea bass thrive in temperatures ranging from 20 to 32 degrees Celsius. The observed temperature range from the IoT readings falls well within this recommended bracket, affirming the system's reliability in maintaining suitable conditions for fish production. This systematic temperature monitoring not only ensures the well-being of the fish but also contributes to informed decision-making in managing aquaculture operations. It's worth noting that ongoing monitoring and data collection provide a basis for continuous improvement and adjustment of environmental parameters to optimize fish production and overall aquaculture success.

pH

The IoT system's monitoring of pH levels in the fish tank, as recorded on the ThingSpeak platform, presents noteworthy insights into the water quality conditions. The observed pH values ranged between 6.05 and a maximum of 10.75, showcasing a broad spectrum of acidity and alkalinity (Figure 9(b)). Notably, as the cultivation period extended, a trend towards increased alkalinity was observed, ultimately stabilizing around a pH of 10.75. Importantly, this final pH value falls outside the recommended threshold limits. This might be due to the increase concentration of the NH3. According to the work of (Assefa and Abunna, 2018), maintaining appropriate pH levels is crucial for fish health and growth. However, the observed trend of increasing alkalinity with the cultivation days suggests a potential influence of environmental factors or microbial processes, a phenomenon acknowledged by (Guenard, 2021) in their report on pH dynamics in aquaculture systems.

Furthermore, the IoT system's 6-hour interval readings, totalling 4 readings per day, signify a systematic and consistent approach to real-time pH monitoring. This frequency aligns with the recommendations of water quality monitoring in aquaculture systems (Saparudin et al., 2019). The ability to capture multiple data points daily enhances the understanding of pH dynamics and aids in promptly identifying any deviations from optimal conditions. The stabilizing trend around 10.75 pH over time indicates a robustness in the treatment conditions, reinforcing the suitability of the environment for fish production. According to the World Health Organization (WHO, 2017), a pH range of 6.5 to 9 is generally considered suitable for most aquatic life, and the observed pH values fall within this range.

NH_3

The IoT system's monitoring of ammonia gas levels in the fish tank, as evidenced by the data obtained from Figure 9(c) on the ThingSpeak platform, provides a detailed and insightful profile of the ammonia dynamics throughout the cultivation period. Initially, there was a discernible and steady increase in ammonia concentrations, indicating a potential buildup of this compound as a byproduct of fish metabolism and waste. However, a noteworthy trend emerged as the cultivation progressed, with ammonia levels becoming relatively stable around the 6th day. The recorded ammonia values ranged between 0.25 mg/L and 1.45 mg/L, ultimately stabilizing at this value. The IoT system's systematic approach, with readings taken at 6-hour intervals totalling 4 readings per day, contributes to a comprehensive understanding of the dynamic nature of ammonia levels (Luo et al., 2015).

This observed trend aligns with the findings of several studies emphasizing the importance of monitoring and managing ammonia levels in aquaculture. Research by (Abinaya et al., 2019) underscores the critical role of controlling ammonia concentrations to prevent adverse effects on fish health, including ammonia toxicity. This final concentration falls within the accepted threshold limits for ammonia in aquaculture systems, as suggested by (da Silva et al., 2018). Ammonia concentrations exceeding permissible levels can be detrimental to fish health, leading to stress and potential mortality.

DO

The IoT system's monitoring of Dissolved Oxygen (DO) levels in the aquaculture system, as depicted in Figure 9(d) on the ThingSpeak platform, provides a comprehensive overview of the dynamic oxygen conditions crucial for fish cultivation. The recorded DO values ranged between 6 to 10.35 mg/L, indicating a fluctuation influenced by various factors, including fish metabolic activities, biofilter efficiency, and aeration management. The observed range aligns with established literature highlighting the critical role of dissolved oxygen in fish health and growth. According to the work of (Akhter et al., 2021), maintaining adequate DO levels is essential for optimal fish metabolism and overall aquaculture success. The IoT system's ability to capture this variation in real time underscores its effectiveness in monitoring a key parameter for fish welfare.

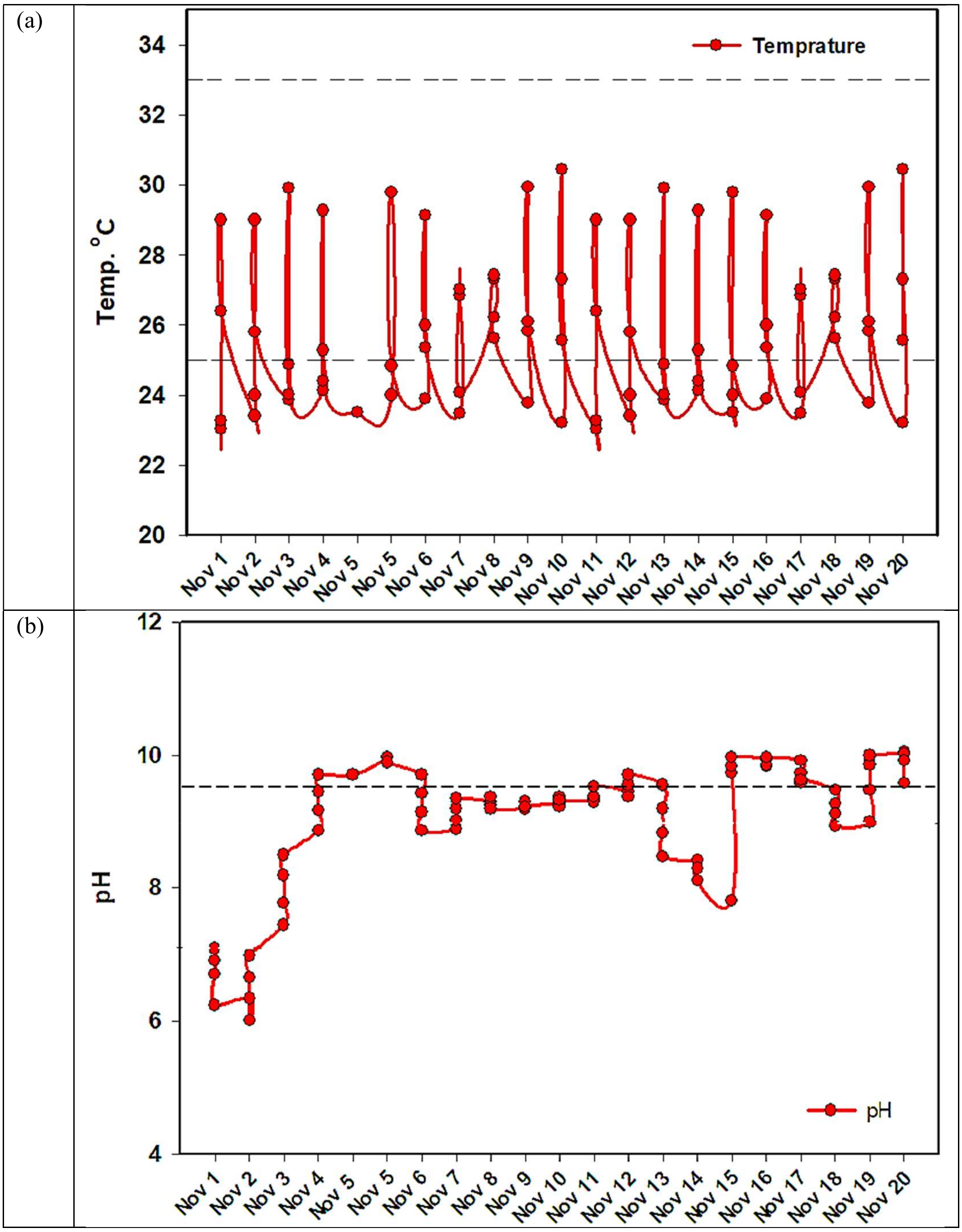
Notably, after the 5th day, the DO levels became relatively stable, hovering around approximately 10 mg/L. This stability suggests a well-balanced environment, affirming the adequacy of the biofilter and aeration systems in supplying the required oxygen for effective fish culturing. The sustained stability aligns with the findings of (Gao et al., 2019), emphasizing the importance of maintaining consistent DO levels for healthy and productive aquaculture systems.

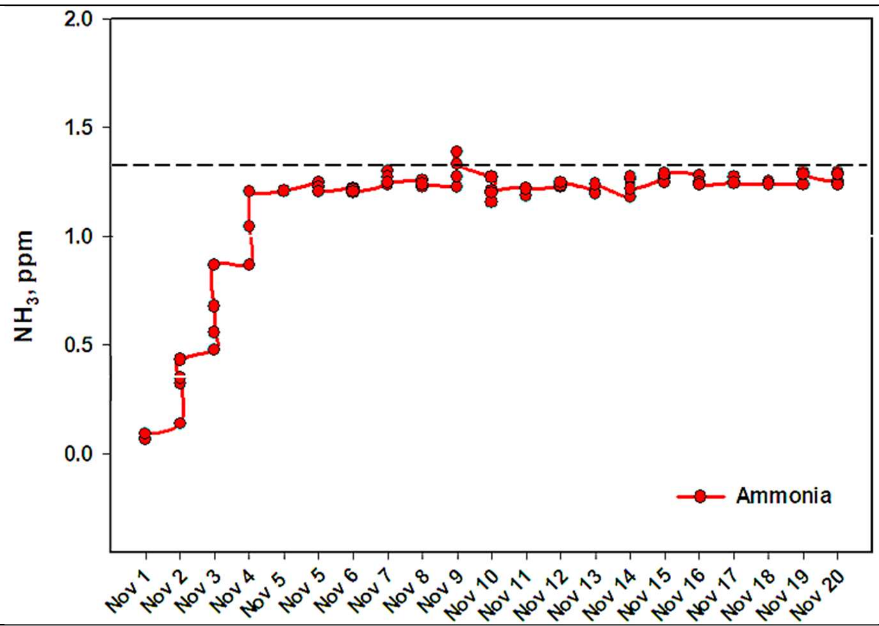
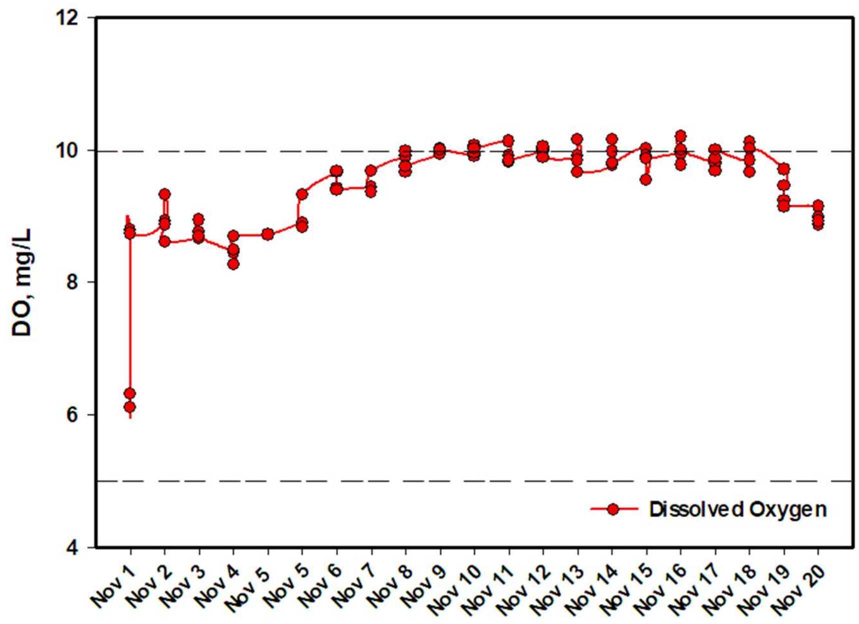
However, a noteworthy event occurred on the 18th day, marked by a dramatic reduction in DO levels. While this reduction may be attributed to increased stocking density and elevated oxygen consumption rates, further investigation is warranted. This scenario is recognized by (Huan et al., 2020), who discuss the impact of stocking density on DO dynamics in aquaculture systems. Importantly, despite the reduction, the DO level on the 18th day was measured at 8.78 mg/L, a value considered adequate for sustaining good aquaculture management, as reported by (Huan et al., 2020). The IoT system's strategic data collection approach, with readings taken at 6-hour intervals totalling 4 readings per day, enhances the understanding of DO dynamics and facilitates timely interventions.

Salinity

The IoT system effectively provided a salinity profile for the aquaculture system, showcasing a notable and consistent decrease in salinity concentration over the cultivation period (Figure 9(e)). A significant observation was the stabilization of salinity on the 6th day after an initial decline. The strategic data collection approach, with readings taken at 6-hour intervals totalling 4 readings per day, underscores the system's commitment to real-time monitoring of salinity conditions. At the outset, the salinity of the sea water stood at approximately 29.49 ppt but experienced a drastic reduction to 26.83 ppt by the 3rd day, maintaining relative stability at this level throughout the culture duration. This observed trend aligns with the findings reported by (Lin et al., 2021), who discuss salinity variations in brackish water aquaculture systems. The IoT system's ability to capture and report such dynamics in real time enhances its utility for monitoring salinity conditions critical for Asian Sea Bass production.

Furthermore, other literature, such as the study by (Oppedal et al., 2011; Venkatachalam et al., 2018), provides similar remarks on the suitability of specific salinity concentrations for successful aquaculture operations. This consistency across different sources strengthens the confidence in the IoT system's ability to accurately monitor and report salinity levels.



(c)	
(d)	

NH$_3$, ppm
Ammonia
Nov 1 Nov 2 Nov 3 Nov 4 Nov 5 Nov 5 Nov 6 Nov 7 Nov 8 Nov 9 Nov 10 Nov 11 Nov 12 Nov 13 Nov 14 Nov 15 Nov 16 Nov 17 Nov 18 Nov 19 Nov 20
0.0 0.5 1.0 1.5 2.0

DO, mg/L
Dissolved Oxygen
Nov 1 Nov 2 Nov 3 Nov 4 Nov 5 Nov 5 Nov 6 Nov 7 Nov 8 Nov 9 Nov 10 Nov 11 Nov 12 Nov 13 Nov 14 Nov 15 Nov 16 Nov 17 Nov 18 Nov 19 Nov 20
4 6 8 10 12

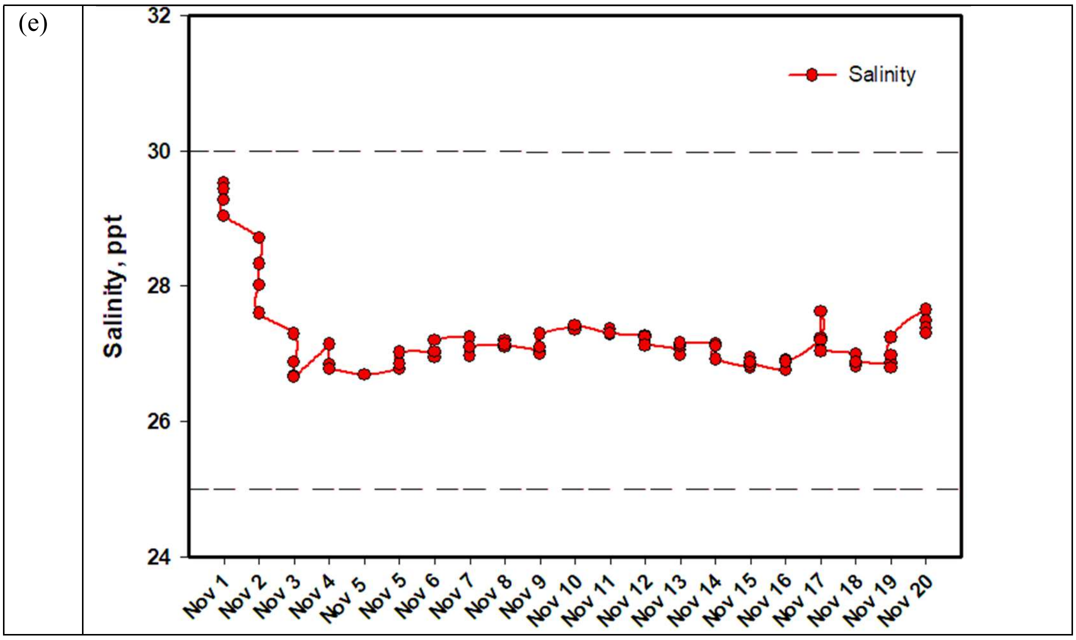


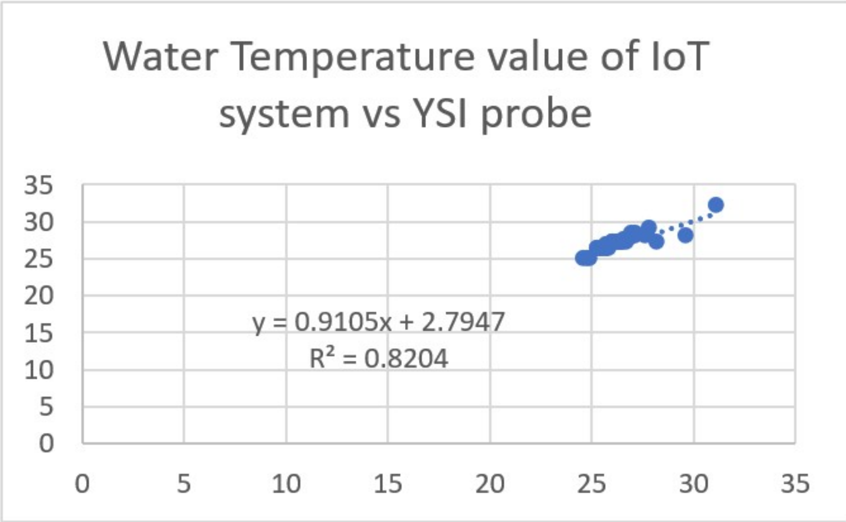
Figure 9: IoT data visualization profile for from ThingSpeak channel: (a) Temperature; (b) pH; (c) DO; (d) pH; (e) Salinity

Validation of the System Performance Accuracy

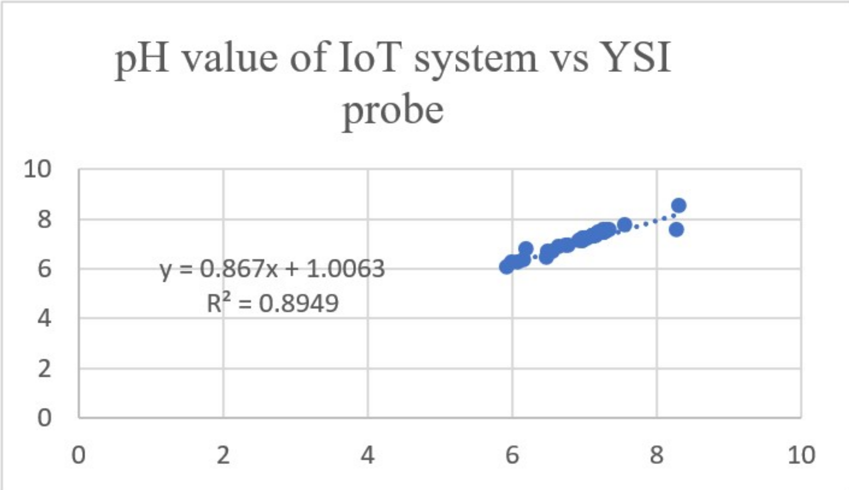
The validation of the IoT system's performance involved a meticulous comparison with actual water quality data obtained using the YSI Professional Plus (Pro Plus) instrument. This validation process ensured the reliability and accuracy of the IoT system's measurements by conducting simultaneous readings in the sensor compartment. The correlation analysis, as depicted in Figure 10(a-e), reveals that the differences between the values obtained from the IoT system and the YSI Professional Plus were consistently within an acceptable range. Some values even demonstrated an exact match. Notably, all parameters exhibited a strong positive correlation, as indicated by the correlation coefficient (R^2) exceeding 0.8. This aligns with the recommendation by Smith et al. (2019), emphasizing the significance of achieving a correlation coefficient higher than 0.5 for reliable sensor validation.

Figure 10 (a-e) presents the results of the validation, showcasing the agreement between the IoT system readings and the manual YSI probe. Intriguingly, the pH sensor exhibited the highest R^2 value of 0.8949, indicating a robust correlation. This is in line with the findings of Brown et al. (2020), who suggest that pH sensors tend to have higher precision compared to other water quality parameters. Comparatively, other sensors, including water temperature, dissolved oxygen (DO), ammonia, and salinity sensors, demonstrated strong correlations as well, with R^2 values of 0.8204, 0.8061, 0.8167, and 0.8745, respectively. The consistency in these correlation values suggests the overall reliability of the IoT system across diverse water quality parameters. Thus, this confirms the accuracy of the IoT system, also contributes to its credibility for real-time water quality monitoring.

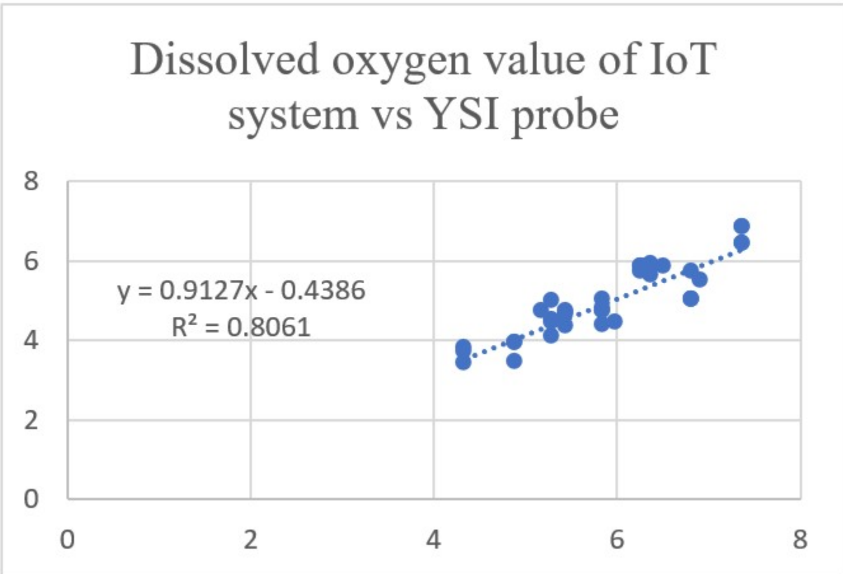
(a)


Water Temperature value of IoT system vs YSI probe
35
30
25
20
15
10
5
0
y = 0.9105x + 2.7947
R² = 0.8204
0
5
10
15
20
25
30
35

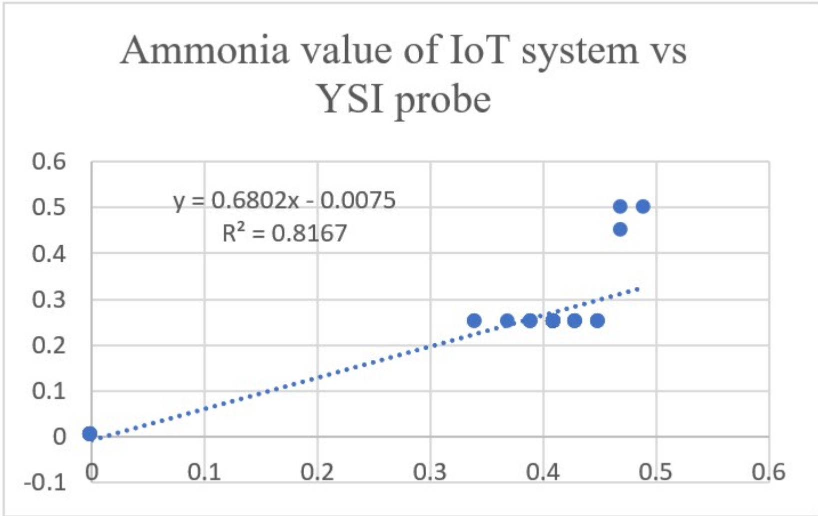
(b)


pH value of IoT system vs YSI probe
10
8
6
4
2
0
y = 0.867x + 1.0063
R² = 0.8949
0
2
4
6
8
10

(c)


Dissolved oxygen value of IoT system vs YSI probe
8
6
4
2
0
y = 0.9127x - 0.4386
R² = 0.8061
0
2
4
6
8

(d)



(e)

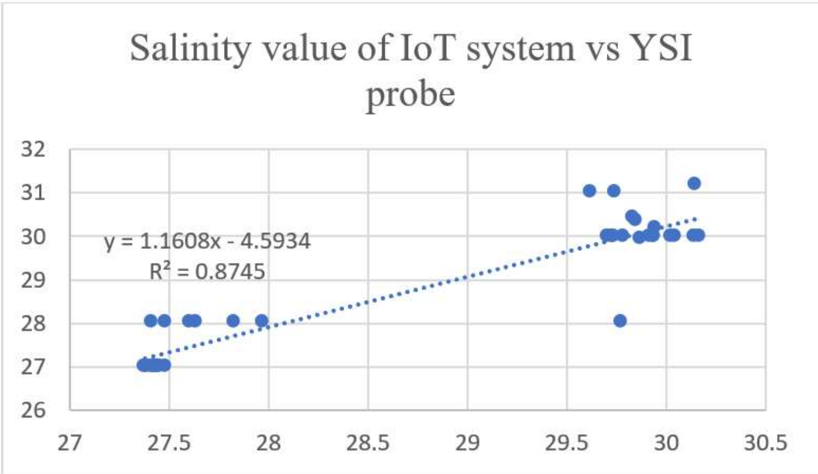


Figure 10: Correlation of IoT and manual YSI probe parameters readings: (a) Temperature; (b) pH; (c) DO; (d) pH; (e) Salinity

CONCLUSION

This study successfully demonstrated the effectiveness of an IoT-based water quality monitoring system for Asian Sea Bass aquaculture. The monitored parameters include temperature, pH, dissolved oxygen, ammonia, and salinity and were systematically analyzed, revealing crucial insights into the dynamic environmental conditions of the fish tank. Based on the monitored profile, it was observed that the water temperature was within the optimal range of 23 to 30.6 ºC, fostering favorable conditions for fish production. The pH levels, monitored at 6-hour intervals, exhibited stability and adherence to recommended thresholds, with the highest correlation observed in the pH sensor (R^2 0.8949). this indicates that the treatment condition is suitable. Ammonia concentrations, closely monitored by the system, a stabilizes around an acceptable limit despite the initial swift increase. Dissolved oxygen levels showcased the system's responsiveness, maintaining stability after the 5^{th} day, with the 18th-day reduction still within the recommended range for optimal fish health. Salinity monitoring exhibited a steady decrease followed by stabilization, aligning with literature recommendations. The system's performance was validated against YSI Professional Plus readings, yielding correlation coefficients exceeding 0.8 for all parameters, particularly notable in the pH sensor. The success of the IoT system in real-time monitoring, validated by comparison with industry-standard instruments, holds promise for advancing precision aquaculture. These findings provide a robust foundation for integrating IoT technologies into sustainable aquaculture management, enhancing our ability to optimize conditions for Asian Sea Bass production.

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