

Monitoring Water Quality Parameters in Shrimp Aquaculture

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Abstract

In shrimp aquaculture, maintaining optimal water quality is essential for ensuring the health and growth of shrimp. For that reason, previous developments have been demonstrated for water quality monitoring. Despite the successful demonstration, total dissolved solid (TDS) has not been measured and thus the excess of TDS which can lead to shrimp stress and mortality could not be monitored. As such, this work presents a real-time monitoring of water quality parameters that measures not only temperature, salinity, dissolved oxygen (DO), pH and turbidity but also TDS. With the use of a solar panel for electricity, the multi-sensor system is capable in monitoring the water quality of a shrimp pond over two consecutive days. Based on the measurement data, the measured range is 6.5 – 9.0 for pH, 19 – 31.5°C for temperature, 9.0 – 25.0 ppt for salinity and 2.0 – 12.0 NTU for turbidity. The range of these parameters is ideal for shrimp aquaculture. Nevertheless, the TDS and DO do not meet the ideal range. TDS should be less than 1500 ppm, with a measured range of 1800 to 3400 ppm. Feed inputs and the buildup of metabolic waste may be the cause of this high TDS value. In the meantime, DO measures in the range of 2.5 to 22.0 ppm, with the lowest DO occurring late at night and falling below the DO limit of 5 ppm. By using mechanical aeration late at night to raise the DO level, this DO shortage can be resolved. The findings demonstrate that in order to guarantee accurate control of crucial parameters, ongoing real-time monitoring of sensor technology is required. Shrimp aquaculture may become much more sustainable and efficient by implementing automated systems for water quality regulation, which also lowers the risks related to environmental variations.

1. Introduction

Aquaculture, or fish farming, has become an increasingly important sector of agriculture, producing nearly 50% of the world's seafood [1]. This practice involves the breeding, rearing, and harvesting of aquatic organisms in various water environments, including ponds, rivers, lakes, and oceans. In shrimp farming, maintaining optimal water quality is a key strategy, as it directly influences the health, growth, and survival rates of shrimp [2]. As highlighted by [3], shrimp farming is a vital industry due to its high demand in global cuisines and its significant economic value. However, despite its demand, the success of shrimp aquaculture is highly sensitive to factors such as feed management, water quality, and biosecurity measures. Therefore, effective aquaculture management must strike a balance between environmental sustainability and achieving optimal production outcomes.

The primary challenge lies in the fact that water quality can be affected by both external and internal factors. External contributors, such as climatic changes, agricultural runoff, and industrial discharge, are significant causes of poor water quality [4], [5]. On the other hand, internal factors, including excretions from the cultured species, decomposition of organic matter, and overfeeding, can also negatively impact water conditions. The complexity of these interacting factors highlights the need for advanced monitoring methodologies and strategic management practices. According to [6], the global aquaculture market was valued at approximately \$202.96 billion in 2021, with expectations for further growth. This increasing market value underscores the necessity of improving water quality management to enable sustainable practices that support both environmental and economic goals.

Water quality is a critical factor in the success of shrimp farming. Maintaining dissolved oxygen (DO) levels above 4 ppm during the day and over 6 ppm at night is essential to prevent stress, mortality, and increased susceptibility to diseases in shrimp [7]. Additionally, the pH level of pond water should be kept between 7.5 and 8.5. High pH levels can lead to toxicity, negatively impacting shrimp growth [8]. Regular monitoring of nitrite and nitrate levels is crucial, as these compounds can accumulate and harm the health of shrimp. Ensuring that nitrite levels remain below 0.5 mg/L is important for their well-being [8]. Furthermore, it is vital to keep total ammonia nitrogen (TAN) levels under 0.1 mg/L to avoid toxicity and stress in shrimp ponds [9]. A study by [10], highlighted that improving water quality in aquaculture systems by just 10 percent could increase fish growth by 5 to 15 percent, demonstrating the direct benefits of effective water quality management.

This work aims to develop and implement advanced monitoring techniques for effective water quality management in shrimp farming. The focus will be on real-time monitoring systems, which will allow for immediate corrective actions and informed, strategic decision-making. Such technology can optimize resource management, reduce environmental impact, and enhance productivity in aquaculture systems. Ultimately, the health and success of the aquaculture industry are closely tied to the sustainability of water management practices that respond not only to operational needs but also to environmental challenges. Therefore, maintaining optimal water quality is essential to ensure shrimp productivity within aquaculture operations. In this context, it is crucial for farmers to adopt continuous monitoring practices and implement appropriate interventions when necessary.

1.1 Literature Review

Previous researchers have developed water quality monitoring systems specifically designed for shrimp aquaculture environments. As stated by [11], traditional methods such as manual sampling and laboratory analysis, while accurate, provide only intermittent information and are time-consuming. The delay in acquiring data often makes it impossible to take timely action when abrupt deterioration in water quality occurs, which can have catastrophic effects on shrimp aquaculture. Moreover, these methods are labor-intensive and costly, making them less practical for most of the industry, especially small and medium sized enterprises, particularly in developing regions. According to [12] and [13], the pH level of water is a crucial factor for shrimp metabolism and growth, and traditional pH test kits or electrodes are often used. These methods assess the alkalinity or acidity of water, which is typically collected as a sample from shrimp ponds. Similarly, [14], highlighted that parameters like ammonia and nitrite are measured using spectrophotometric method. This is one of the most effective ways to determine if toxicity levels, resulting from waste products, are present in the water. Dissolved oxygen is another critical parameter for shrimp health and respiration, and manual probes are typically used to measure oxygen levels, providing insight into whether the water is adequately oxygenated [15].

While these traditional methods provide valuable data, their limitations such as time delays, potential for human error, and high labor costs have highlighted the need for more efficient and reliable methods. With the growing complexity of aquaculture systems, the integration of modern technological solutions has become essential for improving water quality management and enhancing shrimp survival and productivity. Real-time monitoring systems using sensors for key parameters such as temperature, salinity, dissolved oxygen, pH, total dissolved solids (TDS), and turbidity have revolutionized water quality management in aquaculture systems [16]. These systems allow for continuous, real-time monitoring and enable farmers to take immediate corrective actions when water quality falls outside of optimal ranges. For instance, temperature sensors can help maintain stable water temperatures critical for shrimp growth [17], while salinity sensors ensure that the water remains

within the required range for species such as *Litopenaeus vannamei* [18]. Similarly, TDS sensors can monitor dissolved solids in the water, ensuring that shrimp are not exposed to harmful levels of pollutants [19].

The integration of IoT (Internet of Things) technology has further advanced water quality monitoring systems, allowing for remote monitoring through mobile applications. These applications, such as Blynk, enable shrimp farmers to access real-time data on water quality parameters and receive immediate alerts when conditions become unfavorable [20]. Such innovations empower farmers to manage aquaculture operations more efficiently, even from a distance, reducing the need for on-site presence while improving decision-making speed and accuracy. Moreover, these IoT-based systems can store and analyze data trends over time, facilitating better long-term planning and water quality management strategies.

In conclusion, while traditional water quality monitoring methods have been essential in aquaculture management, their limitations in terms of time delays, high labor costs, and potential inaccuracies have driven the shift toward more advanced, real-time monitoring technologies. The adoption of sensor-based systems, combined with IoT technology, has revolutionized shrimp aquaculture management, providing farmers with the tools to ensure optimal water quality, reduce costs, and increase productivity. As these technologies continue to evolve, they promise to make shrimp farming more sustainable, efficient, and resilient to the challenges of an ever-changing aquatic environment.

1.2 Research Limitation and Contribution

The literature survey, as highlighted in studies such as those by [5] and [6], reveals significant advancements in developing IoT-based water quality monitoring systems. However, various limitations and research deficiencies remain that hinder the scalability, efficiency, and practical implementation of these technologies, particularly in shrimp aquaculture systems.

One of the primary challenges is the reliance on unlicensed IoT technologies such as ZigBee, WiFi, and LoRa, which have been widely used in water quality monitoring systems [21], [22]. Although these technologies operate independently and avoid the recurring costs associated with licensed networks, they face constraints such as limited bandwidth, significant power consumption, and the need for additional dedicated gateways to relay measured data to cloud storage. These issues are particularly problematic for large-scale shrimp aquaculture systems where energy efficiency and seamless connectivity are critical for real-time monitoring. Moreover, the limited communication range of some unlicensed technologies, such as ZigBee and WiFi, can reduce their effectiveness in remote or expansive aquaculture farms, necessitating the development of more robust and energy-efficient communication solutions.

In related work, such as the system described in [22], NB-IoT (Narrowband Internet of Things) was employed as the core communication technology to overcome the limitations of short-range wireless systems like WiFi and ZigBee in remote aquaculture environments. However, the NB-IoT-based system required more complex infrastructure, including cloud integration, backend server management, and external visualization platforms like Grafana. This increases technical complexity and the cost of deployment factors that may not be suitable for smallholder shrimp farmers or those without access to advanced technical resources. In addition, TDS parameter was not measured in [22]. It basically represents the combined content of all inorganic and organic substances dissolved in water, including minerals, salts, and organic matter. In shrimp aquaculture, TDS is a critical parameter influencing shrimp health, growth, and overall water quality. A rising TDS may indicate increasing waste, uneaten feed, or mineral buildup, signalling the need for water changes or system adjustments.

In contrast, the Blynk based system developed in this study provides a simpler, more accessible alternative by integrating essential water quality sensors like temperature, salinity, DO, pH, and turbidity into a real-time monitoring setup connected to the Blynk mobile application. Blynk offers a user-friendly, ready-to use interface with built-in features for live data visualization, alerts, and remote control, all without the need for separate gateways or cloud server configuration. Its straightforward setup and minimal technical requirements make it highly suitable for small to medium scale shrimp aquaculture operations. Furthermore, this monitoring device also records TDS level in measuring water quality parameters which was not recorded previously. Inappropriate TDS levels can be detected early, which can avoid shrimp stress and mortality. As such, this contribution addresses the need for practical, low-cost water quality management tools by offering a plug and play solution that empowers farmers with limited technical expertise to maintain optimal water conditions and respond quickly to environmental changes.

2. System Description and Configuration

In this section, an overview of the solar-powered water quality monitoring system for shrimp aquaculture is provided. In specific, the details of the system are elaborated in the following subsections: (i) monitoring system and (ii) prototype.

2.1 Monitoring System

2.1.1 Data Acquisition Layer

The data acquisition layer is developed to measure and transfer water quality parameters from aquaculture ponds to a cloud database using an aggregate of specialized sensors, microcontroller technology, and communication modules. This layer performs an essential function in ensuring the continuous monitoring and management of water quality, which is essential for optimal shrimp health and growth.

As shown in Fig. 1, the device integrates six types of water quality sensors from the DFRobot manufacturer to monitor the parameters. These encompass the SEN0161-V2 pH sensor for measuring acidity or alkalinity, the DS18B20 temperature sensor for tracking pond temperature, the SEN0237-A dissolved oxygen (DO) sensor for assessing oxygen levels, the DFR0300-H electrical conductivity (EC) and salinity sensor to assess ionic content, the TS-300B turbidity sensor to measure water clarity, and the SEN0244 total dissolved solids (TDS) sensor to estimate the concentration of dissolved particles. These sensors are selected for their precision, wide operating ranges, and fast response times, as summarized in Table 1, making them well-suited for aquaculture applications.

The Arduino Uno microcontroller board, as illustrated in Fig. 1, is a core processing unit, interfacing with the sensors to gather and preprocess raw data. It is paired with NodeMCU (ESP8266) Communication module, which facilitates wireless data transfer to a cloud platform for real-time access and analysis. The DC-DC converter ensures stable voltage levels, which enables consistent performance of the system under varying power conditions.

Each sensor undergoes rigorous calibration to guarantee data accuracy, as mentioned in Table 1. The pH sensor makes use of a three-point calibration method with standard buffer solutions of 4, 7, and 10, whilst the turbidity sensor is calibrated with solutions of known NTU values (20, 100, and 400 NTU). The dissolved oxygen sensor requires a two-point calibration using water-saturated air and a zero-oxygen solution. Additionally, the temperature sensor is calibrated by comparison against a dry block calibrator to verify its accuracy. The EC and salinity sensor employs a two-point calibration technique using standard conductivity solutions of 12,880 μS and 80,000 μS to span the expected measurement range. The TDS sensor meanwhile undergoes single-point calibration using a 342 ppm NaCl standard solution, which provides a reliable baseline for total dissolved solids detection. All the sensors are validated prior to field use with curve-fitting methods to confirm sensor accuracy.

Once calibrated, the system consistently collects water quality data, which is processed by Arduino Uno and transmitted to the cloud by NodeMCU, illustrated in Fig. 1. This enables remote monitoring, trend analysis and alert systems to detect deviations from the optimal water quality. The integration of this data acquisition layer supports sustainable aquaculture practice by maintaining the ideal water conditions needed for shrimp farming.

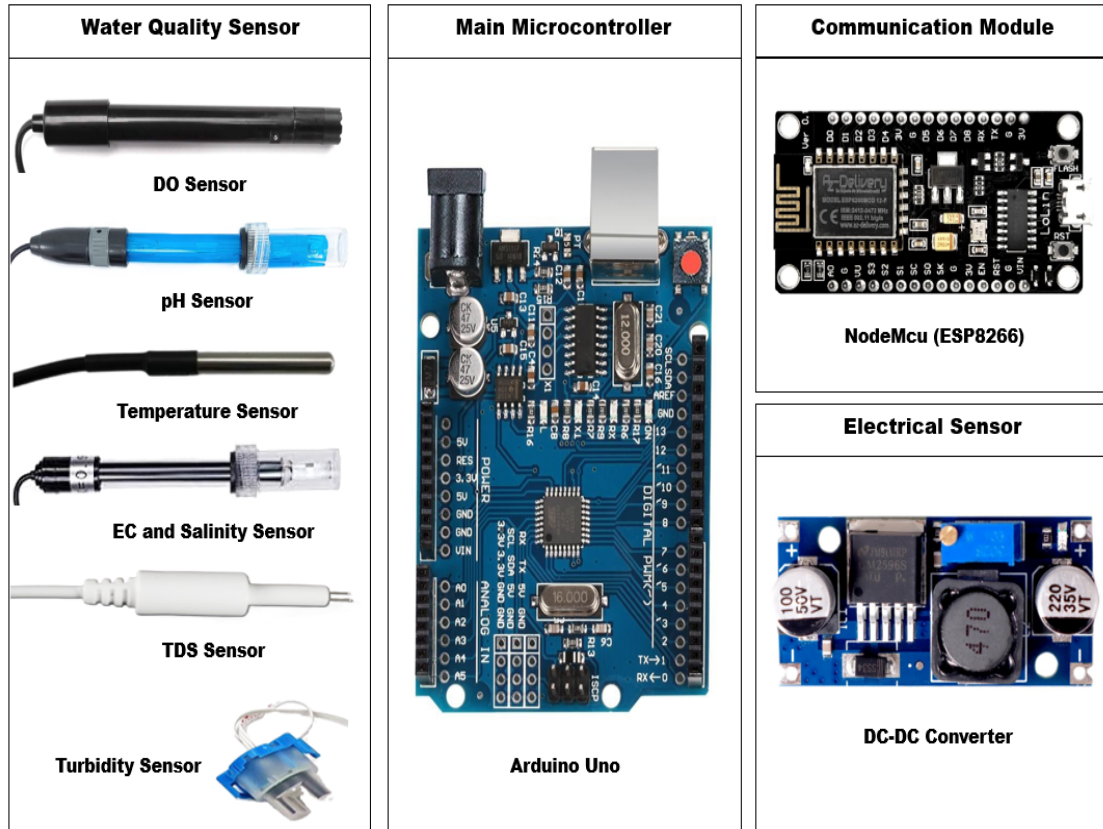


Fig. 1 Illustrates the components of the data acquisition and communication system

Table 1 List of the sensors that were used in the research

Sensor	Model	Range	Accuracy	Response time	Calibration method	Calibration equipment
pH	SEN0161-V2	0 to 14 pH	± 0.1	<1min	Three-point	Standard buffer solutions of 4, 7, and 10
Temperature	DS18B20	-10 to 85 °C	± 0.5	Within 0.75s	Comparison	Dry block calibrator
DO	SEN0237-A	0 to 20 mg/L	$\pm 10\%$	98% within 90s	Two-point	Water-saturated air (100%) 0% saturated DO solution (0%)
EC and Salinity	DFR0300-H	10-100 ms/cm	$\pm 5\%$	90% within 1s	Two-point	Standard solutions of 12,880 μS and 80,000 μS
Turbidity	TS-300B	0 to 1000 NTU	$\pm 3\%$	<500ms	Three-point	Turbidity standard solutions of 20, 100, and 400 NTU
TDS	SEN0244	0 to 1000 ppm	$\pm 10\%$	<1s	Single-point	Standard solutions of 342 ppm NaCl

2.1.2 Communication Layer

This study aimed to develop the monitoring system as a standalone unit using a new wireless access technology for observing water quality in real-time. As illustrated in Fig. 2, the communication layer was designed to transfer data from sensors to the cloud and provided remote access for continuous monitoring and analysis. The system contains a multi-sensor network consisting of sensors for measuring temperature, salinity, dissolved oxygen (DO), pH, turbidity and total dissolved solids (TDS). These parameters are crucial indicators of water quality and directly affect shrimp health and growth.

The communication layer begins with data acquisition from the sensors, which becomes an interface with the Arduino Uno microcontroller board. The controller processes raw sensor information and transmits it to a NodeMCU (ESP8266) module. The NodeMCU, equipped with Wi-Fi functionality, serves as the communication gateway, facilitating the seamless transfer of information to the cloud. Through this wireless connection, real-time statistics are continuously uploaded to the cloud provider, ensuring data availability for further analysis. The cloud platform presents a stable and dependable means for storing and processing large datasets, which is crucial for monitoring water quality especially over extended intervals.

In this system, the Blynk server functions as an intermediary cloud platform between the NodeMCU and the Blynk mobile or web application. The NodeMCU transmits data via Wi-Fi directly to the Blynk cloud server, which temporarily stores and manages the sensor data. This setup eliminates the need for complex custom backend infrastructure or third-party cloud services, simplifying deployment and maintenance.

For remote monitoring, the Blynk application is employed as the graphical person interface (GUI). Blynk presents aquaculture operators with an intuitive platform to visualize water quality statistics on smartphones or other smart devices. The GUI shows real-time data trends, sending indicators in case of parameter deviations, and lets users make statistics-driven selections to make sure satisfactory situations. Additionally, the communication layer supports bidirectional data exchange, enabling remote control and configuration of the sensors when necessary. This capability enhances the system's flexibility and responsiveness to changing environmental conditions.

Compared to traditional water quality monitoring systems, which often depend on manual sampling and laboratory testing, this wireless communication framework notably reduces the time required for data acquisition and analysis. Real-time access to water quality information ensures that operators can promptly intervene to mitigate unfavorable conditions, preventing shrimp stress, disease outbreaks, and potential losses. Wireless sensor networks (WSNs) and Internet of Things (IoT) platforms have demonstrated their effectiveness in previous studies. For instance, a wi-fi multi-sensor system, integrating temperature, pH, DO, and electrical conductivity (EC) sensors using an ESP32 Wi-Fi module, has demonstrated its effectiveness in freshwater aquaculture [23], [24]. Similarly, a LoRa-primarily based system has proven advantages in huge-scale aquaculture monitoring [25], [26]. This research highlights the reliability and applicability of wireless technology in aquaculture environments.

The standalone monitoring system works independently, powered by a solar energy system, which is depicted in Fig. 2, and it ensures uninterrupted operation even in remote locations. Solar-driven IoT systems, as described by [27], are increasingly being used in aquaculture for their sustainability and ability to overcome the challenges of power outages in rural areas. This makes the communication system very reliable, adaptable and sustainable for the environments of shrimp farming.

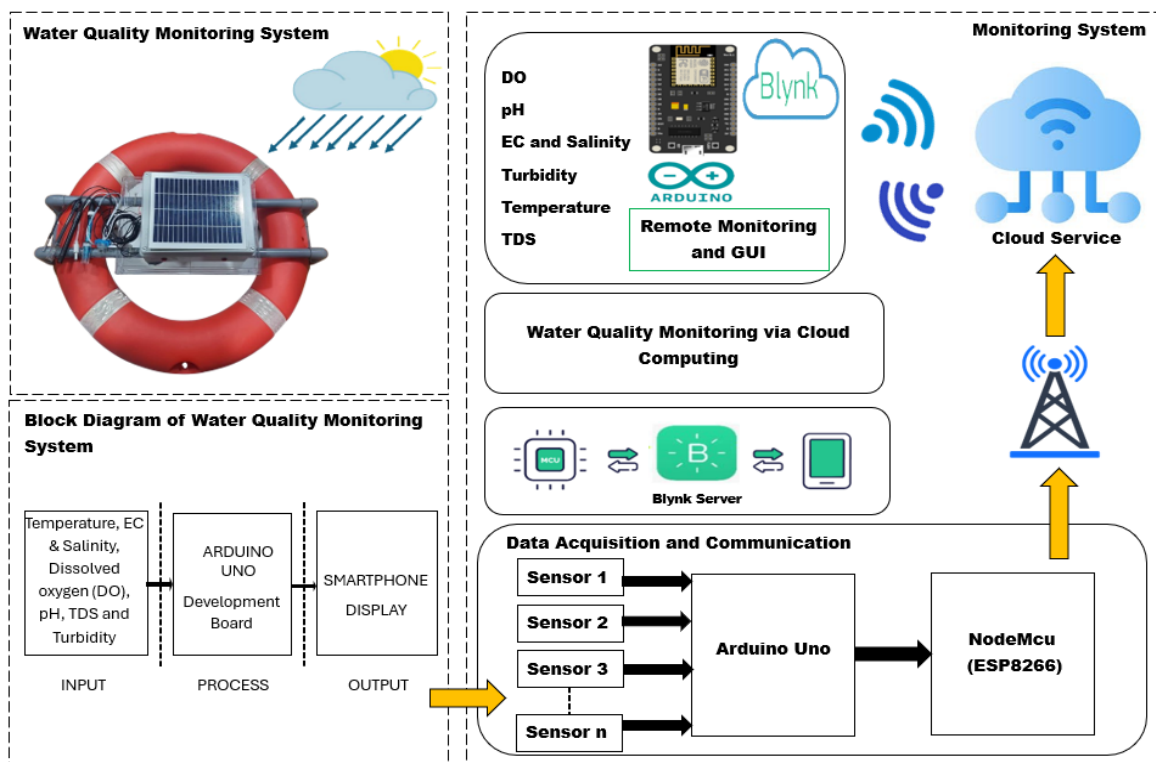


Fig. 2 An overview of the standalone water quality monitoring system for aquaculture (shrimp)

2.1.3 Cloud Server Layer

The cloud server performs three functions: (i) receiving and storing data from data acquisition and communication system, (ii) providing a graphical user interface (GUI) for remote monitoring, and (iii) serving the data to other applications (i.e. Cloud Computing). As shown in Fig. 2, the cloud server acts as the central hub to manage water quality data in aquaculture (shrimp) ponds.

The cloud server receives data transmitted by NodeMCU (ESP8266) module using Wi-Fi connectivity through a wireless network, which allows spontaneous and real-time communication between monitoring systems and cloud infrastructure. This reliable connection ensures that water quality parameters including temperature, salinity, DO, pH, TDS, and turbidity are immediately uploaded to the cloud server for processing, storage and analysis to the water quality parameters collected. Taking advantage of the capabilities of wireless communication, the system facilitates continuous data transmission without the need for long physical wiring, and this is especially suitable for remote aquaculture environment.

In addition, the Cloud Server is integrated with the Blynk platform to provide a GUI for remote monitoring. The Blynk server functions as a middleware platform, enabling seamless interaction between the NodeMCU microcontroller and the mobile application interface. It manages the data flow, authentication, and device control in real-time allowing two-way data exchange between the hardware and the user dashboard. Through GUI, users can access real-time data, visualize trends and receive parameter deviation notifications. This interface ensures that aquaculture farmers can effectively monitor and manage water quality, even from remote places. Beyond monitoring, the cloud server supports further data processing through cloud computing. This enables the system to perform advanced analytics, generate trends and integrate with other applications as required. As illustrated in Fig. 2, the cloud server layer is essential for ensuring real-time accessibility, scalability, and decision-making in shrimp aquaculture systems.

2.1.4 User Application Layer

Blynk was used to develop a remote monitoring application to display water quality parameters in aquaculture (shrimp) ponds. As shown in Fig. 3, the Blynk platform provides a versatile GUI that enables aquatic farmers to have water quality parameters such as DO, pH, temperature, turbidity, TDS, and salinity. The application is compatible with both mobile devices and web browsers, ensuring for real-time remote monitoring, flexibility and accessibility. The Blynk application integrates various widgets, consisting of graphs, gauges, and notifications, to symbolize real-time and historic data intuitively. Alerts can be configured to inform users whilst any parameter deviates from predefined thresholds, making sure immediate action to mitigate the deficiencies. Studies which include those via [28], [29] have validated the effectiveness of mobile based monitoring platforms like Blynk in reducing response times and improving decision-making processes in aquaculture systems.

In this system, the NodeMCU (ESP8266) acts as a communication module that transfers sensor data to the cloud, where it can be remotely accessed by the Blynk application. The data first passes through the Blynk server, which functions as an intermediary cloud service managing data routing, authentication, and storage for real-time visualization. This server plays a key role in linking the hardware system with the GUI, ensuring data integrity and fast communication cycles between the sensor device and the end-user interface. According to [30], the integration of Blynk with IoT-enabled aquaculture systems complements operational efficiency by minimizing manual data collection and enabling 24/7 monitoring. Additionally, a development in [31] highlighted Blynk's reliability and scalability in IoT based systems, making it a popular choice for monitoring real-time data in aquaculture.

Blynk additionally permits customers to investigate historical trends in water quality data, which is important for understanding long-term patterns and their impact on shrimp health and growth. This functionality aligns with findings through [32], who mentioned that monitoring systems with retrieved data analysis enhances management practices and reduces aquaculture risks. The system compatibility with alert configurations prompts proactive management, as discussed by [33], who emphasized the importance of real-time alerts for maintaining optimal aquaculture conditions. As illustrated in Fig. 3, the user application layer plays a critical role in connecting the data collection system with end users. It does not only improve monitoring functions but also provides insights to optimize shrimp aquaculture productivity, reduce operating costs and improve sustainability.

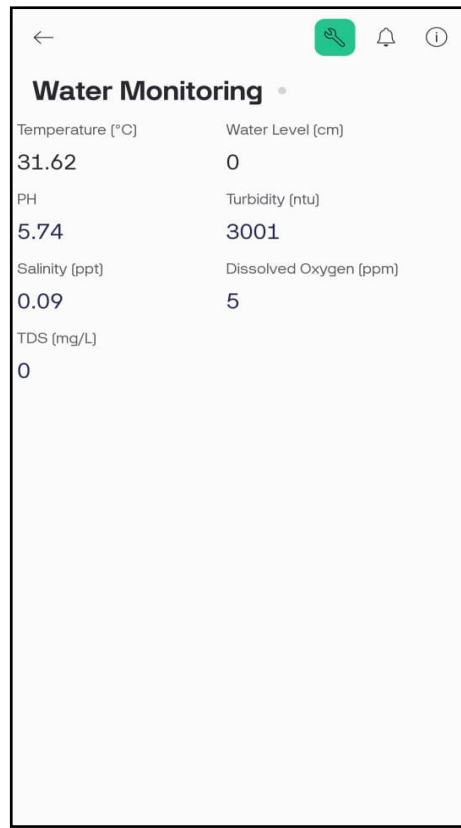


Fig. 3 An overview of Blynk IoT dashboard displaying real-time water quality monitoring data

2.2 Prototype

The prototype was built based on the proposed monitoring system for standalone water quality measurement for shrimp aquaculture and it incorporates solar powered energy to enable sustainable and remote operation. As shown in Fig. 4, the system has a modular design that includes key components such as a solar panel for power generation, a sealed enclosure for housing electronic circuits and a set of sensors mounted externally to collect water quality data.

Inside the enclosure, the prototype integrates an Arduino Uno microcontroller board for data processing and a NodeMCU (ESP8266) module for wireless communication with the cloud server. The system also includes a charge controller to control the power flow between the solar panel and the 12V recharge battery, thus ensuring continuous operation in low light conditions. The sensors, connected by waterproof wiring, measures parameters such as DO, pH, salinity, turbidity, temperature and TDS. The outer design ensures sturdiness and buoyancy, with the device set up on a lifestyles buoy to remain afloat in aquaculture ponds. The enclosed layout protects the inner electronics from water damage. The long wires are connected with the sensors such that it can facilitate sensor replacement or maintenance. This setup demonstrates the feasibility of deploying a low-cost, energy-efficient, and reliable monitoring solution tailored for aquaculture applications.

The research was conducted at Muar, Johor, Malaysia, a prominent area for aquaculture activities, mainly shrimp farming. This location has become chosen for its active aquaculture operations and suitability for evaluating the performance of the water quality monitoring system. Data collection was taken over a 2-day duration. The monitoring system was designed to measure key water quality parameters which are critical to shrimp farming, including temperature, salinity, DO, pH, TDS, and turbidity. These parameters had been recorded using commercial sensors integrated with a solar-powered energy system for sustainability. The data were transmitted and visualized in real-time using the Blynk application, providing continuous insights into water quality variations. This ongoing data acquisition ensures that the system captures both short-term fluctuations and long-term trends in water quality, essential for maintaining optimal conditions for shrimp aquaculture.

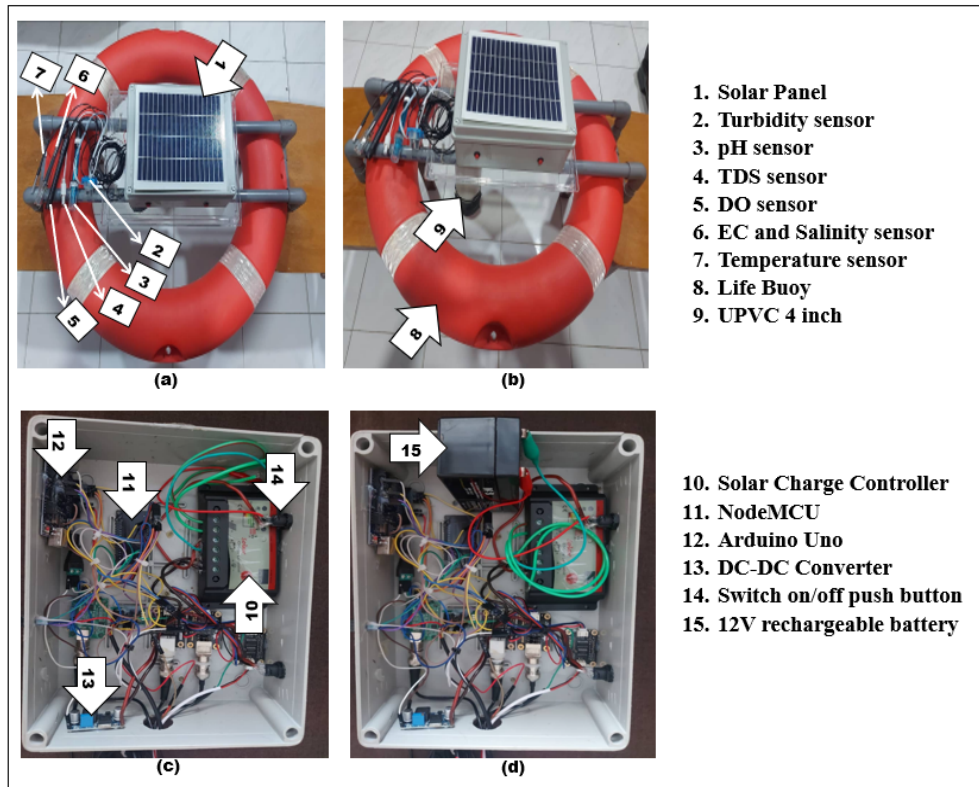


Fig. 4 Prototype of the proposed standalone water quality monitoring system for shrimp aquaculture, showing internal components (a, b); and external components (c, d)

3. Results and Discussion

The results from the water quality monitoring system at Muar, Johor, demonstrate significant variations in pH levels across the two-day observation period, as shown in Fig. 5(a) and Fig. 5(b). On the first day (Fig. 5a), the pH levels fluctuated between approximately 6.5 and 9.0, with a notable drop occurring around 18:30. This variation suggests dynamic changes in water conditions, possibly influenced by environmental factors such as feed input, biological activity, and aeration processes. On the second day (Fig. 5b), the pH range was slightly smaller, between 7.2 and 9.2, demonstrating a more stable condition with a trend of increasing pH during specific time intervals. The output demonstrates that pH levels tend to rise during daylight hours, likely due to increased photosynthetic activity, where oxygen production from aquatic plants and algae contributes to higher pH values [34].

When the pH level drops below 7, buffering agents such as sodium bicarbonate or calcium carbonate can be introduced into the pond to stabilize the pH and maintain optimal conditions for shrimp health. To lower elevated pH levels, strategies such as partial water exchange, reducing photosynthetic activity such as by limiting excessive algae growth through shading or the application of algicides, and carefully applying acidifying agents like aluminum sulfate or phosphoric acid in controlled amounts can be used. Maintaining balanced nutrient input and monitoring phytoplankton density are also essential to avoid drastic pH fluctuations.

These findings highlight the importance of continuous water quality monitoring to maintain optimal conditions for shrimp growth, as abrupt changes in pH can stress the shrimp, affecting their metabolism and survival rates. The observed pH trends align with studies that suggest ideal pH levels for shrimp farming should remain within 7.5 to 8.5 to ensure healthy growth and prevent stress-related issues [35]. Furthermore, the differences between the two days indicate potential external influences such as feeding schedules, aeration adjustments, or microbial activity, which require further analysis.

Overall, the real-time monitoring system effectively captures water quality dynamics, enabling timely intervention to stabilize pH levels. The data shown in Fig. 5 confirms the capability of the system to track fluctuations and detect anomalies in water conditions. Future research should incorporate additional parameters such as ammonia concentration to provide a more comprehensive understanding of water quality variations in shrimp aquaculture systems.

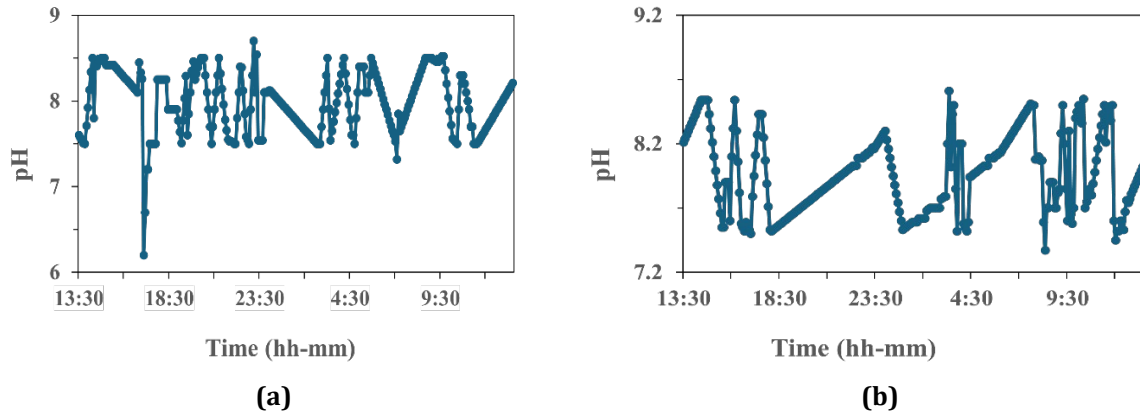


Fig. 5 Variation of pH levels in shrimp aquaculture over two consecutive days: (a) represents the first day, while (b) represents the second day

The temperature variations recorded over two consecutive days in shrimp aquaculture are depicted in Fig. 6(a) and Fig. 6(b). The first day's data Fig. 6(a) exhibit fluctuating temperature trends, ranging approximately between 27.5°C and 31.5°C. The sharp oscillations suggest dynamic environmental conditions, possibly influenced by external factors such as ambient temperature changes, water circulation, or aeration systems in the aquaculture pond. Such fluctuations can impact shrimp metabolism, growth rate, and overall health, as shrimp are highly sensitive to abrupt temperature variations [36].

On the second day, Fig. 6(b), the temperature pattern shows a more stable trend initially, maintaining an average of around 29°C before a significant drop occurs in the early morning hours, reaching nearly 19°C. This sudden decline may have resulted from environmental cooling, or external interventions such as water exchange or aerator operation. A subsequent rise in temperature is observed, indicating a recovery phase. Prolonged exposure to suboptimal temperatures can induce stress in shrimp, affecting feed intake, immune response, and overall productivity [37].

Monitoring temperature fluctuations in real time is crucial for optimizing shrimp aquaculture conditions. The data collected highlights the importance of implementing automated control systems or early warning mechanisms to mitigate the effects of extreme variations. Integrating smart sensor technologies and IoT-based monitoring can enhance aquaculture management by providing timely alerts and enabling rapid corrective measures [38].

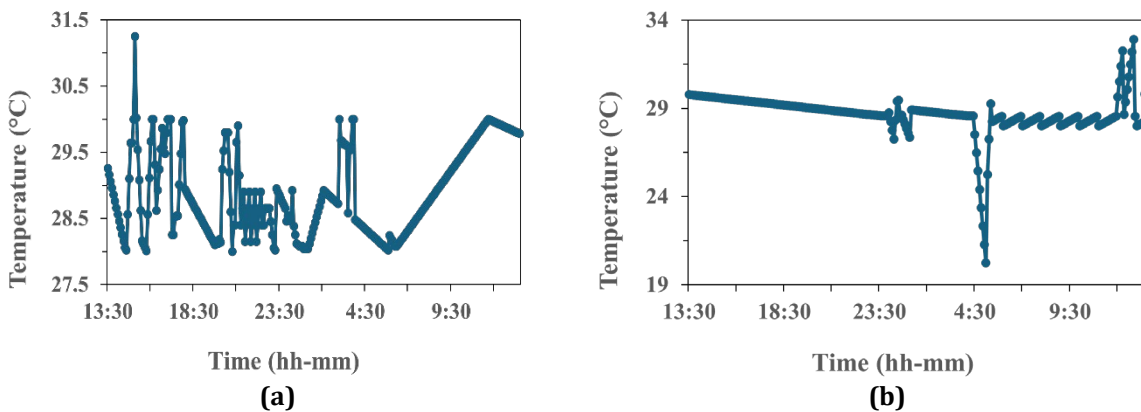


Fig. 6 Variation of temperature levels in shrimp aquaculture over two consecutive days: (a) represents the first day; while (b) represents the second day

The Total Dissolved Solids (TDS) levels in the shrimp aquaculture system were monitored continuously over two consecutive days, as shown in Fig. 7. The results indicate fluctuations in TDS concentrations throughout the observed period, likely influenced by factors such as feeding activities, water exchange, and biological processes in the pond environment.

On the first day (Fig. 7a), the TDS values exhibited high variability, with sharp increases and decreases, particularly during the initial monitoring period. These fluctuations could be attributed to feed inputs and

metabolic waste accumulation, which can temporarily elevate TDS levels. The spikes and dips observed may also be due to water aeration and sediment resuspension, common in intensive aquaculture systems [34].

On the second day (Fig. 7b), TDS levels showed a relatively more stable pattern, with some intermittent fluctuations. A notable drop in TDS occurred around midnight, which may be linked to water exchange or sedimentation processes. The more stable trend observed later suggests that the system may have reached equilibrium after the initial disturbances. Regular monitoring and proper management of TDS are essential for maintaining optimal water quality, as excessive variations can stress shrimp and affect growth performance [40].

Overall, the findings highlight the dynamic nature of TDS levels in shrimp aquaculture ponds, emphasizing the importance of continuous monitoring to ensure water quality remains within suitable thresholds. Future studies should further investigate the correlation between TDS variations and shrimp health indicators to optimize farm management strategies.

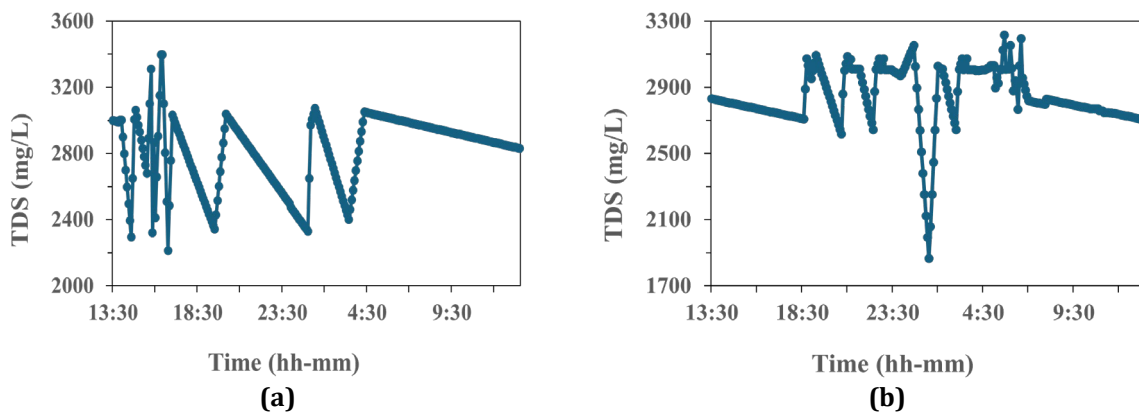


Fig. 7 Variation of total dissolved solids levels in shrimp aquaculture over two consecutive days: (a) represents the first day; while (b) represents the second day

The salinity levels in shrimp aquaculture ponds exhibited significant temporal variation over the two observed days, as shown in Fig. 8. On the first day (Fig. 8a), salinity fluctuated between approximately 9 and 29 ppt, showing a declining trend throughout the monitoring period. The data indicates irregular but frequent fluctuations, likely influenced by external factors such as tidal changes, evaporation rates, and freshwater influx from rainfall or water exchange processes. These variations can significantly impact shrimp growth and metabolism, as extreme fluctuations can induce osmotic stress [41].

On the second day (Fig. 8b), the salinity pattern showed a different trend, with an initial stable period ranging from 10 to 15 ppt, followed by a sharp increase reaching up to 30 ppt. This increase could be attributed to water management practices such as pond drainage and water replenishment, which are commonly employed in shrimp farming to optimize water quality parameters [36]. The observed trend highlights the importance of continuous monitoring to maintain optimal salinity levels, as abrupt changes could negatively affect shrimp survival and growth rates.

Overall, these findings underscore the dynamic nature of salinity in shrimp aquaculture ponds and the need for proper management strategies to ensure stable conditions. Maintaining salinity within an optimal range is crucial for shrimp health and productivity, as deviations from the ideal range (typically 10–25 ppt for many shrimp species) can lead to physiological stress and increased susceptibility to diseases [40]. Further studies incorporating additional environmental factors such as temperature and dissolved oxygen levels could provide a more comprehensive understanding of water quality dynamics in aquaculture systems.

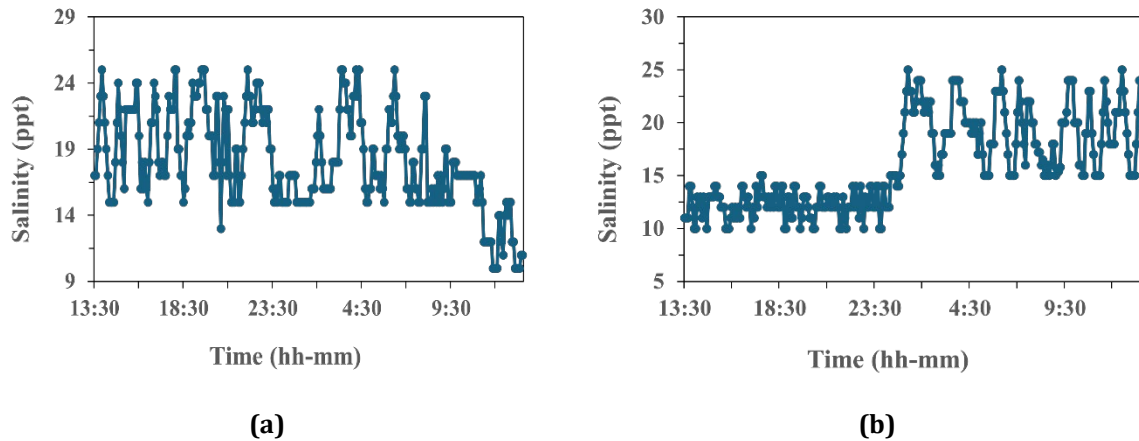


Fig. 8 Variation of salinity levels in shrimp aquaculture over two consecutive days: (a) represents the first day; while (b) represents the second day

Dissolved oxygen (DO) is a crucial parameter in shrimp aquaculture, directly affecting the health and productivity of the cultured organisms. As shown in Fig. 9(a) and 9(b), the DO levels exhibited substantial fluctuations over both days, with peaks and troughs occurring at different times. On the first day, the DO concentration showed a high variability, reaching values above 20 ppm at certain intervals, followed by sharp declines. This could be attributed to the photosynthetic activity of phytoplankton during daylight hours, which enhances oxygen production, whereas respiration and microbial decomposition processes contribute to oxygen depletion during the night. The lowest DO concentrations were observed in the early morning hours, a common phenomenon due to the absence of photosynthesis and continued oxygen consumption by aquatic organisms and microbial communities.

On the second day, represented by Fig. 9(b), the overall trend appeared more stabilized, with DO levels remaining mostly within the range of 5–15 ppm. Compared to the first day, extreme fluctuations were reduced, suggesting potential adjustments in aeration or changes in environmental conditions such as water temperature and organic matter decomposition. Proper aeration management is critical in aquaculture systems to prevent hypoxic conditions that can stress or even be fatal to shrimp [36]. Maintaining DO levels above 5 ppm is generally recommended for optimal shrimp growth and survival [42].

The observed trends highlight the importance of continuous monitoring and proactive management of DO in shrimp ponds. Sudden drops in oxygen levels, particularly during nighttime and early morning, necessitate interventions such as mechanical aeration to maintain a stable environment for shrimp. Furthermore, excessive DO fluctuations could indicate imbalances in pond ecology, such as excessive algal growth or organic matter decomposition, which should be addressed through proper feeding strategies and water exchange.

In conclusion, the results emphasize the dynamic nature of DO in aquaculture systems and underscore the necessity of real-time monitoring to prevent adverse effects on shrimp health and production. Implementing aeration strategies and optimizing pond management practices can help maintain stable DO levels, ensuring a conducive environment for shrimp farming.

Turbidity is a crucial water quality parameter in shrimp aquaculture, as it influences light penetration, alga growth, and the overall health of shrimp [36]. Figure 10 illustrates the fluctuations in turbidity over a 24-hour period for two consecutive days. The results indicate that turbidity levels varied dynamically, with noticeable peaks and troughs at different times of the day.

On the first day (Fig. 10a), turbidity values fluctuated mostly between 3 to 10 NTU, with sporadic spikes reaching above 10 NTU. This variability can be attributed to feeding activities, sediment resuspension due to shrimp movement, and external environmental factors such as water exchange and aeration [44]. Similarly, on the second day (Fig. 10b), the turbidity levels followed a comparable pattern, ranging mostly from 2 to 12 NTU. However, there were more frequent high peaks, suggesting increased particulate matter in the water column, which may have resulted from intensified feeding or biological activity.

Comparing both days, the second day exhibited slightly higher turbidity variations, which could be due to cumulative organic matter buildup from uneaten feed and shrimp excretion. High turbidity levels can lead to oxygen depletion and stress in shrimp, affecting growth rates and survival [45]. Therefore, continuous monitoring and proper management strategies, such as optimizing feeding practices and ensuring efficient water exchange, are essential to maintaining optimal water quality in shrimp aquaculture systems.

These findings highlight the importance of real-time monitoring of turbidity in aquaculture ponds to ensure stable water quality conditions. Future studies should incorporate additional parameters, such as dissolved

oxygen and ammonia levels, to provide a more comprehensive assessment of the water quality dynamics in shrimp farming.

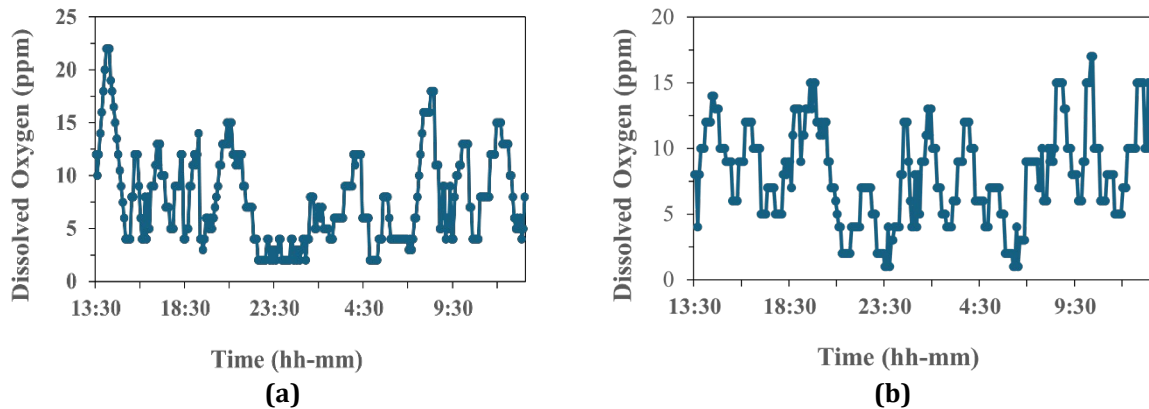


Fig. 9 Variation of Dissolved Oxygen levels in shrimp aquaculture over two consecutive days: (a) represents the first day; while (b) represents the second day

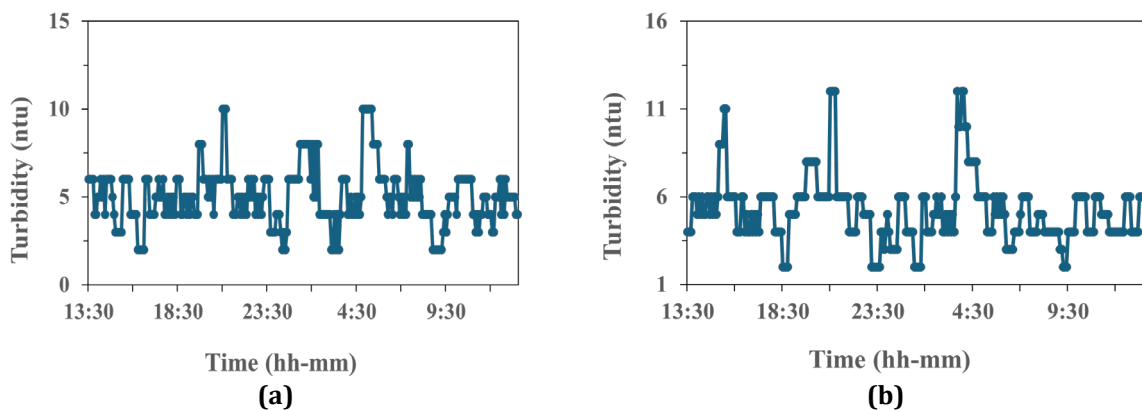


Fig. 10 Variation of turbidity levels in shrimp aquaculture over two consecutive days: (a) represents the first day; while (b) represents the second day

Although only two days of data were collected, the continuous real-time monitoring system managed to capture essential short-term fluctuations in water quality parameters such as pH, DO, temperature, TDS, salinity and turbidity during daytime and nighttime. These continuous data points allowed identification of continuous daily variation patterns and immediate responses to environmental changes. While longer observation periods are recommended for capturing broader seasonal trends, the two-day duration can be justified for practicality of this prototype to be used for overnight measurement at site. This study is also a part of an ongoing monitoring process where data collection is still continuing. This short-term dataset was sufficient to demonstrate the system's responsiveness, reliability, and potential for early detection of water quality issues in shrimp aquaculture.

The performance of the developed system was evaluated through its ability to operate continuously in outdoor field conditions using solar energy. The system maintained consistent wireless connectivity and transmitted data in real-time to the Blynk application without interruption. This demonstrates its capability to function as a standalone solution without dependency on wired power sources or external networking infrastructure. Throughout the two-day observation period, the system showed stable uptime with no hardware or communication failures, validating its field reliability. Sensor responsiveness was validated through timely detection of water quality fluctuations, confirming the reliability and precision of the monitoring setup. System logs verified that each sensor delivered data within defined time intervals with minimal latency, showing strong integration between the data acquisition and transmission layers. For instance, the system accurately captured daily variations in parameters such as pH, DO, temperature, TDS, salinity and turbidity, especially during night and early morning, demonstrating the capability of the sensors and communication layer to respond effectively to dynamic changes. These sensor readings were visualized through the Blynk interface in real time, and alert

notifications were triggered when values approached critical thresholds. These operational outcomes reflect not just the environmental conditions, but the system's effectiveness in detecting, processing, and transmitting data in real-time with minimal human intervention. Hence, the system meets the design goals of automation, reliability, and usability for aquaculture environments.

4. Conclusion

In conclusion, the monitoring of key water quality parameters, including pH, DO, temperature, turbidity, salinity and TDS, provides crucial insights into the aquatic conditions necessary for optimal shrimp growth. The observed fluctuations in pH over two days indicate the influence of biological processes, while variations in other parameters such as dissolved oxygen and temperature suggest the effects of external factors like feeding schedules, aeration, and environmental conditions. Over the two consecutive days, the measured range is 6.5 – 9.0 for pH, 19 – 31.5°C for temperature, 9.0 – 25.0 ppt for salinity and 2.0 – 12.0 NTU for turbidity. These measurements fall under optimal range for shrimp aquaculture. However, for the TDS and DO, they fall short under optimal range. TDS which has a measured range from 1800 to 3400 ppm is supposed to be lower than 1500 ppm. This high value of TDS could be attributed to feed inputs and metabolic waste accumulation, and this can be reduced by performing partial water changes using low-TDS water sources or incorporating activated carbon filters to remove dissolved substances. Meanwhile, DO records a measurement range between 2.5 and 22.0 ppm and it is found that the low DO is observed at late night which fall short of DO range higher than 5 ppm. This DO deficiency can be overcome by implementing mechanical aeration at late night to increase the DO level. The results highlight the need for continuous real-time monitoring using advanced sensor technologies to ensure precise control of critical parameters. Implementing automated systems for water quality regulation can significantly improve sustainability and efficiency in shrimp aquaculture, reducing the risks associated with environmental fluctuations.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Vicknes Chan, Noran Azizan Cholan, Nurfatimah Che Abd Rashid, Siti Farhana Mohamad Jaafar; **data collection:** Vicknes Chan, Linges Paramalingam, Nor Hafizah Ngajikin; **analysis and interpretation of results:** Vicknes Chan, Noran Azizan Cholan, Kim Gaik Tay; **draft manuscript preparation:** Vicknes Chan, Noran Azizan Cholan, Budi Astuti. All authors reviewed the results and approved the final version of the manuscript.

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