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Development of an Integrated Dissolved Oxygen Monitoring System in a Prawn Nursery Pond

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ABSTRACT

This study developed and evaluated an integrated dissolved oxygen (DO) monitoring system for a prawn nursery pond. Using a research and development approach, the system was designed to automate oxygen-level monitoring, activate aeration when DO levels fall below a user-defined threshold, and provide real-time visualization through a web-based interface. The system integrated a DO probe sensor, Arduino microcontroller, NodeMCU-ESP8266 Wi-Fi module, web server, database, graphical user interface, and aeration system using air-stone diffusers. Laboratory testing was conducted using a 16 x 8 x 10-inch aquarium tank with 5 liters of water, while field testing was conducted to determine system functionality, connectivity, usability, accuracy, reliability, and efficiency. The system was validated by three IT experts, three fishery experts, and three end users or prawn farmers using an ISO 9126-based evaluation instrument and a five-point response scale. Results showed very high acceptability ratings from IT experts (4.95), fishery experts (4.92), and users (4.97), all verbally interpreted as Strongly Agree. The findings confirmed that the system could monitor DO values in real time, activate aerators to regulate oxygen levels, generate graphical reports, and support remote access through Wi-Fi-enabled devices. The study concludes that the integrated DO monitoring system can improve water-quality management, reduce manual monitoring work, and support more efficient and sustainable prawn nursery operations.

Keywords: *dissolved oxygen monitoring, prawn nursery pond, aeration control, microcontroller, aquaculture automation, water quality monitoring*

INTRODUCTION

Aquaculture is one of the fastest-growing food production systems worldwide, and its expansion has increased the need for sustainable and efficient water-quality management. In prawn nursery operations, dissolved oxygen (DO) is a critical water-quality parameter because inadequate oxygen can cause stress, reduced growth, disease vulnerability, and mortality among aquatic organisms. Hypoxia and anoxia remain among the most common natural causes of fish kills, making oxygen monitoring a major operational concern in aquaculture systems (Alosairi et al., 2021; Boyd, 2022; Kibria, 2014).

Prawn and shrimp farming have become economically important because of the strong market demand for high-value aquaculture products. In the Philippines, prawn production forms part of a fisheries sector that contributes substantially to food supply and livelihood. However, more intensive nursery and grow-out operations increase oxygen demand and heighten the risk of low DO, especially when stocking density, feeding, water exchange, and aeration are not properly managed (Briggs et al., 2004; Macusi et al., 2022; Tahiluddin & Terzi, 2021).

The shrimp nursery stage serves as the transitional phase between hatchery and grow-out production. At this stage, the survival and growth of Whiteleg shrimp or Pacific white shrimp (Litopenaeus vannamei) depend greatly on stable environmental conditions. Aeration is commonly used to maintain adequate oxygen levels, and the source manuscript notes that DO should remain above 3.0 mg/L to avoid harmful stress conditions. Because oxygen concentration fluctuates with time of day, temperature, salinity, photosynthesis, respiration, and water movement, manual observation may not be enough to prevent sudden oxygen decline (Boyd et al., 2019; Suwoyo et al., 2021).

Recent developments in microcontrollers, sensors, wireless networks, and web-based visualization tools provide opportunities to improve aquaculture monitoring. Through automation, farmers can receive real-time DO readings, adjust aeration thresholds, store water-quality data, and view reports through connected devices. These capabilities reduce dependence on repeated manual checking and support faster response when oxygen values reach critical levels (Boonsong et al., 2020; Kim et al., 2023; Li et al., 2019).

This study therefore developed an integrated dissolved oxygen monitoring system for a prawn nursery pond. Specifically, it aimed to design and validate a system capable of real-time oxygen measurement, remote monitoring, threshold-based aerator activation, database storage, and graphical data visualization. The system was intended to support water-quality management, lessen personnel costs and managerial duties, and help improve the sustainability and efficiency of prawn nursery operations.

Literature Review

Dissolved Oxygen and Prawn Nursery Water Quality

Dissolved oxygen is a central water-quality factor in aquaculture because it directly affects respiration, metabolism, feeding behavior, and survival of fish and crustaceans. Ali and Mishra (2022) explained that oxygen concentration influences freshwater fish health, while Boyd (2022) emphasized that DO management remains a major concern in aquaculture systems. In prawn nursery ponds, oxygen deficiency is particularly harmful because postlarvae and juveniles are vulnerable to environmental stress during early growth.

The source manuscript highlights that DO concentration changes throughout the day. It tends to decrease at night because photosynthesis stops while respiration and oxygen-consuming processes continue. During daytime, DO may rise because photosynthetic activity contributes oxygen to the water. These fluctuations show why continuous monitoring is needed, especially in artificial nursery environments where stocking and feeding can increase oxygen demand (Boyd et al., 2019; Dodds, 2002).

Literature on shrimp and prawn farming also shows that oxygen management supports productivity. Briggs et al. (2004) discussed the movement and culture of Penaeus vannamei in Asia and the Pacific, while Suwoyo et al. (2021) examined nursery practices under different densities using aeration systems. These studies support the need for aeration-assisted monitoring technologies that can keep water conditions within safe and productive ranges.

Microcontroller-Based Monitoring and Smart Aquaculture

Smart aquaculture applies sensors, embedded devices, wireless communication, and software interfaces to monitor and manage pond conditions. The study used a DO sensor, Arduino microcontroller, NodeMCU-ESP8266 Wi-Fi device, relay module, web server, and a graphical interface to form an integrated monitoring and control system. This design aligns with studies showing that real-time monitoring platforms can strengthen data collection and improve decision-making in fish and shrimp production (Boonsong et al., 2020; Kim et al., 2023).

Microcontroller technologies are useful because they can read sensor values, trigger actuators, and transmit data through networks. In this study, the Arduino controlled the aeration mechanism, while the NodeMCU-ESP8266 provided Wi-Fi communication for the monitoring system. Such devices support a cost-efficient approach because they are flexible, programmable, and compatible with web-based applications that allow remote viewing of system data.

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Prediction and monitoring studies also support the importance of data-driven oxygen management. Li et al. (2019) investigated dissolved oxygen prediction in fishery ponds using machine learning, while Kim et al. (2023) examined DO management approaches for aquaculture enhancement. Although the present system focused on real-time monitoring and threshold-based aeration rather than predictive analytics, these studies indicate the broader value of digital oxygen management in aquaculture.

Aeration Control, Automation, and Sustainable Prawn Production

Aeration is an important intervention for maintaining oxygen at levels suitable for aquatic animal growth. In the source manuscript, the aeration system used air-stone diffusers controlled by a microcontroller. When DO values fall below a predetermined threshold, the aerators activate automatically, allowing the system to regulate oxygen levels without requiring constant manual intervention.

Automation contributes to sustainability by improving response time and reducing the labor burden of routine monitoring. The system automatically saves sensor readings in a database, converts readings into graphical data, and displays them through the user interface. These functions allow farmers or managers to review trends, identify poor oxygen conditions, and adjust thresholds based on pond requirements.

Sustainable aquaculture requires balancing productivity, animal welfare, water quality, and operational efficiency. Boyd et al. (2019) emphasized the need for improved sustainable aquaculture practices, while Macusi et al. (2022) discussed environmental and socioeconomic issues associated with shrimp farming in the Philippines. The integrated DO monitoring system responds to these concerns by supporting timely aeration control and data-based management in prawn nursery operations.

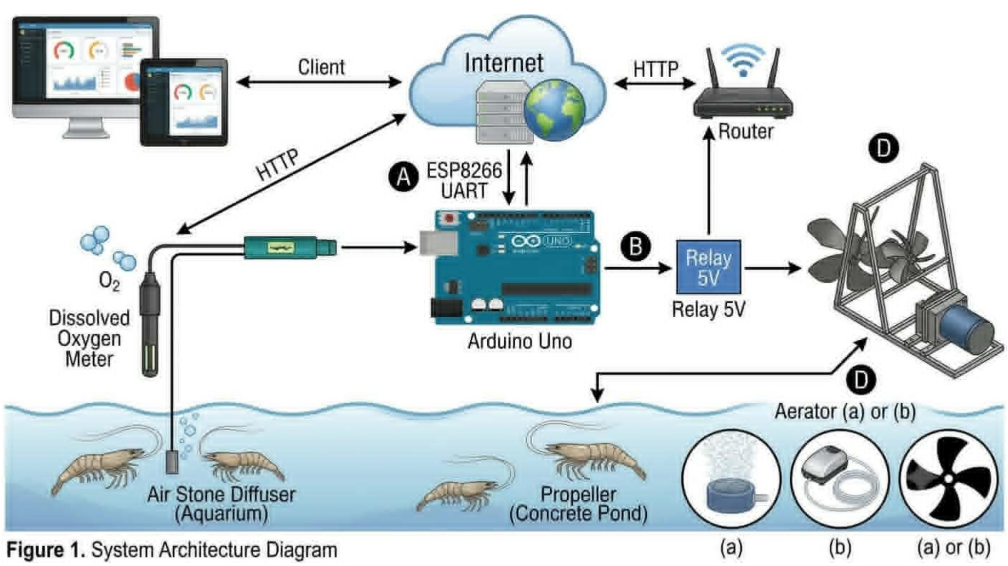

Figure 1. *Conceptual framework/system overview of the integrated dissolved oxygen monitoring system*

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METHODS

Research Design

The study used a research and development (R&D) approach to design, develop, and validate an integrated dissolved oxygen monitoring system for a prawn nursery pond. The R&D process followed three phases: preliminary data gathering, system development, and validation or evaluation. This approach was appropriate because the study focused on producing a functional technological system and determining its acceptability, accuracy, efficiency, and usability.

Research Locale and Experimental Setup

The system was developed for use in a prawn nursery pond, particularly for Whiteleg shrimp or Pacific white shrimp (Litopenaeus vannamei). Preliminary information was gathered through interviews and observation of prawn-farm operations, including pond ecosystems, shrimp life-cycle activities, and water-quality monitoring practices. Laboratory testing was conducted using a 16 x 8 x 10-inch aquarium tank containing 5 liters of water with an 8-inch water depth, a submersible thermometer, and artificial sunlight simulation. Actual field testing was also performed to evaluate the system in a more realistic aquaculture context.

Participants and Validators

The system was evaluated by three groups of validators: three IT experts, three fishery experts, and three end users or prawn farmers. The IT experts evaluated system functionality, reliability, interoperability or connectivity, usability, and user interface. The fishery experts assessed the system in terms of functionality, reliability, usability, accuracy, efficiency, and user interface. The end users evaluated the system based on functionality, usability, and user interface in relation to practical aquaculture use.

System Components and Research Instrument

The integrated system consisted of a dissolved oxygen probe sensor, Arduino microcontroller, NodeMCU-ESP8266 Wi-Fi module, LM2596 DC-DC converter, one-channel relay module, aerators with air-stone diffusers, web server, database, and web application. The Arduino read the DO values and controlled the aerators, while the NodeMCU-ESP8266 enabled network communication. The web application stored readings, presented graphical visualization, and allowed users to set the oxygen-level threshold.

The main evaluation instrument was a questionnaire based on the ISO 9126 quality standard. A five-point response scale was used: 4.50-5.00, Excellent/Strongly Agree; 3.50-4.49, Very Satisfactory/Agree; 2.50-3.39, Satisfactory/Slightly Disagree; 1.50-2.49, Fair/Disagree; and 0-1.49, Poor/Strongly Disagree.

Data Gathering Procedure

During the preliminary phase, the researcher reviewed literature, conducted interviews with prawn-farm owners, consulted IT professionals and aquaculture experts, and observed actual workplaces to identify water-quality monitoring needs. During the development phase, the system architecture, network connection, control circuit, and web application were created and refined. During validation, the system was tested in laboratory and field settings and then rated by IT experts, fishery experts, and users.

In laboratory testing, the DO probe was submerged in the aquarium tank and readings were automatically saved in the database, transformed into graphical data, and displayed through the interface. In field testing, the system was used to demonstrate real-time DO monitoring, threshold setting, aerator activation, report generation, and accessibility through devices connected to Wi-Fi.

Data Analysis

Weighted mean was used to analyze the acceptability ratings from the validators. The arithmetic mean formula x = sum fx/n was used, where x represents the mean, f represents the frequency, and n represents the total number of responses. The results were interpreted using the five-point verbal description scale adopted in the study.

Ethical and Safety Consideration

The study gathered information from relevant experts and users for system improvement and validation. Respondents evaluated the system based on their expertise and actual experience. Laboratory and field testing were conducted carefully to avoid harm to users, equipment, and aquaculture organisms. The data collected from the system evaluation were used only for research and system-development purposes.

RESULTS AND DISCUSSION

System Design and Operational Features

The developed system integrated sensing, control, network, aeration, and visualization components into a single DO monitoring platform. The system measured the current oxygen level through a probe sensor, transmitted the readings through the microcontroller and Wi-Fi module, saved the values in a database, and displayed the results through a web-based interface. When the DO value fell below the threshold set by the user, the aerators automatically activated to increase oxygen in the water.

The system overview shows the interaction among the DO sensor, Arduino-based embedded unit, Wi-Fi communication, aerator, web server, and user devices. This structure enabled the system to function as both a monitoring and control platform. The design also supported report generation, percentage summaries of good and bad readings, and adjustable time intervals for saving acquired data.

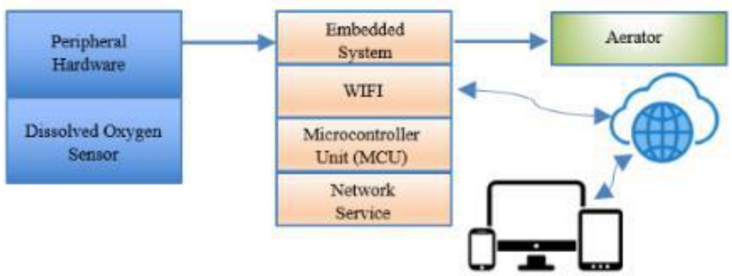

Figure 2. *Structure of the dissolved oxygen monitoring system*

Table 1. Summary of Core System Components and Functions

Component	Function in the System
Dissolved oxygen sensor	Measures oxygen level in the water and provides the main input for monitoring and aeration control.
Arduino microcontroller	Reads DO sensor data and controls the aerator through the relay module.
NodeMCU-ESP8266 Wi-Fi module	Enables wireless communication between the monitoring device and the web application.
Relay module and aerator	Activates aeration when DO level falls below the user-defined threshold.
Web server and database	Stores readings and supports access to historical and current DO data.
Web application/interface	Displays graphical visualization, reports, and user settings for threshold and data interval.

Laboratory and Field Testing

Laboratory testing demonstrated that the system could collect DO readings from the aquarium tank and transmit the readings to the web application. The use of artificial sunlight, floating plants, and a controlled tank environment allowed the researcher to observe oxygen-level behavior and verify whether readings were captured and stored properly. The field test further demonstrated that users could dynamically set the threshold value based on the optimal pond condition and observe data through graphical visualization.

The system also showed practical value because it could be accessed through any device connected to Wi-Fi. This feature supports remote observation within the local network and reduces the need for repeated manual

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inspection. The graphical interface improved usability by presenting readings in a form that can be interpreted by users, IT validators, and fishery experts.

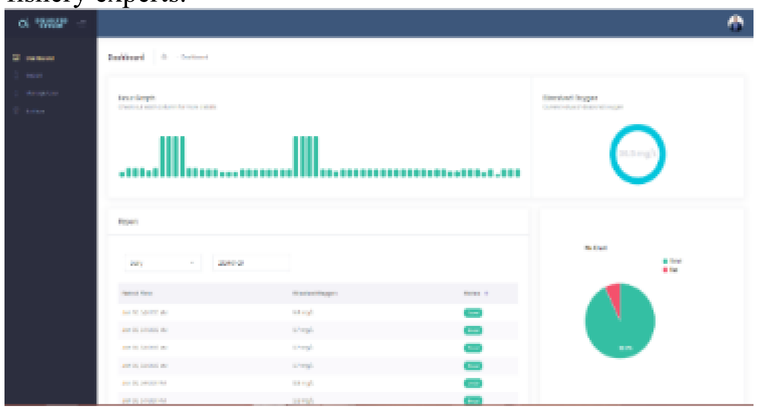

Figure 3. *Graphical user interface for dissolved oxygen monitoring*

Acceptability of the Integrated System

The system obtained very high acceptability ratings from all three validator groups. IT experts gave an overall mean of 4.95, fishery experts gave an overall mean of 4.92, and users gave an overall mean of 4.97. All ratings were interpreted as Strongly Agree, indicating that the system was viewed as highly acceptable in terms of its intended technical and aquaculture functions.

The IT experts' rating suggests that the system design was acceptable in functionality, reliability, interoperability, connectivity, usability, and user interface. The fishery experts' rating supports the system's relevance to aquaculture operations, particularly its ability to monitor DO and control aeration. The users' rating indicates that the system was practical and understandable for potential use in prawn nursery pond management.

Table 2. *Overall Acceptability Ratings of the Integrated DO Monitoring System*

Evaluator Group	Number of Validators	Overall Mean	Verbal Interpretation
IT experts	3	4.95	Strongly Agree
Fishery experts	3	4.92	Strongly Agree
Users/Prawn farmers	3	4.97	Strongly Agree

Monitoring, Aeration Control, and Management Implications

The findings show that the integrated system can support DO monitoring and aeration control in a prawn nursery environment. Because the user can set the threshold value, the system can be adjusted to match the desired pond condition. Once the threshold is reached, the aerators activate to increase oxygen content, demonstrating that the system performs both sensing and corrective action.

The system also provides management advantages. It records data automatically, generates reports, and displays values through graphs, making it easier to analyze water-quality conditions over time. In prawn nursery operations, such features can reduce personnel costs and routine monitoring duties while supporting quicker decisions when oxygen conditions become unfavorable.

The results align with the literature emphasizing that oxygen management is essential to aquaculture sustainability and productivity. By integrating a sensor-based monitoring system and an automated aeration mechanism, the study contributes a practical tool for improving pond management and reducing the risks associated with hypoxia and anoxia.

Table 3. System Functions Demonstrated During Testing

System Function	Observed Output/Implication
Real-time DO monitoring	The current oxygen level was captured and displayed through the system interface.
Threshold setting	Users could adjust the aeration activation point based on desired pond conditions.
Automatic aeration	Aerators activated when the DO level fell below the predetermined threshold.
Database storage	Readings were saved automatically for later review and analysis.
Graphical visualization	DO readings were transformed into graphical data for easier interpretation.
Wi-Fi accessibility	The application could be viewed on devices with Wi-Fi connection.

CONCLUSION

The study concluded that the integrated dissolved oxygen monitoring system successfully monitored and controlled DO levels in a prawn nursery pond setting. The system combined sensor-based oxygen measurement, microcontroller control, Wi-Fi communication, data storage, graphical visualization, and aeration activation into one functional platform. It allowed users to set threshold values, monitor current oxygen levels, generate reports, and access the application through Wi-Fi-enabled devices.

The very high ratings from IT experts, fishery experts, and users confirmed that the system was acceptable, reliable, useful, and practical for aquaculture monitoring. The findings further indicate that automation can improve water-quality management by reducing manual monitoring work, supporting faster response to low oxygen conditions, and helping maintain a more suitable environment for prawn nursery operations.

Recommendation

Prawn farmers and aquaculture operators may adopt sensor-based DO monitoring systems to support more consistent water-quality management, especially in nursery ponds where early growth stages are sensitive to oxygen fluctuation. The system may be used as a support tool for monitoring, aeration control, and record keeping.

System developers should further improve the prototype by strengthening waterproofing, sensor calibration, long-term outdoor durability, and power management. Future versions may also include solar-energy optimization, mobile notifications, cloud backup, and predictive analytics for early warning of oxygen decline.

Fishery and aquaculture institutions may conduct wider field testing in intensive, semi-intensive, and extensive pond systems to determine system performance under different water depths, stocking densities, temperatures, and salinity conditions. Future researchers may also compare automated aeration with traditional aeration practices in terms of cost, survival rate, growth performance, and production yield.

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