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Internet of things-based water quality monitoring design to improve freshwater lobster farming management

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ABSTRACT

The development of lobster farming requires careful water quality monitoring to ensure optimal growth and health. This study introduces a novel internet of things (IoT)-based water quality monitoring system designed specifically for lobster farming applications, operating on the Antares IoT platform. The system incorporates pH, temperature, and turbidity sensors to measure critical water quality parameters. The sensors were calibrated and validated using standard methods, yielding high accuracy, with average values of 98.74% for pH, 98.78% for temperature, and 98.56% for turbidity. The study also involved direct monitoring over five days, with pH values ranging between 8-10, temperatures between 23-27 °C, and stable turbidity at 90-99 NTU. The novelty of this system lies in its ability to provide real-time, reliable data and predictive analysis to support effective water quality management in lobster farming. Unlike traditional water quality monitoring systems that lack real-time data analysis or predictive capabilities, this system integrates both monitoring and forecasting features, allowing for more proactive management. Additionally, it offers higher accuracy and lower sensor drift compared to older, manual water quality monitoring methods. Experimental results indicate that the proposed monitoring system can deliver accurate and reliable data, supporting optimal farming conditions. These findings align with and expand upon existing literature, offering a more integrated and efficient solution for real-time and accurate monitoring in lobster farming.

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1. INTRODUCTION

Freshwater lobsters have become increasingly popular due to their nutritional value, flavor, and health benefits [1]. Lobsters are rich in easily digestible proteins, amino acids, fatty acids, carotenoids, vitamins, and minerals essential for consumer health [2], [3]. Their high nutritional value and abundant antioxidants make lobsters a popular seafood choice [4]. The growing global demand for lobsters is driven by their delicious taste and significant health benefits [5]. However, freshwater lobster farming requires special attention to water quality to ensure optimal growth and health [6]. Water quality parameters such as temperature, pH, dissolved oxygen, and ammonia levels must be closely monitored [7], [8]. Fluctuations and suboptimal water quality can affect lobster physiology, increasing stress and disease risk [9]. Therefore, adequate water quality monitoring is a crucial factor in the successful cultivation of lobsters.

The main challenge in freshwater lobster farming is maintaining water quality consistently at optimal levels to support the health and productivity of the lobsters [10], [11]. Many farmers still rely on manual methods to monitor water quality, which are often inefficient and do not provide real-time data [12]. This can result in delays in taking corrective actions when sudden changes in water quality occur. The lack of an efficient and automated water quality monitoring system capable of providing real-time data exacerbates the problem, leading to increased mortality rates, reduced growth, and economic losses in lobster farming.

To address these issues, a commonly proposed solution uses internet of things (IoT) technology to automate and enhance water quality monitoring processes [13], [14]. IoT technology enables real-time data collection through sensors connected to a network system [8]. These sensors continuously measure critical water quality parameters such as pH, temperature, and turbidity. The collected data can then be transmitted to a centralized digital platform, where it is analyzed and displayed to farmers [7], [15]. This approach empowers farmers to make quick, informed decisions to maintain optimal water conditions, thereby improving lobster health and farm productivity. By leveraging IoT-based systems, this solution offers a modern, scalable, and efficient approach to mitigating the challenges of traditional water quality monitoring in aquaculture.

Various studies have demonstrated the effectiveness of IoT technology in water quality monitoring in the aquaculture sector [14], [15]. For instance, Marselina *et al.* developed an IoT-based system for monitoring water quality in lobster farming ponds using the Antares IoT platform, showing success in effective monitoring [11]. Damodaran *et al.* demonstrated that IoT-based water quality monitoring systems are effective and cost-efficient, which is crucial for large-scale applications in aquaculture [16]. These studies illustrate how the application of IoT can overcome the limitations of traditional monitoring methods.

Although many studies have highlighted the benefits of IoT technology in water quality monitoring, however, there is still a need for more research focused specifically on its application to freshwater lobster farming. Many studies focus on fish [9] or drinking water applications [17], while in-depth research on IoT implementation for freshwater lobsters is limited. While previous studies addressed water quality monitoring broadly, they often lacked the specificity required for different aquaculture species, such as freshwater lobsters, which have unique environmental needs. This gap highlights the necessity for tailored solutions in aquaculture.

This study aims to design and implement an IoT-based water quality monitoring system tailored to the needs of freshwater lobster farming. The novelty of this research lies in its comprehensive approach, which monitors water quality parameters and provides predictive analysis and actionable recommendations. Unlike prior work, this study integrates predictive modeling with real-time monitoring, offering both immediate and long-term management insights. Additionally, it includes features that alert farmers to potential risks, providing preemptive measures for lobster health optimization. The scope of the study includes developing hardware and software, testing the system in real farming environments, and evaluating the system's impact on the health and productivity of lobsters. Thus, this research is expected to contribute significantly to the sustainable management of freshwater lobster farming.

2. MATERIAL AND METHOD

This study employed several essential components to build the IoT-based water quality monitoring system. The system incorporated a pH sensor (PHSEN0161) to measure water acidity, a temperature sensor (DS18B20) to monitor water temperature, a turbidity sensor to assess water clarity, an ESP8266 Wi-Fi module for wireless data transmission, and an Arduino Uno microcontroller for controlling the sensors and transmitting data to the ESP8266. Additionally, the system featured a power management module to ensure the stable and uninterrupted operation of the sensors, particularly in outdoor environments. The IoT platform used for real-time data monitoring and visualization was Blynk, selected for its user-friendly interface and compatibility with the ESP8266 module. Sample preparation entailed assembling the components, as shown in Figure 1. The sensors were installed in a freshwater lobster farming pond. Each sensor was calibrated and validated using standard instruments to ensure measurement accuracy [18]. The calibration process involved adjusting the sensors to ensure that the obtained values matched the reference values from the standard instruments [19]. The validation process involved collecting data five times for each sample. The experimental setup included strategically placing the sensors at various points in the lobster farming pond to capture localized variations in water quality. These placements were crucial for ensuring comprehensive coverage of the pond and accurate data collection.

The experimental system consisted of several crucial steps. First, the pH, temperature, and turbidity sensors were calibrated using standard instruments with known reference values. Validation was carried out by repeatedly testing water samples five times for each sensor, yielding standard deviation and accuracy levels for the sensors. To further ensure system reliability, each calibration session was cross-verified by comparing results with secondary reference instruments from a different manufacturer. Second, the sensors were connected to the Arduino Uno, the central controller. The Arduino Uno was connected to the ESP8266 to transmit data to the cloud platform wirelessly. Data were collected in real-time and stored on the cloud platform for further analysis. The data transmission process was optimized to minimize latency and ensure robust connectivity, even in remote areas with limited network coverage. Third, the sensors were placed at various points in the lobster farming pond. Data were continuously collected and transmitted to the cloud platform. The data collection process was conducted over a specific period to gather sufficient data for statistical analysis. The data collection strategy ensured that sufficient data was obtained, allowing for accurate trend analysis and predictions about potential water quality changes.

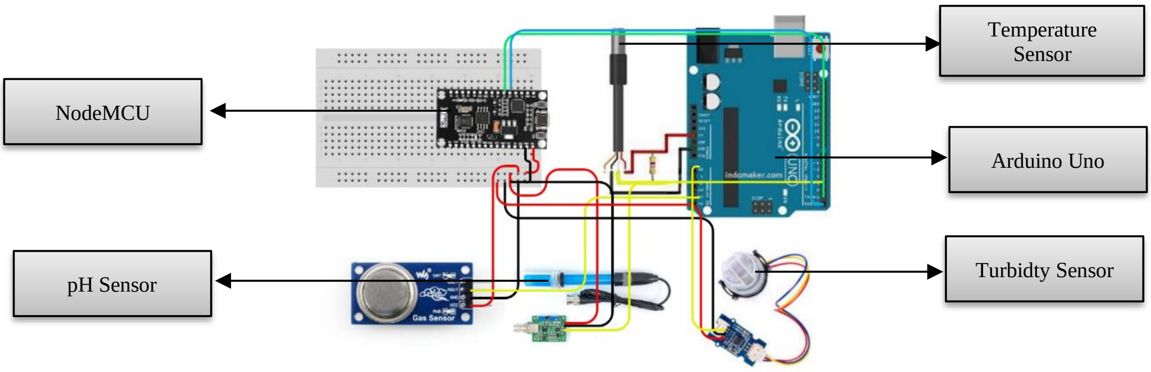


Figure 1. Electronic scheme

The statistical analysis included calculating the mean values, standard deviations, sensor accuracy, and trend analysis. The mean value was calculated from the measurement results for each sensor during the monitoring period. The standard deviation was calculated from the measurement results to determine data variation [20]. Sensor accuracy was determined by comparing the sensor measurements with reference values from standard instruments [21]. Trend analysis was conducted to identify significant trends and patterns in the water quality monitoring data. Advanced statistical tools were used in trend analysis to predict potential changes in water quality and provide proactive recommendations, essential for long-term monitoring. The results of this statistical analysis were used to evaluate the system's performance and to make recommendations for water quality management in freshwater lobster farming. These insights were further visualized through interactive dashboards on a digital platform, enabling farmers to access real-time data and actionable recommendations with ease.

3. RESULTS AND DISCUSSION

3.1. Results

The system includes a pH sensor, temperature sensor, turbidity sensor, Arduino Uno microcontroller, and ESP8266 Wi-Fi module, strategically positioned in a freshwater lobster farming pond to measure localized variations in water quality. Prior to deployment, each sensor is calibrated and validated against standard references to ensure accurate readings. This calibration is performed to ensure that the measurement results are consistent with the expected values and reliable. The system operates in a controlled indoor environment to ensure the stability of the measured parameters, with data transmitted in real-time to a cloud platform. All collected data is then directly displayed on the platform for further analysis.

The calibration results showed a clear correlation between the sensor outputs and the reference values, indicating that the sensors were accurately calibrated and capable of providing reliable data. The pH sensor calibration equation is $y = 0.0372x + 38.524$, where y represents the reference pH value and x denotes the sensor's ADC output. The temperature sensor calibration equation is $y = 0.9571x + 3.1838$, where y represents the reference temperature and x denotes the sensor's temperature output. The turbidity sensor's calibration equation is $y = 1120.4\sqrt{x} + 5742.3x - 4352.9$, where y represents the NTU value and x is the sensor output. Proper calibration is essential to ensure that all sensors function effectively under real-world conditions and deliver reliable results for monitoring water quality in lobster farming. This calibration also suggests potential broader applications in various aquaculture environments, where well-monitored water quality is essential for the health and growth of cultured organisms.

Sensor validation was performed by taking five repeated measurements to ensure the consistency and accuracy of the data produced by the system. Each sensor showed different standard deviation values, reflecting variations in their performance. The pH sensor had an average standard deviation of 0.026, with a minimum of 0.011 and a maximum of 0.054 in Figure 2(a), indicating very low variation and high consistency in pH measurements. The temperature sensor had an average standard deviation of 0.33, with a minimum of 0.18 and a maximum of 0.47 in Figure 2(b), showing slightly more variation in temperature measurements, but still within acceptable limits for this application. The turbidity sensor had an average standard deviation of 2.75, with a minimum of 1.58 and a maximum of 3.84 in Figure 2(c), indicating some variation, but still providing consistent results. These results increase confidence in the use of these sensors in real-world applications and demonstrate that the developed system has broad potential for use in aquaculture.

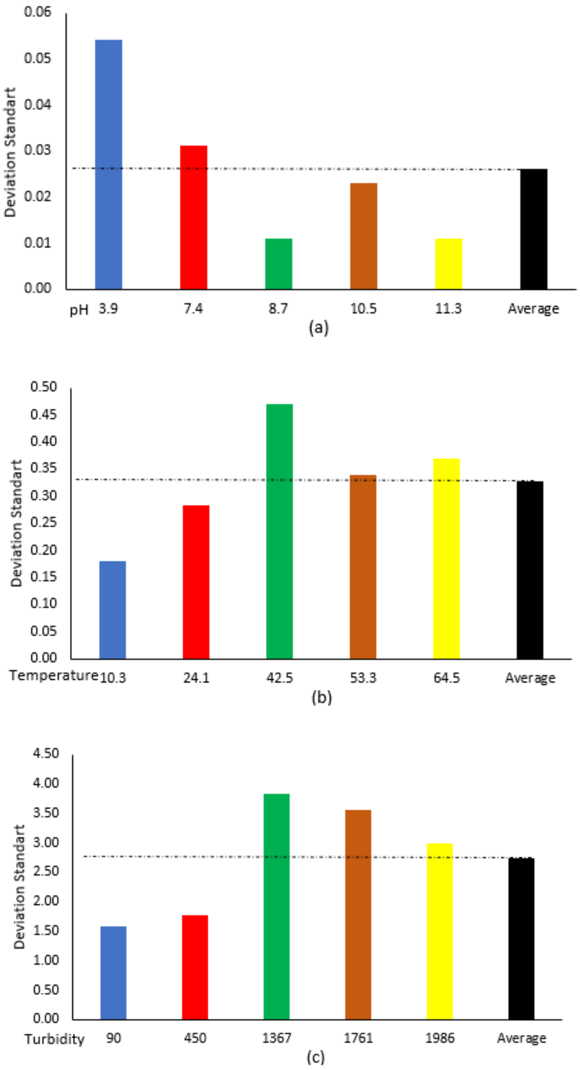


Figure 2. Standard deviation values of the sensors used to measure water quality parameters (a) pH, (b) temperature, and (c) water turbidity

The pH sensor had an average accuracy of 98.74%, with a minimum of 97.96% and a maximum of 99.75% in Figure 3(a). This indicates that the pH sensor measures acidity levels with high precision, which is crucial for maintaining optimal conditions in aquaculture. The average accuracy of the temperature sensor was 98.78%, with a minimum of 98.36% and a maximum of 99.77% in Figure 3(b). This high accuracy ensures that the temperature sensor provides reliable temperature data, a key parameter in maintaining the health and growth of cultured organisms. The turbidity sensor had an average accuracy of 98.56%, with a minimum of 97.46% and a maximum of 99.16% in Figure 3(c). This high accuracy enables precise water clarity monitoring, which is essential for maintaining water quality and aquatic animal health. The consistently high accuracy of all these sensors indicates that the monitoring system used in this study is highly efficient and reliable, instilling confidence in the generated data.

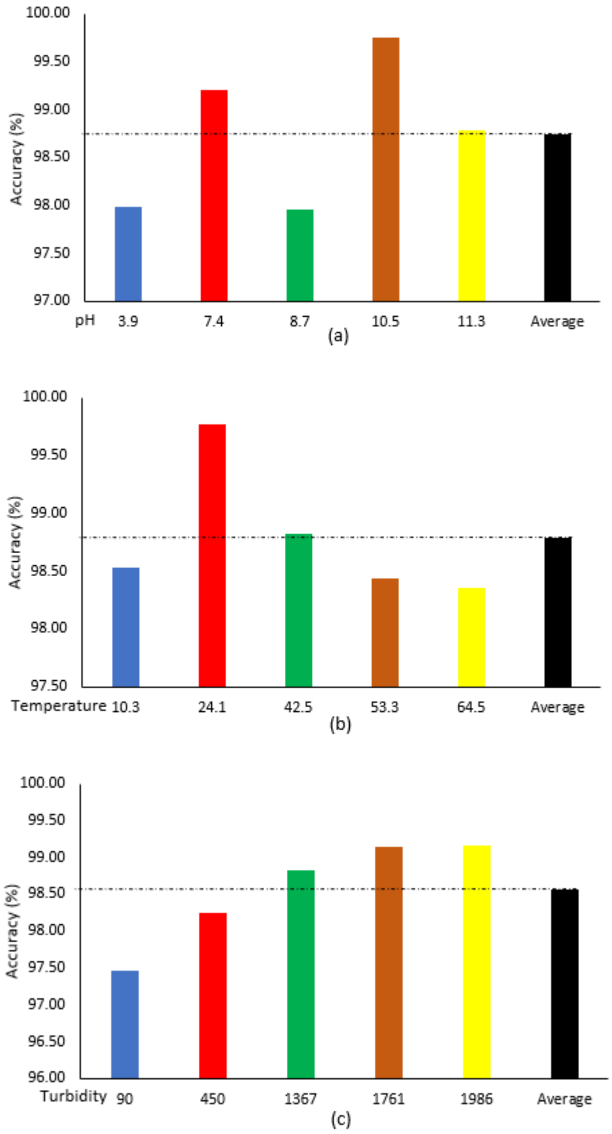
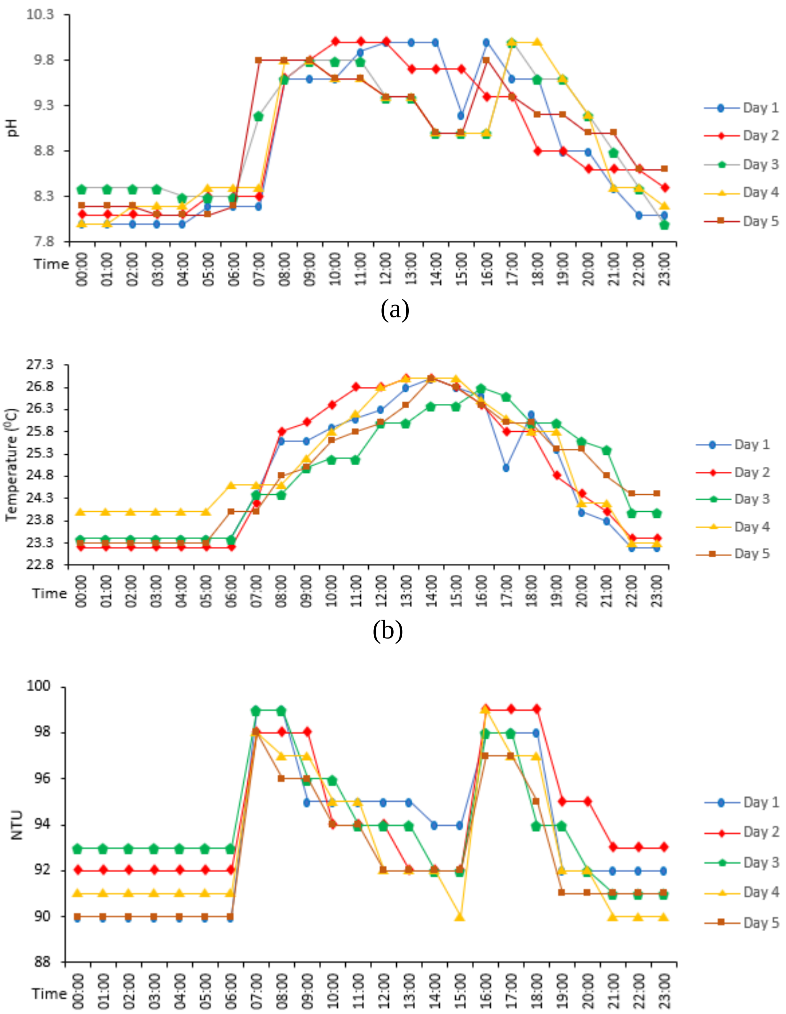


Figure 3. Accuracy values of the sensors used to measure water quality parameters: (a) pH, (b) temperature, and (c) water turbidity

The pH values measured over five days ranged from 8 to 10 in Figure 4(a), with the highest readings typically observed after feeding. This is likely caused by feed residues and increased metabolic activity, which influence the chemical balance of the water. The observed pH fluctuations reflect the system's response to external inputs, such as feed. The temperature fluctuated between 23 °C and 27 °C in Figure 4(b), with the highest temperatures generally occurring during the day. These fluctuations follow the daily environmental temperature cycle, with solar heating peaking at midday. Maintaining stable temperatures within this range is essential for the health and growth of cultured organisms. The turbidity remained stable at 90-99 NTU in Figure 4(c). This stability suggests that the filtration and water quality management systems are functioning properly, maintaining water clarity despite daily activities and feeding. Stable turbidity also indicates that there are no significant disturbances in the system, such as overfeeding or excessive organic matter decomposition. Overall, the data demonstrates that the water quality parameters are within the optimal range to support a healthy and productive aquaculture environment, confirming the effectiveness of the monitoring and management system.



(a)

(b)

(c)

Figure 4. Monitoring results from the sensors used to measure water quality parameters over five days (a) pH, (b) temperature, and (c) water turbidity

3.2. Discussion

Sensor calibration and validation demonstrated a strong linear correlation between sensor outputs and reference values. Repeated measurements during validation ensured the sensors' consistency and accuracy. The validation results revealed low standard deviation and high accuracy, confirming the sensors' reliability for continuous water quality monitoring. The increased pH variation after feeding suggests the need for proper feed management. The temperature remained within the optimal range for lobster growth. The stability of turbidity values reflects good water conditions, which are essential for lobster health. This study aligns with the literature that emphasizes the importance of sensor calibration and validation to ensure data accuracy [8]. Implementing IoT technology in water quality monitoring offers significant advantages in efficiency and effectiveness. Previous studies have also demonstrated that effective water quality monitoring is crucial for preventing adverse conditions for lobsters [11], [20], thus reinforcing the importance of accurate and reliable monitoring highlighted by this research. An accurate and reliable water quality monitoring system enables lobster farmers to quickly identify and respond to changes in water conditions [12], [13]. This will improve productivity and reduce the risk of economic loss in lobster farming. Given the high demand and nutritional value of lobsters, the implementation of this system is expected to set a new standard in modern aquaculture practices [1].

The findings of this study strongly align with existing scientific literature, which emphasizes the importance of sensor calibration and validation for ensuring accurate data in water quality monitoring [21], [22]. In this study, the pH, temperature, and turbidity sensors demonstrated high accuracy with low standard deviation, confirming their reliability for continuous monitoring. Liu *et al.* [23] emphasized the importance of calibration under varied conditions to ensure sensors function correctly in diverse environments [23]. This is consistent with the findings of this study, which show that the sensors performed reliably even after multiple tests. Other studies also emphasize the importance of accuracy in water quality monitoring for lobster aquaculture. For instance, Su *et al.* [24] emphasized the need for a comprehensive water quality monitoring system in aquaculture to ensure an optimal environment for lobster growth [24]. This study demonstrates that by using well-calibrated sensors, farmers can ensure that water conditions remain within the optimal range, crucial for the health and growth of lobsters. Aonullah also emphasized that water quality parameters such as pH, temperature, and turbidity are essential for successful lobster farming [25]. The findings of this study, which demonstrate the high stability and accuracy of these sensors, support this view and confirm that this technology can be effectively implemented in aquaculture practices.

The sensors were validated five times, with results showing low standard deviation and high accuracy, supporting the findings of Maag *et al.* [26], which demonstrated that proper calibration improves sensor data quality [26]. The high accuracy of the temperature and pH sensors in this study aligns with the findings of Li *et al.* [12] and Ahumada *et al.* [27] who emphasized the importance of calibration in monitoring air pollutants and the efficiency of heating, ventilation, and air conditioning (HVAC) systems, respectively [12], [27]. This suggests that the same calibration principles can be applied to water quality monitoring in aquaculture. This study's findings highlight the critical importance of sensor calibration and validation for water quality monitoring, consistent with existing scientific literature. For example, Septiana *et al.* [21] and Liu *et al.* [23] emphasized the need for sensor calibration under varying environmental conditions. This is reflected in the study's findings, which show that the sensors function reliably after repeated testing. This indicates that the sensors used in this study were properly calibrated, ensuring their accuracy and reliability. However, there are notable differences compared to the literature. For example, Li *et al.* [12] and Ahumada *et al.* [27] focused on sensor calibration for monitoring air pollutants and HVAC system efficiency, whereas this study focuses on water quality in aquaculture. Although the same calibration principles can be applied, the specific application differs, underscoring this research's unique contribution to the literature on aquaculture.

These findings have significant implications for lobster farming practices. Farmers can monitor water quality in real-time using well-calibrated sensors, ensuring that conditions remain optimal for lobster growth. This is crucial given the high demand for lobsters, driven by their excellent taste and nutritional value, as noted by Ngginak *et al.* [28] and Arumugam *et al.* [5]. Accurate monitoring can reduce economic losses linked to poor water quality and enhance productivity. This study suggests that IoT technology can be effectively integrated into water quality monitoring systems for lobster aquaculture. Previous studies, such as those by Marselina *et al.* [11], support this, demonstrating the efficiency and effectiveness of IoT-based water quality monitoring. Thus, this research supports existing literature and provides new insights and practical applications for the aquaculture industry. The integration of this technology can set a new standard in water quality monitoring, helping lobster farmers achieve better results with reduced risks.

Despite significant advancements in the development of IoT-based water quality monitoring systems for lobster aquaculture, some limitations remain. Firstly, this study was conducted on a limited scale and may not account for all environmental variables that could influence water quality and lobster growth. Broader and longer-term testing would provide a better understanding of the system's response to prolonged changes in the aquaculture environment. Although the accuracy of the sensors used in this study is relatively high, further research is necessary to address potential issues, such as sensor drift, which could impact long-term data reliability. Advancements in calibration techniques and more sophisticated validation methods could further enhance the reliability of this monitoring system. Further research should focus on the advanced development of IoT systems for integration with technologies such as artificial intelligence (AI) or machine learning to enable more sophisticated data analysis. Future studies could also explore the combined effects of environmental variables, such as pH, temperature, and turbidity, on the health and growth of lobsters in a holistic manner. The implementation of more advanced and cost-effective sensor technology could expand the applicability of this system across various scales of aquaculture, from small-scale to commercial operations.

4. CONCLUSION

In conclusion, this study successfully demonstrated that using well-calibrated pH, temperature, and turbidity sensors is crucial in monitoring water quality in lobster aquaculture. These sensors exhibited high accuracy and low standard deviation, supporting the reliability of the obtained data. The IoT technology applied in this monitoring system has significant potential to enhance the efficiency of lobster aquaculture by ensuring optimal environmental conditions. Further implementation of this technology is expected to support the sustainable growth of the aquaculture industry and provide more reliable outcomes in maintaining lobster health.

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AUTHOR CONTRIBUTIONS STATEMENT

This paper uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
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I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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