Implementation of IoT-based water quality monitoring instruments in cantang grouper cultivation ponds

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ABSTRACT

Grouper fish farming in Indonesia has great potential, but water quality management remains a challenge. Manual monitoring at hatchery D-Marine aquaculture struggles to detect sudden changes, risking mass mortality. This study developed an IoT-based water quality monitoring system using an ESP32 microcontroller, DS18B20 temperature sensors, pH sensors, dissolved oxygen (DO) sensors, a micro-SD card, an organic light emitting diode (OLED) display, and the Ubidots platform. The methodology involved device design, sensor calibration, and field testing. Calibration showed sensor accuracy above 90%. Field tests recorded water temperatures of 26.84 °C (tank 1) and 27.74 °C (tank 2), with pH values of 6.73 and 6.87, which did not meet Indonesian national standard (SNI) standards. Data transmission to Ubidots had a 95% packet delivery ratio (PDR) for device 1 and 97% for device 2. The system successfully provided real-time water quality data, supporting effective farm management. However, improvements to the dissolved oxygen sensor and an automatic control system are needed for better stability and efficiency.

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1. INTRODUCTION

Cantang grouper cultivation has great potential in the Indonesian fisheries sector. Based on data from the Ministry of Maritime Affairs and Fisheries (KKP), Indonesia was ranked eighth as the world's exporter of fishery products in 2020 [1]. Domestic and international market demand makes cantang grouper a commodity with high economic value [2]. One area that has great potential in cultivating cantang grouper is the nursery business carried out by the hatchery D-marine aquaculture located in Tanjungpinang, Riau Islands. Hatchery D-marine aquaculture is a microbusiness operating in this field, with a strategic location providing great opportunities to increase production results.

Success in cultivating cantang grouper is greatly influenced by optimal water quality management [3]. Poor water quality can cause stress to fish, inhibit their growth, and even cause death [4]. Monitoring water quality, which includes temperature, pH, and dissolved oxygen (DO), is very important in supporting fish survival. Based on the guidelines of the national standardization body, the optimal water temperature is in the range of 28–32 °C, pH ranges between 7.5-8.5, and DO levels are at least 4 mg/L. Proper monitoring of these three parameters is very important for fish survival and growth [5].

In traditional aquaculture systems, water quality monitoring is generally carried out manually. Manual water quality monitoring methods have several significant limitations in the context of cantang grouper cultivation. First, the level of accuracy is often low as it heavily depends on the operator's skills and precision, along with the potential for human error in recording or measurement. Second, timeliness is an issue because sampling and analysis are not conducted continuously, making it difficult to quickly detect sudden changes in water parameters such as temperature, pH, or DO, which can pose risks to fish health. Third, this method is labor-intensive, requiring physical presence for data collection, analysis, and recording, which can increase operational costs and reduce overall efficiency. When water quality is at a critical level, corrective action is often too late, which can lead to mass fish deaths [6].

Technology internet of things (IoT) can be a solution to this problem by enabling real-time monitoring of water quality [7]. The IoT enables the connection of physical objects to the internet, facilitating data collection and remote process control [8]. This technology integrates various devices, sensors, and communication protocols, allowing for seamless data exchange and analysis [9]. The designed system provides continuous information regarding water quality conditions. Thus, farmers can easily access data to take timely corrective action, reducing the risk of fish mortality [10]. Therefore, this research aims to design and implement an IoT-based water quality monitoring system in cantang grouper cultivation, which is expected to help farmers manage water quality more efficiently and provide useful information regarding water quality conditions. This study presents an innovative implementation of an IoT-based water quality monitoring system specifically designed for cantang grouper cultivation, to address the limitations of manual monitoring methods, as well as to tackle challenges and provide solutions for improving the system's accuracy and reliability.

2. METHOD

2.1. System design

The monitoring system consists of two devices with main components: ESP32, micro-SD card module, DS18B20 temperature sensor, pH sensor, DO sensor, organic light emitting diode (OLED) display, ADS1115 ADC module, and Ubidots platform. Input from the temperature, pH, and DO sensors is processed by the ESP32 microcontroller to be displayed on the OLED display, stored on micro-SD, and sent to Ubidots via WiFi. The system block diagram appears in Figure 1. The IoT-based water quality monitoring system developed in this study presents several novel aspects compared to existing similar systems. The system is specifically designed to monitor water quality parameters most relevant to this species, such as temperature, pH, and DO, in real-time. The combination of sensors is tailored to local water conditions and the characteristics of the hatchery where the system is implemented, allowing for higher measurement accuracy and compatibility with the operational environment. The system is also adapted to real-world challenges, such as limited signal coverage at the hatchery site, low power requirements, and ease of maintenance by farmers, making it more practical for field application. Furthermore, the integration with a cloud-based analytics platform (Ubidots) enables real-time data visualization and allows farmers to make quick decisions remotely.

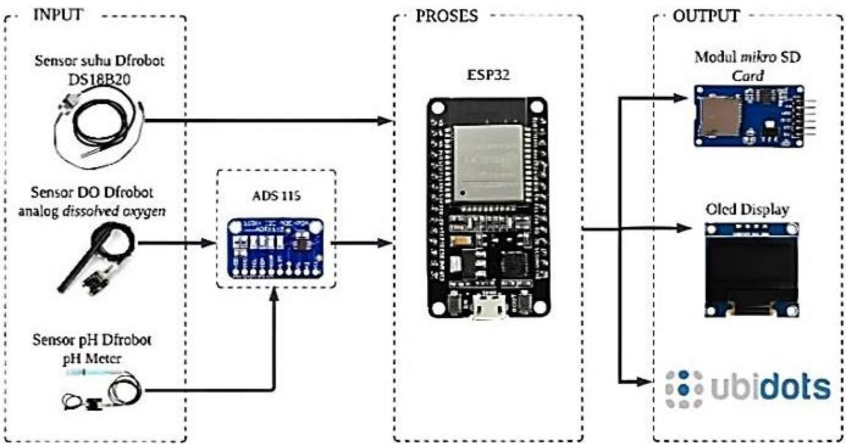


Figure 1. System planning block diagram

All electronic components of this device are placed in a protective box to prevent damage due to splashing water, making it safer. The design of the device includes several parts, such as the top of the device has a 5V power port, an on/off button, and a reset button to reset the system. At the bottom there are connectors for each main sensor connected by cables and designed to be submerged during measurement. The polyvinyl chloride (PVC) pipe frame structure maintains the stability of the device and makes it easy to install in the cultivation pond. The final appearance of the device is shown in Figure 2.

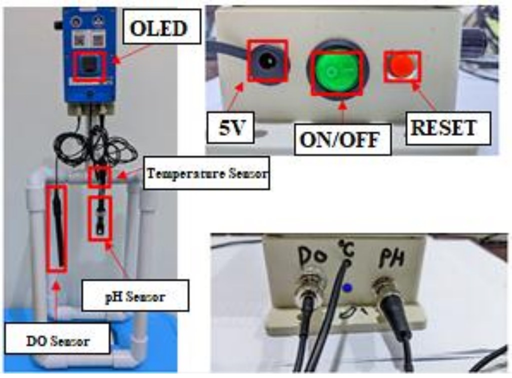


Figure 2. Physical form of the device

On the front, there is an OLED screen that displays measurement data directly. The device also includes a quick response (QR) code that directs users to the Ubidots dashboard for monitoring in real-time. For data transmission to the Ubidots platform, the message queuing telemetry transport (MQTT) communication protocol is used. MQTT is chosen because it has low data overhead, making it highly efficient for sending small amounts of data periodically. It is suitable for IoT devices that have limited power and unstable network connections. It supports publish/subscribe communication, which makes it easier for the system to manage data from multiple sensors simultaneously. MQTT allows the system to efficiently transmit sensor data to Ubidots, where the data is analyzed and displayed in the form of graphs or dashboards that are easy for users to understand. The device dashboard display on the Ubidots platform can be seen in Figure 3.

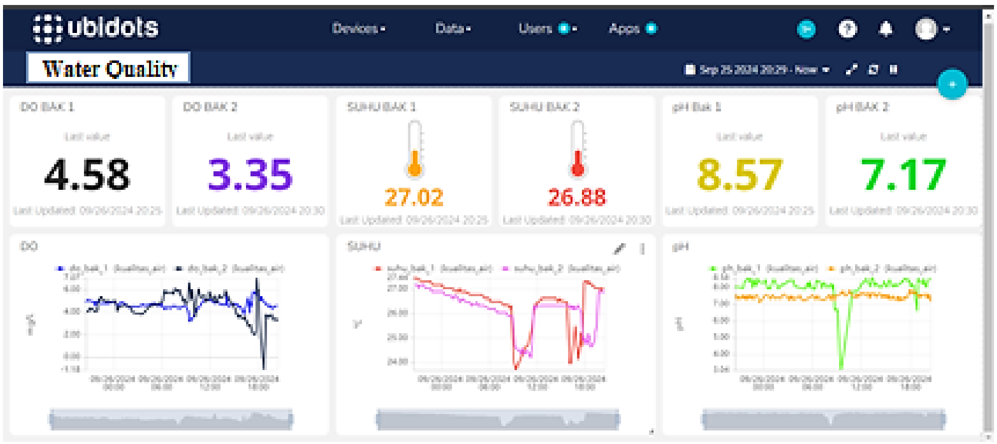


Figure 3. Ubidots platform view

2.2. Data analysis procedure

Sensor calibration is carried out to increase measurement accuracy, using linear regression, root mean square error (RMSE), standard deviation, and accuracy as a method of evaluating and improving performance [11]. Calibration results are obtained through a comparison between sensor measurements and standard measuring instruments to ensure precision [12]. Linear regression analysis allows estimation of future values while minimizing errors [13]. RMSE functions to determine the difference in values error from each sensor with standardized measuring instruments [14]. Standard deviation can explain how precise a sensor is in making measurements [15].

Analysis of IoT device performance is needed to understand system reliability and internet connectivity in the process of transmitting and receiving data to the server platform Ubidots [16]. Packet delivery ratio (PDR) is calculated based on the number of packets successfully received by the server from the total packets sent by the device. The higher the PDR percentage, the better the system performance in transmitting data without packet loss [17].

Analysis of cantang grouper cultivation water quality patterns was carried out by comparing temperature, pH, and DO measurement data against quality standards. Data is collected periodically, and then the average value for each parameter is calculated. Water quality trends are analyzed using time series graphs to identify fluctuations during cultivation, which requires sensor precision. The overall research procedure can be seen in Figure 4.

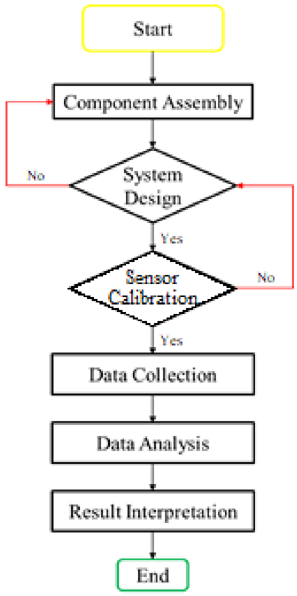


Figure 4. Research procedures

3. RESULT AND DISCUSSION

This research successfully integrates ESP32 microcontrollers with temperature, pH, and DO sensors, enabling real-time data acquisition and transmission via the Ubidots platform. The findings indicate that water quality parameters at the D-marine aquaculture hatchery do not meet the Indonesian national standards (SNI). This highlights the urgent need for automated monitoring solutions.

3.1. Sensor calibration

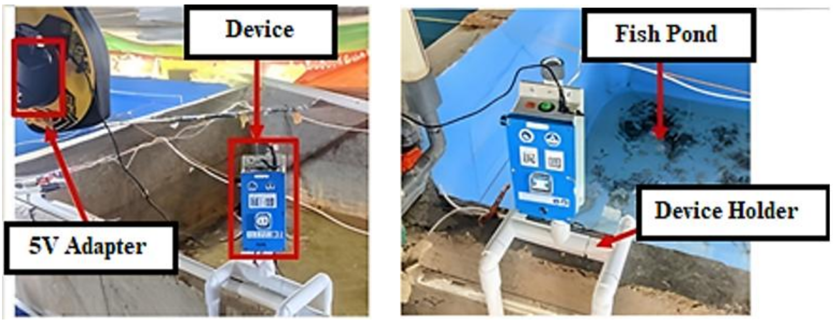
The results of the calibration of each sensor carried out using direct comparison with standard measuring instruments can be seen in Table 1. Based on Table 1, the sensor calibration results show very good values, where the accuracy of all temperature, pH, and DO sensors in the two different devices has a range of accuracy values from 95.38% to 99.58%. According to Krishnendhu and Mohandas [18], a sensor in a device is categorized as very good if it has an accuracy above 93%.

Table 1. Sensor calibration result

Sensor	Device	Linear regression equation	RMSE	Standard deviation	Accuracy (%)
Temperature	1	$y = 1.0903x - 2.4528$	0.78 °C	5.81 °C	98.45
Temperature	2	$y = 0.985x + 0.36$	0.17 °C	6.30 °C	99.58
pH	1	$\mathrm{y} = 0.00073\mathrm{x} - 0.3882$	0.14	2.432	97.51
pH	2	$\mathrm{y} = -0.0072\mathrm{x} + 99.385$	0.56	2.654	95.38
DO	1	$\mathrm{y} = 8.25\mathrm{x} + 1404$	0.38 mg/L	0.30 mg/L	99.07
DO	2	$\mathrm{y} = 8.25\mathrm{x} + 1404$	0.21 mg/L	0.26 mg/L	97.93

3.2. Field test

Field testing will be carried out at the hatchery D-marine aquaculture from 17 October 2024 at 15:30 WIB to 23 October 2024 at 23:55 WIB. Figure 5 shows devices 1 (Figure 5(a)) and 2 (Figure 5(b)) placed in a water-safe area on the upper edge of pool 1 and pool 2, as the devices are not waterproof. Meanwhile, Figure 6 illustrates the sensors positioned in the water using a floating medium, ensuring that their placement consistently follows the water depth of the pool. The device collects data every 5 minutes.



(a) (b)

Figure 5. Device placement: (a) device 1 and (b) device 2

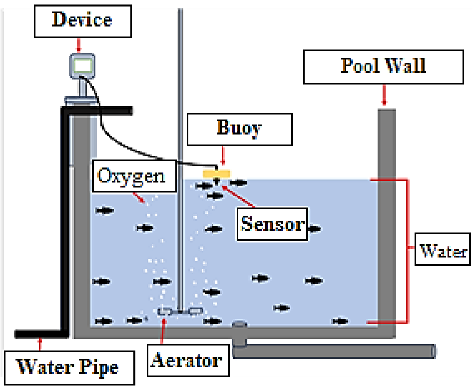


Figure 6. Sensor condition in the pool

3.3. Water temperature analysis

Analysis of water temperature patterns for cantang grouper was carried out on observation data with a time span from 17 October to 23 October 2024. Data analysis used a descriptive statistical approach to determine the suitability of water conditions with SNI [19]. Based on SNI, the minimum temperature limit set is 28 °C (green line) and the maximum temperature is 32 °C (red line). The temperature pattern on device 1 and 2 can be seen in Figure 7. On both devices, the temperature decreased in the morning, during water changes, and at night.

The measurement results show that the temperature on both devices does not meet the standards of the National Standardization Agency set for cantang grouper cultivation. The average temperature values can be seen in Table 2. Chu *et al*. [20] states that temperatures that are too low in the cultivation environment can cause fish death, so adjustments need to be made to achieve optimal results. Likewise, if the temperature is too high, it can affect the level of oxygen solubility, where an increase in temperature will cause the metabolic activity of aquatic organisms to increase and result in oxygen consumption doubling [21].

This is closely related to the statement by Favero, *et al*. [22] which states that water temperature significantly influences feed consumption, feed conversion, and daily growth rate in cultivated organisms. Based on the Table 2, the temperature difference measured by device one and device two with SNI data is around 4.53 °C at minimum temperature and 0.13 °C at maximum temperature. The average temperature on both devices has not yet entered the range of SNI temperature data.

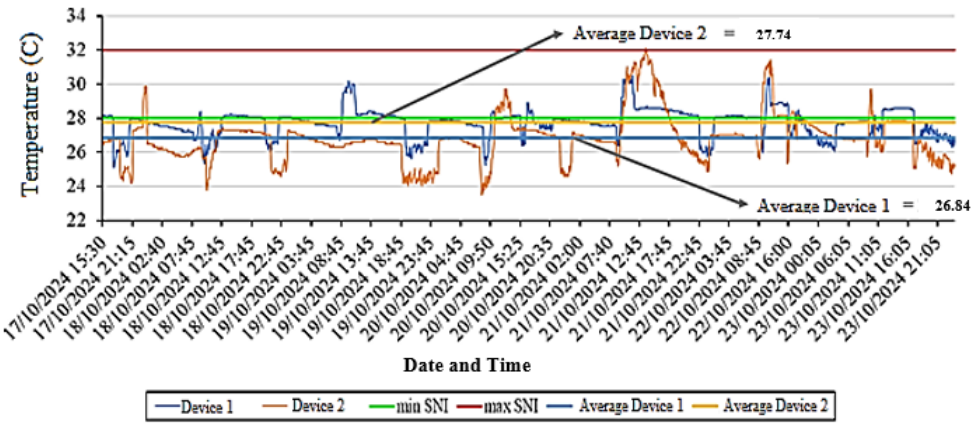


Figure 7. Water temperature pattern of device 1 and device 2

Table 2. Comparison of temperature measurement results with SNI standards

Parameter	Device 1 (°C)	Device 2 (°C)	SNI
Minimum temperature	25.11	23.47	28
Maximum temperature	31.01	32.13	32
Average temperature	26.84	27.74	28-32

3.4. Water pH analysis

The accumulation of excess feed residue in aquaculture systems can significantly impact water quality and pH levels. Residual feed can adsorb heavy metals, affecting microbial degradation and potentially entering the food chain [23]. This condition needs special attention because cantang grouper requires an optimal pH range of 7.5-8.5 for good growth based on SNI. The pH pattern in devices 1 and 2 can be observed in Figure 8.

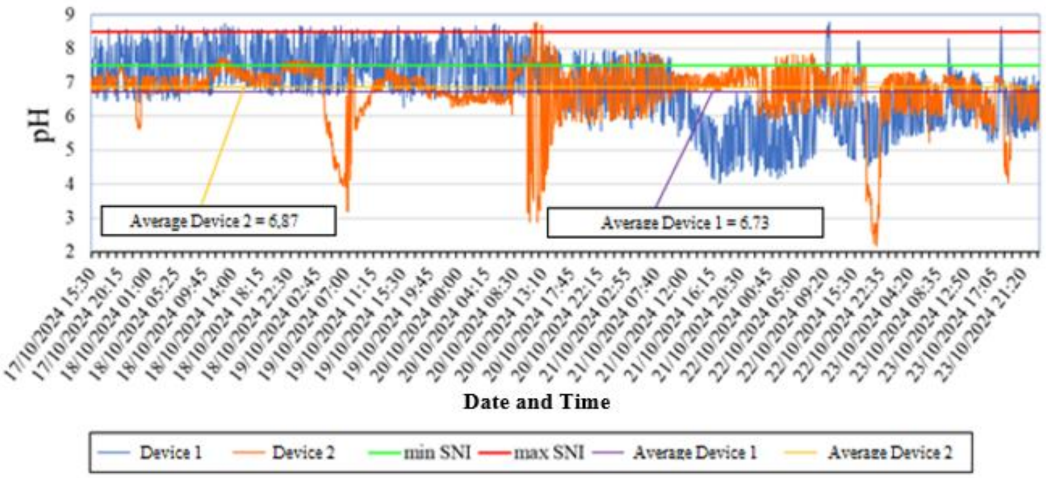


Figure 8. Water pH pattern of device 1 and device 2

Observation of the pH values on both devices shows that the average results tend to be below the SNI standards for cantang grouper cultivation. Leftover food that settles in the pond will undergo a decomposition process by microorganisms, which then produces ammonia and other compounds that affect the pH of the water [24]. The pH parameter has a significant impact on the health and growth of fish in aquaculture ponds. Low pH values can reduce fish appetite and increase susceptibility to pathogens [25]. A comparison of the pH values measured on both devices with SNI standards can be seen in Table 3.

Based on the comparison of pH measurement values with SNI in Table 3, has a significant difference. Device 1 has a difference with SNI of 4.69 at minimum pH, and 0.29 at maximum pH. Meanwhile, device 2 has a difference of 3.48 at minimum pH, and 0.27 at maximum pH. The average pH value on both devices has not yet entered the SNI pH range.

Table 3. Comparison of pH values with SNI standards

Parameter	Device 1	Device 2	SNI
Minimum pH	2.18	4.02	7.5
Maximum pH	8.79	8.77	8.5
Average pH	6.73	6.87	7.5-8.5

3.5. Analysis of dissolved oxygen

DO fluctuations or a decrease in DO values are thought to occur due to the position of the sensor not being touched by water during the water change process. Sensor readings have difficulty returning to normal conditions after this disturbance occurs. The factor that the position of the sensor is not optimal when changing the water is the main cause of fluctuations in DO values during the observation period. The DO pattern for device 1 and device 2 is shown in Figure 9.

Based on the measurement results, the DO values measured on both devices show variations but are still within the tolerable range according to the SNI 6487.4:2014 standard. DO fluctuations are caused by the sensor not being in contact with water when changing the water, and the decrease in DO value is due to the increasingly depleted water touched by the sensor so that the oxygen produced is not as high in value. This condition is caused by the need for the DO sensor to adapt to reach a stable value after changes in measurement environmental conditions [26]. Therefore, it is necessary to add a small container to the sensor as a water reservoir to ensure the sensor remains submerged during the measurement process [27]. In addition, according to [28], fluctuations in DO levels in a pond are influenced by thermal stratification, which is related to the water depth, and the mixing of water masses. A comparison of the DO values measured on both devices with SNI standards can be seen in Table 4.

Based on the comparison of DO data, the measurement results have a very far range from the SNI standard values. When the minimum DO in device one shows a value less than the standard, while at maximum conditions it exceeds the standard. This also happened on the second device. However, the average DO value of the two devices fell into the SNI standard value range.

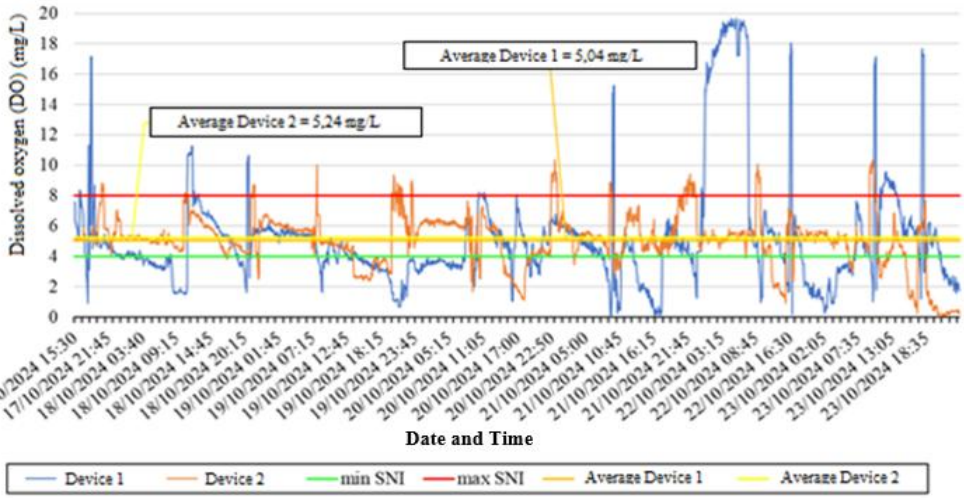


Figure 9. Water DO pattern of device 1 and device 2

Table 4. Comparison of dissolved oxygen values with SNI standards

Parameter	Device 1 (mg/L)	Device 2 (mg/L)	SNI
Minimum DO	0.93	0.03	>4
Maximum DO	10.37	20.23	<8
Average DO	5.04	5.24	5-7

3.6. Data delivery performance

During field testing, device 1 generated 5145 data stored on the micro-SD card, with 5010 data sent to the server, resulting in a PDR of 97.38%. On device 2, of the 5145 data stored, only 4889 data were sent, resulting in a PDR of 95.02%. Data transmission to the Ubidots platform showed satisfactory results, with PDR classified as good based on the category [29]. Data that was not sent was possibly caused by internet signal interference during the field test [30]. Therefore, it is important to store backup data in a micro-SD card.

4. CONCLUSION

This research shows that the design, implementation, and testing of water quality monitoring devices in cantang grouper cultivation ponds at the hatchery D-marine aquaculture were successful. The calibration results show good accuracy with a value of ≥95% on each sensor. Measurement of water quality parameters shows that the average water temperature ranges between 26.84 °C in pool 1 and 27.74 °C in pool 2, DO in device 1 is 5.04 mg/L and device 2 is 5.23 mg/L, and pH is between 6.73 in pond 1 and 6.87 in pond 2, which still does not meet SNI standards. Additionally, the DO sensor showed unstable readings during water changes. Performance of sending data to the platform Ubidots is recorded with a PDR above 95% to be considered satisfactory. Although these devices show advantages in accuracy and efficiency of data transmission, some limitations need to be addressed, especially in DO sensors. Sensor modification is required by adding a container so that the sensor remains submerged and the accuracy of reading oxygen levels can be increased, as well as integrating an automatic control system to keep water quality parameters stable and optimal. The study also identifies critical challenges, such as sensor instability during water changes, and proposes modifications to improve accuracy and stability. These insights provide a foundation for further advancements in smart aquaculture technology, emphasizing the necessity of integrating automatic control systems to optimize fish farming efficiency.

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AUTHOR CONTRIBUTIONS STATEMENT

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Anggarudin										✓				
Dwi Eny Djoko Setyono										✓				
Henky Irawan										✓				

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
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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 author declares that this article does not have any conflict of interest with other parties.

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