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Implementation system monitoring and control temperature and pH in urban silver catfish hatchery to enhance efficiency and responsiveness based on IoT

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A B S T R A C T

AKA Farm is an urban agriculture-based silver catfish hatchery enterprise in Bogor Regency. AKA Farm has successfully met local demand for silver catfish fry production by utilizing limited space within vacant houses in Cihideung Ilir village. The comprehensive facilities, including electricity, wells, roads, and drainage channels, support the success of this operation. Challenges in the silver catfish hatchery are associated with low efficiency and responsiveness due to the complexity of the production process, resulting in suboptimal harvest outcomes. The primary contribution of this research lies in developing and implementing an innovative IoT-based monitoring and control system to address water quality conditions, as fluctuations in water temperature and pH significantly impact fish metabolism and survival. The main objective of this study is to improve efficiency and responsiveness in the hatchery process, aiming for optimal harvest outcomes. The integrated system utilizes the Blynk application for real-time monitoring and control. Another advantage of the system is its automation; when the temperature and pH are not optimal, the actuators automatically optimize the aquarium conditions according to applicable standards. The actuators control heating lamps and release acidic or basic solutions. The system performs real-time and remote monitoring and control, reducing delays in responding to changes in the aquarium environment ultimately substantially improving the survival and growth of silver catfish. Implications of this research include assisting farmers in saving time and energy while increasing the productivity of silver catfish hatcheries. The study also reinforces the system's ability to create reliable water quality, supporting the well-being of silver catfish and ultimately enhancing performance in urban farming.

1. INTRODUCTION

Urban agriculture has emerged as a solution to the decreasing availability of arable land due to urban development. The primary contribution of this research lies in the development and implementation of an innovative IoT-based monitoring and control system for silver catfish hatchery in the context of urban agriculture. This study addresses

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the challenges of maintaining optimal water quality conditions, particularly temperature and pH, for silver catfish fry in aquariums, which are crucial for their growth and survival.

AKA Farm, an urban agriculture-based silver catfish hatchery enterprise located in the Bogor Regency, has successfully met the local demand for silver catfish fry production by utilizing limited space within vacant houses equipped with electrical facilities, wells, roads, and drainage channels in the Cihideung Ilir village. However, maintaining optimal water quality conditions in confined-space aquariums is critical to this endeavor. Fluctuations in water temperature and pH can significantly impact fish metabolism and survival. The silver catfish hatchery process at AKA Farm takes place over one month within aquariums measuring (90 x 50 x 35) cm, resulting in harvest yields ranging from 200,000 to 350,000 silver catfish fry per month.

Optimal water temperature and pH levels are pivotal factors influencing the metabolism of silver catfish. Water temperature acts as a growth and distribution-limiting factor for fish, as patin are often less tolerant of temperature changes [1]. Waste produced from fish excretion and leftover feed can also impact water pH levels, potentially leading to fish mortality [2]. To achieve optimal growth, farmers must consistently monitor aquarium water quality through responsive heating and drainage processes. This research addresses the crucial need for efficient monitoring and remote control of water parameters within the aquarium, particularly for successful silver catfish hatcheries.

The continuous evolution of technology in this field has been evident [3]–[9]. This research builds upon this evolution by introducing an innovative IoT-based monitoring and control system using Blynk Software for remote monitoring and controlling aquarium conditions. Incorporating various sensors, automatic lighting, and pumps, the system provides real-time data on water temperature and pH, allowing farmers to regulate water quality from any location using smartphones or internet-connected PCs facilitated by Blynk Software for remote data logging related to aquarium conditions [10]. While numerous previous studies have explored water quality monitoring using various technologies and methods, this research distinguishes itself by focusing on the specific challenges of the silver catfish hatchery process at AKA Farm.

It aims to replace manual methods, drawing inspiration from researchers such as Salih *et al.* [7], who developed a smart monitoring system for fish farming with parameters like temperature and pH without focusing on specific fish commodities or integrating IoT technology and actuators. Billah *et al.* [11] created a water quality monitoring system for catfish ponds integrated with IoT, measuring parameters including temperature, pH, and dissolved oxygen without integrating actuators for aquaculture condition control. Rosaline *et al.* [12] monitored several parameters in fish farming but did not focus on specific fish commodities and did not involve IoT and automatically working actuators. Periyadi *et al.* [13] designed a smart monitoring and automatic pH control system applied only to guppy fish with pH control using liquid valves. Nasir & Mumtazah [14] researched tanks that would be applied to catfish farming, measuring parameters such as temperature, pH, water turbidity, air temperature, and light. Although integrated with IoT using Thingspeak, the system has not yet been integrated automatically with actuators as a control system. Kumar *et al.* [15] study also involved monitoring water level parameters in fish farming tanks integrated with IoT using Blynk. Studies by Ya'acob *et al.* [16] on monitoring water temperature and pH in freshwater fish farming were integrated with websites, and Blynk did not have a control system involving actuators. These studies have significantly contributed to advancing agricultural applications [17]–[22].

Innovation in this research lies in the accessibility and automation of this IoT-based monitoring and control system for farmers anytime, anywhere, through smartphones or internet-connected PCs. The system is intelligent because it can work automatically; when the monitored temperature and pH are not optimal, the actuators will optimize the aquarium conditions according to applicable standards. The actuators will control the heating lamps and release acidic or basic solutions, providing real-time information on water temperature and pH and the conditions in the aquarium. It will simplify farmers' tasks and enhance the reliability of water quality. This research aims to improve efficiency and responsiveness in urban aquaculture, specifically by simplifying the silver catfish hatchery process by implementing an innovative IoT-based monitoring and control system. The right water quality significantly influences healthy fish habitat, resulting in the maximum and optimal fish fry production.

2. RESEARCH METHODS

2.1. Research location and duration

The research was conducted at AKA Farm, located in Cihideung Ilir Village, Ciampea Subdistrict, Bogor Regency, West Java Province, with geographical coordinates of -6.570469 S/106.72199 E, the research period spanned one month, from June 4th to July 4th, 2023.

2.2. Conceptual framework

AKA Farm holds significant development potential. To ensure water quality reliability, careful consideration of temperature and pH conditions in the aquarium during production is crucial. Variations in water temperature, especially at night and in colder conditions, often lead to abnormalities. Workers typically use a gas stove for heating, affecting both water temperature and allowing pH abnormalities. Therefore, this research aims to design:

1. Real-time and automated water temperature monitoring and control:
   Temperature sensors detect water conditions, with a microcontroller executing preprogrammed commands. If the temperature falls outside the 28°C to 30°C range, the light activates to raise or maintain the temperature as needed.
2. Real-time and automated water pH monitoring and control:
   pH sensors monitor water conditions, with a microcontroller executing preprogrammed commands. If pH deviates from the 6.5 to 8.5 range, a pump releases a solution to adjust pH. It ensures that pH remains within the normal range to maintain water quality.

The implementation of real-time monitoring and control facilitates the management of aquarium heating, water drainage, and replacement, easily monitored and controlled. It eliminates time and resource constraints, enhancing water quality reliability for optimal production results. Temperature, pH values, and actuator status can be accessed through the Blynk application on smartphones or PCs, providing real-time insights from anywhere.

2.3. System design

Fig. 1 illustrates the research phases involving developing the IoT-based monitoring and control system for the silver catfish hatchery. IoT-based monitoring and control system is specifically designed to monitor and regulate the temperature and pH levels within the silver catfish hatchery aquarium. In the initial data processing stage, a meticulous system design involves comprehensively analyzing the system's requirements. The requirements are categorized into three main parts: input requirements, process requirements, and output requirements. Fig. 2 was obtained through a collaborative focus group discussion (FGD) involving aquaculture experts, catfish farmers, and control system technicians.

The operational procedures include monitoring, involving the real-time collection of data from various sensors integrated into the system, providing crucial information about water temperature and pH levels within the aquarium. The control element is an automatic response system where IoT-based technology enables immediate environmental adjustment. For example, if the system detects deviations from optimal temperature or pH levels, the control system can trigger actions such as activating heating lamps or adjusting chemical solutions to maintain the desired conditions. The dynamic interaction between monitoring and control ensures that the aquaculture habitat remains conducive to the optimal silver catfish fry development. The designed system operates in real-time and automatically, following the desired program, providing intelligence in monitoring and controlling the process effectively.

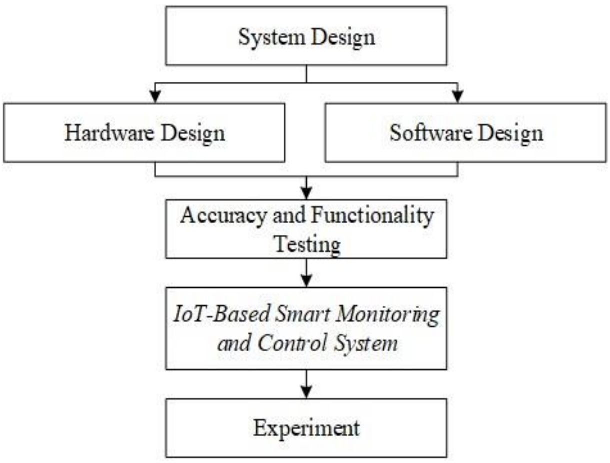

Fig. 1. Research phases

2.4. Device design

IoT-based monitoring and control systems have two main components: hardware design and software design. The hardware design is divided into two circuit designs: measurement and action circuits. An Arduino UNO microcontroller and

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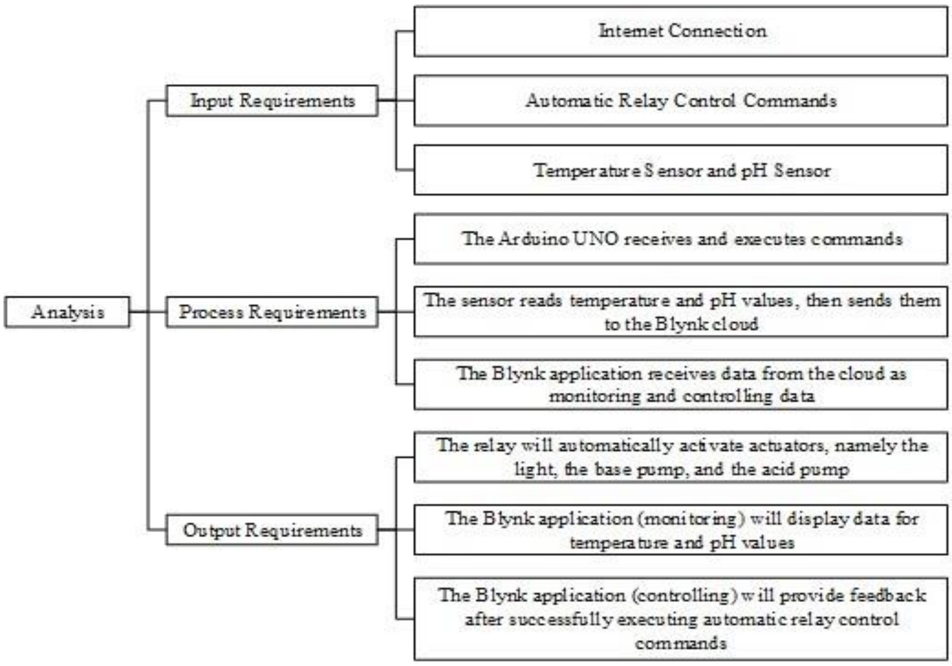

Figure 2. System requirement analysis diagram

Wi-Fi sensor are used in the measurement circuit, connected to temperature and pH sensors, serving as input for the program [23]–[25]. Fig. 3 depicts the conceptual system design

Meanwhile, the action circuit includes actuators such as lights, acid pumps, and base pumps, serving as program output. The software design also comprises two components: a database and IoT. The database is utilized within the Blynk application as an IoT-based smart monitoring and controlling application [26]–[28].

The hardware components for the IoT-based monitoring and control system will be designed using Fritzing software [29], [30]. Fig. 4 illustrates the design of all hardware components crucial for the system's operation. The components include the water temp DS18B20 (temperature sensor), liquid pH sensor E-201C (pH sensor), ESP8266

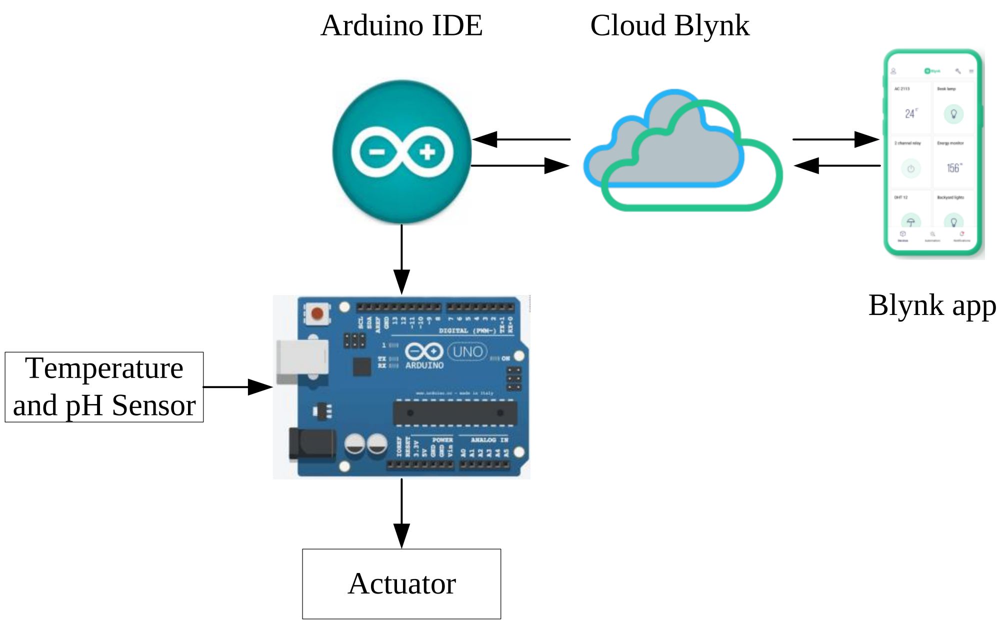

Fig. 3. Conceptual design

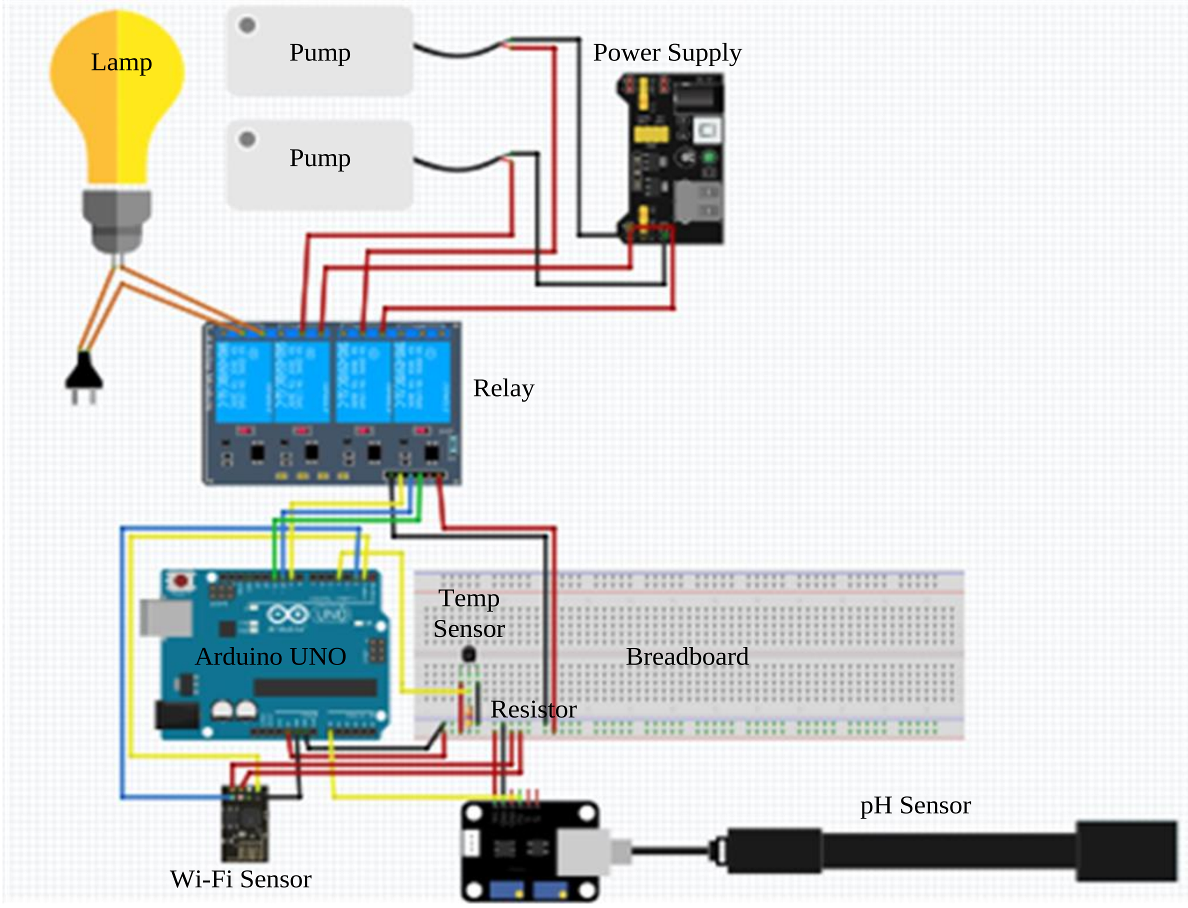

Fig. 4. Hardware design simulation

ESP-01S Wi-Fi transceiver (Wi-Fi sensor), breadboard, relay 4 channel, 47KΩ resistor, plug, light, mini pump, and power supply, connected with various small cables, which will later carry electric currents. It ensures that the hardware is capable of executing the program As for IoT, command coding is performed using the Arduino IDE software to establish connections between sensor devices, device networking to Wi-Fi, and device integration with the Blynk application [31]–[33].

2.5. Testing

The primary objective of designing this system is to create an automatic monitoring and control system capable of ensuring optimal water quality for the habitat of silver catfish within an aquarium. The system's evaluation involves implementation, including testing processes on the designed hardware and the programmed system. The test results are then compared against established standards to ensure that the system operates within the parameters set by the SNI.

The system's success is measured through testing, including assessing the sensors' systematic error [34] and conducting black box testing on the programmed system to ensure validity [35], as detailed in Section 3. It is anticipated that the final results of the testing for this IoT-based monitoring and control system will enhance breeder efficiency and responsiveness. Consequently, the reliability of water quality and the health of the habitat can be optimally maintained.

3. RESULTS AND DISCUSSION

3.1. Existing condition

Based on field studies and interviews, it is evident that time and human resource constraints are the reasons why farmers at AKA Farm still manually monitor and control water temperature and pH. During the production process of silver catfish hatchery, aquarium heating is achieved by workers igniting gas stoves to raise the room temperature within the aquariums. It is primarily done to normalize water temperature in the aquariums, especially during nighttime and in the

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face of colder environmental temperatures. This manual heating method demands extra vigilance and tight supervision to avoid fire risks in the farming facility or unstable water temperatures. Furthermore, the aquarium water drainage and replacement scheduling at AKA Farm occurs only once every three days, with no routine pH control. Farmers assume that within three days, the aquarium water becomes contaminated due to leftover fish feed and metabolism byproducts. However, they may not be aware that other environmental factors can also influence pH fluctuations. There is a need for automation to transition from manual to digital monitoring and control methods. To address these challenges, there is a need for automation in transitioning from manual to digital monitoring and control methods.

3.2. IoT-based monitoring and control system for temperature and pH

The manual control process that farmers have used has limitations that have become increasingly apparent as AKA Farm's aquaculture business grows. One of the issues that arises is related to the efficiency and responsiveness of silver catfish hatchery operations. Therefore, through this research, an IoT-based automated system is designed to enable remote monitoring and control. Fig. 5 illustrates the design of the IoT-based monitoring and control system.

Fig.5. IoT-based monitoring and control system

The temperature sensor detects real-time values within the designated optimal temperature range of 28°C to 30°C [36]. If the temperature sensor reads below 28°C, the designed system will activate a heating lamp as an actuator to increase the temperature inside the aquarium. Conversely, if the water temperature is within the range of 28.01°C to 30°C, the system automatically turns off the lamp to maintain a stable temperature.

The system also considers the pH level through a pH sensor calibrated according to the recommended range in SNI 01: 6483.4 - 2000, specifically between pH 6.5 and 8.5. If the pH value falls below 6.5, the system activates an alkaline fluid pump to increase the pH. Conversely, if the pH reaches 8.5, an acidic fluid pump is activated to lower the pH. Maintaining the pH within the specified range is crucial for preserving water quality in the aquarium. Therefore, when the sensor detects a pH value between 6.5 and 8.5, the pump is disabled to prevent unnecessary pumping of acidic or alkaline fluids.

The system is also programmed to be accessible through the Blynk smartphone application (Fig. 6) or via a website (Fig. 7). The user interface of the monitoring and control system provides an easy way to visualize and control the aquarium conditions remotely. The internet connection linked to the Blynk cloud programmed in the system allows quick responses for breeders, enabling them to monitor and control aquaculture remotely.

Fig. 6. Blynk application interface on smartphone

3.3. Testing

The accuracy test on the sensor is calculated by determining the error value. Error calculation involves assessing the temperature sensor test's systematic error or systematic error type. Systematic errors are defined as measurement errors that constantly affect the measurement results [37]. System functionality testing is carried out using the black box testing method to test the functions of each feature in the system [38].

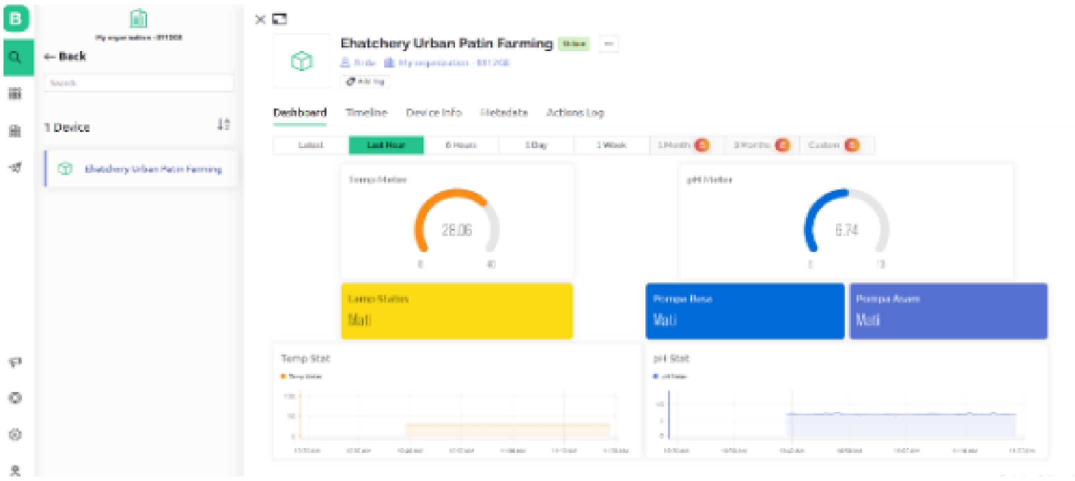

Fig. 7. Blynk application interface on website

3.3.1. *Water temperature sensor*

The input device utilized in this system is the Water Temp DS18B20 temperature sensor. The temperature sensor's accuracy in reading water temperature in the aquarium is evaluated through testing. The method compares the temperature readings obtained from the Water Temp DS18B20 sensor with those from a water thermometer. The testing uses three types of liquids: cold water, regular water, and hot water. Each liquid type is measured for its temperature using the thermometer and the respective temperature sensor, with three measurements for each. The error calculation is carried out using Eq. 1.

$$Error = \frac{|\text{Value of thermometer- Value of sensor}|}{\text{Value of thermometer}} \text{ x } 100\% \quad (1)$$

The test results are presented in Table 1. It can be observed that the values obtained from the DS18B20 temperature sensor readings are not always identical to those from the manual thermometer. The average relative error in temperature readings is 3.785%.

Table 1. Temperature sensor testing

No	Fluid Type	Thermometer	Temperature Sensor	Error %
1	Cold Water	10	10	0
2	room Temperature water	28	28.5	1.785
3	Hot water	50	51	2
Average error %				3.785

3.3.2. *Water pH sensor*

The pH sensor testing is conducted to evaluate the sensor's accuracy level in reading the acidity and alkalinity levels of water in the aquarium. This testing is carried out using a calibration method with pH Buffer solutions, and the results will be compared with the readings from the Liquid E-201C pH sensor. The testing process is repeated three times. Subsequently, the measurement results' average values from the accuracy test are calculated, followed by the determination of error values. The error calculation is carried out using Eq. 2.

$$Error = \frac{|\text{Value of pH Buffer - Value of sensor}|}{\text{Value of pH Buffer}} \text{ x } 100\% \quad (2)$$

The test results are presented in Table 2. It can be observed that the values obtained from the pH sensor readings are not always identical to those from the pH buffer. The average relative error in pH readings is 3.283%.

Table 2. pH sensor testing

No	pH Buffer	pH Sensor	Error %
1	4.01	3.96	1.246
2	6.86	6.91	1.166
3	9.18	9.10	0.871
Average error %			3.283

3.3.3. *Functional of the light*

Lamp testing aims to ensure that the light control function on the system runs well. This test includes turning on and off, as required. It can be seen that valid results were obtained for each scenario that was conducted (Table 3).

3.3.4. *Functional of the pump*

Pump testing aims to test the function of the pump controller on the system. This test involves turning on and off the pump as required. The test results are presented in Table 4. It can be seen that

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Table 3. Functional testing of the light

No	Test scenario	Expected result	Conclusion
1	Automatically turn on the light when aquarium water temperature ≤ 28.00℃	The light turns on automatically when the temperature ≤ 28.00℃	Valid
2	Automatically turn off the light when aquarium water temperature = 28.01 – 30.00 ℃	The light turns off automatically when temperature = 28.01 – 30.00 ℃	Valid

Table 4. Functional testing of the pump

No	Test scenario	Expected result	Conclusion
1	Automatically turn on the base liquid pump when aquarium water pH≤ 6.5	Automatically turn on the base liquid pump when aquarium water pH ≤ 6.5	Valid
2	Automatically turn off the pump when aquarium water pH = 6.51 – 8.5	The pump turns off when pH = 6.51 – 8.5	Valid
3	Automatically turn on the acid liquid pump when aquarium water pH ≥ 8.51	The pump turns on automatically and delivers acid liquid when pH ≥ 8.51	Valid

valid results were obtained for each of the three scenarios that were conducted.

3.3.5. *Functional of blynk*

Blynk testing aims to ensure that the application interface of Blynk application interface can communicate with the system effectively. This test includes sending and receiving data through the Blynk application to control and monitor the temperature and pH of the aquarium water. The test results are shown in Table 5. It can be seen that from the six scenarios that have been conducted, valid results were obtained for each scenario.

3.4. Experiment

IoT-based monitoring and control systems underwent a comprehensive design process and testing phase, resulting in highly accurate system components. The subsequent testing phase took

Table 5. Functional testing of blynk

No	Test scenario	Expected result	Conclusion
1	Provide information about water temperature value	Can provide information about water temperature value	Valid
2	Provide information about water pH value	Can provide information about water pH value	Valid
3	Provide information about the status of the lamp according to the water temperature value reading.	Can provide information about the status of the lamp, whether on or off, according to the water temperature value reading	Valid
4	Provide information about the status of the pump according to the water pH value reading.	Can provide information about the status of the pump, whether on or off, according to the water pH value reading	Valid
5	Display a graphical chart of changes in aquarium water temperature conditions.	Can display a real-time graphical chart of changes in water temperature conditions	Valid
6	Display a graphical chart of changes in aquarium water pH conditions	Can display a real-time graphical chart of changes in water pH conditions	Valid

place at AKA Farm over two weeks to optimize the system's real-time performance and its ability to autonomously monitor and control aquarium water quality, with a specific focus on water temperature and pH levels.

The experiment's results revealed that the lowest recorded temperature during specific hours from 2 AM to 5 AM was approximately 27.73°C. Environmental factors influenced the temperature fluctuations during these early morning hours. The system was well-designed, optimizing water temperature within the optimal range for silver catfish fry. This optimization included the automatic control of aquarium lighting and effectively managed temperature fluctuations during this critical period. Table 6 provides the average extreme temperature points over 14 days.

Table 6. Extreme points of temperature water

Time	Temperature value
2	27.73
3	27.81
4	27.86
5	27.95

The average aquarium water pH ranged from 6.10 to 6.50, indicating an acidic environment below the predefined lower limit of 6.5. However, the IoT-based monitoring and control system effectively managed the pH levels within this range through automatic control of acid and base pumps. The system achieved optimization of pH levels for silver catfish fry. Table 7 summarizes these extreme pH values.

Table 7. Extreme points of pH water

Time	pH value	Time	pH value	Time	pH value
0	6.48	8	6.40	16	6.40
1	6.46	9	6.35	17	6.44
2	6.42	10	6.17	18	6.40
3	6.44	11	6.25	19	6.36
4	6.38	12	6.28	20	6.46
5	6.44	13	6.13	21	6.41
6	6.38	14	6.10	22	6.46
7	6.35	15	6.31	23	6.50

Overall, the research results demonstrate that the IoT-based monitoring and control system significantly enhances the efficiency and responsiveness in maintaining the environment of the silver catfish hatchery. It positively impacts fish survival, maintains optimal water quality, and supports the success of urban farming by keeping the water temperature and pH at ideal levels. This experiment reinforces the system's ability to create reliable water quality that supports the well-being of silver catfish, ultimately improving performance in urban farming.

3.5. Implications

3.5.1. *Managerial implications*

This research carries significant implications for practitioners in urban-based silver catfish hatcheries. The IoT-based monitoring and control system developed in this research provides a practical solution for enhancing efficiency and responsiveness in silver catfish hatchery operations. Practitioners can adopt this system to monitor and control aquarium water conditions in real time. It aids in optimizing the fish environment, reducing mortality rates, and increasing silver catfish fry production. Other recommendations include implementing similar systems in hatchery operations to ensure that silver catfish thrive in optimal water quality conditions.

3.5.2. *Theoretical implications*

The theoretical implications of this study are highly significant for the development of monitoring and control theories in the cultivation of silver catfish in urban agriculture. This research addresses gaps in knowledge from previous studies [7], [11], [12], [14]–[16]. The foundation of this study is the application of IoT technology in urban agriculture. Through this research, understanding of the concepts and implementation of IoT is expanded to enhance efficiency and responsiveness in fish farming, with a focus on creating a healthy habitat for fish to optimize harvest yields. Thus, the design of this research can provide valuable contributions regarding the use of smart technology in the context of urban agriculture, particularly in the cultivation of silver catfish fingerlings [20], [39], [40].

3.5.3. *Integration with previous research*

This research integrates with previous research in developing monitoring and control systems for fish farming. It illustrates how the technology developed in this research overcomes the limitations identified in the previous research and provides a more profound understanding [7], [11], [12], [14]–[16]. The continuity between the findings of this research and previous research lies in the utilization of sensors for monitoring.

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Furthermore, development was carried out in this research by designing and programming automatic monitors and controls based on sensor readings integrated with smartphones and actuators. This research focuses explicitly on cultivating silver catfish seedlings in an urban environment. Although integrating the results of this study with previous research, it is recognized that there is still room for further investigation, especially in the context of other fish farming practices or different urban farming environments. Therefore, this study confirms previous findings and paves the way for further exploration

4. CONCLUSION

The challenges in the hatchery of silver catfish are associated with low efficiency and responsiveness due to the complexity of the production process, leading to suboptimal outcomes. Therefore, this research proposes a solution by implementing an innovative IoT-based monitoring and control system designed to enhance efficiency and responsiveness in the hatchery process. This system enables significant improvement in monitoring and controlling water quality, positively impacting the habitat of healthy fish and optimizing fish fry production.

The study contributes significantly to understanding and addressing environmental challenges in silver catfish hatcheries. The monitoring system provides accurate real-time information on temperature and pH, with the ability to automatically adjust to changing conditions. As a result, the survival and growth of silver catfish can be substantially improved. The research also reinforces the system's capability to create reliable water quality, supporting the well-being of silver catfish and ultimately enhancing performance in urban farming.

The hope is that the findings of this research will contribute positively to sustainable development and increased fish production in urban contexts. As a direction for future research, consideration should be given to adding additional parameters influencing aquaculture water quality and integrating them with artificial intelligence (AI) to create a more intelligent water quality prediction system.

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