

The Internet of Things-based Smart Aquarium for Goldfish

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Abstract— Maintaining an ornamental fish aquarium requires continuous water quality monitoring and regular feeding management. However, manual monitoring is often inefficient and inconsistent, especially for users with limited time. Water temperature and pH are critical parameters that influence the health and survival of goldfish (*Carassius auratus*). This study proposes an Internet of Things (IoT)-based smart aquarium system that can automatically monitor and control water quality while providing scheduled feeding management. The system integrates an ESP32 microcontroller with DS18B20 temperature sensors, PH-4502C pH sensors, a DS3231 real-time clock, servo-based feeding mechanisms, and relay-controlled actuators for heating, cooling, and pH regulation. Sensor data is transmitted to a Firebase Realtime Database, enabling real-time monitoring and remote configuration via an Android app developed with MIT App Inventor. The main contribution of this work is the integration of real-time monitoring, automated environmental control, and configurable feeding management within a unified IoT architecture. Unlike previous studies that focused mainly on monitoring or single-parameter control, the proposed system introduces a time-based safety mechanism that uses the real-time clock (RTC) to prevent excessive pH correction. It also allows for the remote adjustment of feeding parameters through a cloud-based platform. The experimental results demonstrate that the system successfully maintains the water temperature within the range of 24–26 °C and the pH level between 6.5 and 7.5. This is achieved while executing scheduled feedings twice per day and ensuring reliable actuator performance. The system demonstrates stable operation with an average data transmission latency of approximately one second, indicating effective Internet of Things (IoT) communication. Overall, the smart aquarium system provides a practical, scalable, and user-friendly solution for managing aquariums intelligently, significantly reducing the need for manual intervention to maintain optimal environmental conditions for goldfish.

Keywords: Goldfish, Smart Aquarium, Internet of Things, ESP32, Firebase



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INTRODUCTION

As shown in Figure 1, Goldfish (*Carassius auratus*) are one of the ornamental freshwater fish that humans have successfully bred. Goldfish originate from China. Their ancestors are Prussian carp, which are silver or gray in color. They began to be cultivated in China more than a thousand years ago during the Jin dynasty and developed rapidly during the Song dynasty. Initially, goldfish were rarely golden or red in color, and they were kept in garden ponds by the

imperial family and nobility. Gold was considered a symbol of the empire. Through centuries of strict selective breeding, unique variations in color and body shape began to emerge, such as those seen today [1], [2], [3], [4], [5], [6], and [7].



Figure 1. Goldfish

Goldfish are freshwater fish that prefer clean, calm waters. Goldfish are sensitive to water quality, so maintaining clean and stable water conditions is essential for their health and longevity. Although they are farmed, they require specific water conditions to stay healthy, as shown in Table 1 [3], [5], [7], [8], [9], [10], and [11].

Table 1. Specific conditions preferred by Goldfish

Water Quality Parameters	Preferred Conditions	Description
Water Temperature	25 – 32°C	They are cool-water fish, but they tolerate this temperature range well, especially in tropical climates like Indonesia.
Acidity Level (pH)	6,0 – 7,0 (Neutral)	Water that is slightly acidic to neutral is best. Avoid sudden pH fluctuations.
Dissolved Oxygen (DO)	3 – 7 ppm	Maintaining adequate oxygen levels is very important. Aquariums and ponds require adequate aeration, such as air bubbles.
Ammonia Level (NH ₃)	Maximum 0,05 mg/L	Ammonia, nitrite, and nitrate are all toxic to fish. Since goldfish produce significant organic waste, it is essential to have good filtration and to regularly change the water.
Level of CO ₂	Maximum 10 ppm	

Goldfish are a species of fish that can easily adapt to new environments. Environmental conditions greatly influence the growth and development of fish. Several factors influence favorable environmental conditions, including pH levels and water temperature. However, overfeeding can lead to waste buildup, increasing ammonia levels, and causing poor water quality, which makes fish susceptible to disease [12, 13, 14, 15, 16, 17, 18]. According to Duta's research, an automated system was developed for monitoring and controlling water quality in goldfish aquariums using the Internet of Things (IoT) and fuzzy logic. This system applies rules with high accuracy and effectively controls water parameters [6]. Meanwhile, research by Rosyadi et al. [19] developed an automated system that uses sensors and control devices connected to an ESP32 microcontroller to monitor and control pH and temperature in goldfish aquariums. The system is accessed via Wi-Fi using the Blynk application. Research

by [20] found that the automatic feeding system for carp uses an Arduino Uno with an RTC DS3231 and a servo motor to feed the fish at 8:00 a.m., 12:00 p.m., and 4:00 p.m. and sends a notification if the feed supply is low. Febryanto's research results indicate that he successfully designed an automatic aquarium water conditioning and feeding system using Arduino. The system is equipped with effective turbidity and ultrasonic sensors, as well as an RTC for scheduled feeding [21].

A comparison with previous research can be seen in Table 2 for improvements made to the previous system with the newly developed system.

Table 2. Comparison of the Proposed System with Previous Smart Aquarium Studies

Study	Platform/ Controller	Parameters Monitored	Control Mechanism	IoT Connectivity	Automatic Feeding	Unique Features
Duta (2025) [6]	ESP-based system	pH, temperature	Fuzzy logic control	IoT monitoring	No	Intelligent control of water parameters using fuzzy logic
Rosyadi et al. (2023) [19]	ESP32	pH, temperature	Threshold control	Blynk mobile application	No	Smartphone monitoring of aquarium conditions
Febryanto (2022) [21]	Arduino	Turbidity, feeding	Timer- based control	Limited monitoring	Yes	Automatic feeding and water monitoring
Satriawan et al. (2023) [15]	IoT-based microcontroller	pH, temperature	Monitoring only	IoT monitoring	No	Real-time monitoring of water conditions Integrated monitoring, automated environmental control, cloud- based configuration, and scheduled feeding in a single IoT architecture
Proposed System	ESP32	pH, temperature	Threshold- based control with RTC safety constraint	Firebase cloud database and Android application	Yes	

The proposed system differs from previous studies by integrating multiple functionalities into a unified IoT-based architecture. These functionalities include real-time environmental monitoring, automated control of water temperature and pH levels, cloud-based data management using the Firebase Realtime Database, remote system configuration through a mobile application, and an automatic feeding mechanism scheduled using a real-time clock (RTC). By combining these capabilities within a single platform, the proposed system provides

a more comprehensive and practical smart aquarium management solution compared to earlier approaches that typically focus on isolated monitoring or control functions.

METHOD

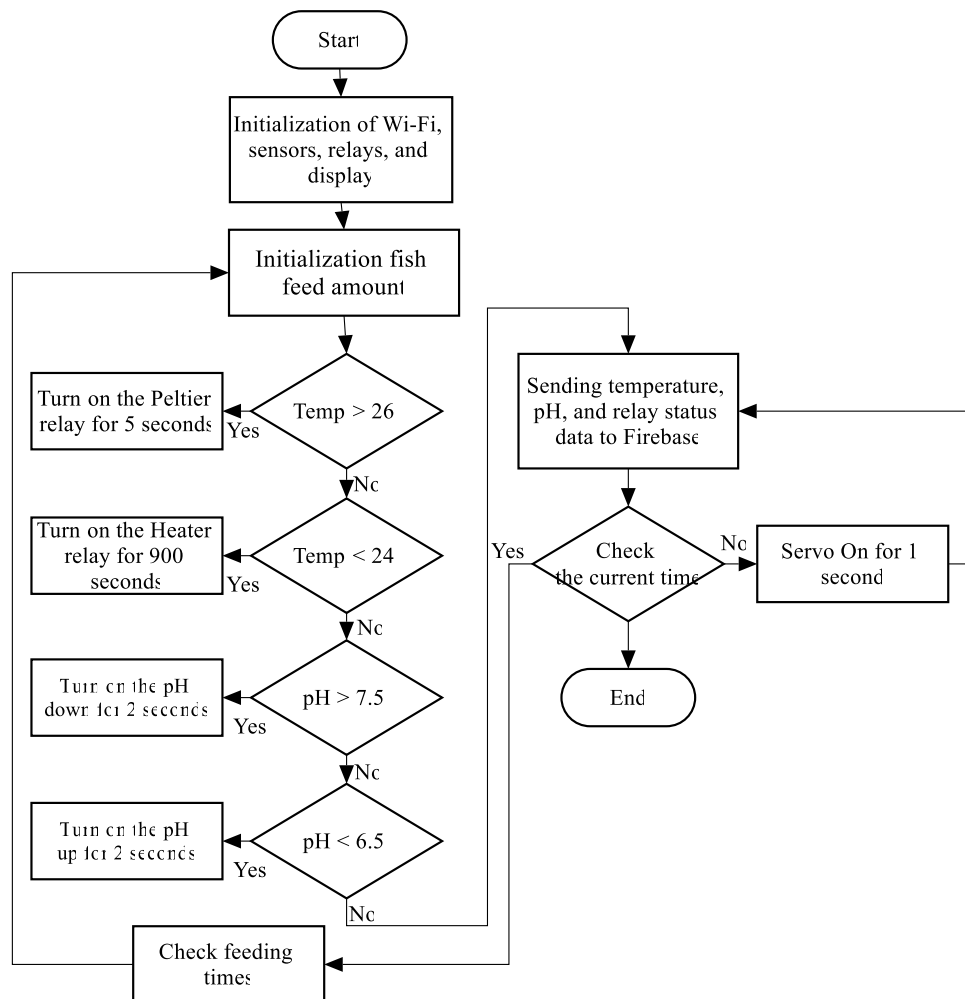


Figure 2. Scientific Approach

This research employs a scientific approach, a method based on scientific principles that involves a series of systematic stages for collecting and analyzing data, as illustrated in Figure 2. The system block diagram is shown in Figure 3, and a full circuit schematic is depicted in Figure 4. The system consists of several input devices, including a DS18B20 temperature sensor, a pH sensor, and a DS3231 real-time clock (RTC) module. The DS18B20 temperature sensor reads the water temperature digitally via OneWire communication. The ESP32 microcontroller processes this temperature value to determine whether to turn on the heater or cooler (Peltier) via a relay. A pH sensor is used to determine the degree of acidity or alkalinity of the water. The sensor produces an analog voltage signal that is converted by the ESP32's internal ADC (analog-to-digital converter) into a digital value. After calibration, the pH value is used to turn on the pH-up or pH-down pump and bring the water's pH value into the right range. The ESP32 is a microcontroller equipped with an integrated Wi-Fi module, making it ideal for developing Internet of Things (IoT) projects [22]. The first step is to connect the ESP32 to the Firebase Realtime Database using the ESP32's Wi-Fi connection. Data such as temperature, pH level, feeding time, and device status are displayed on a 20x4 I2C LCD screen for direct monitoring. This data is also sent to Firebase, allowing remote access via an Android

application based on MIT App Inventor [23]. Seamless integration between the hardware and software enables this system to monitor and control aquarium conditions automatically and efficiently in real time.

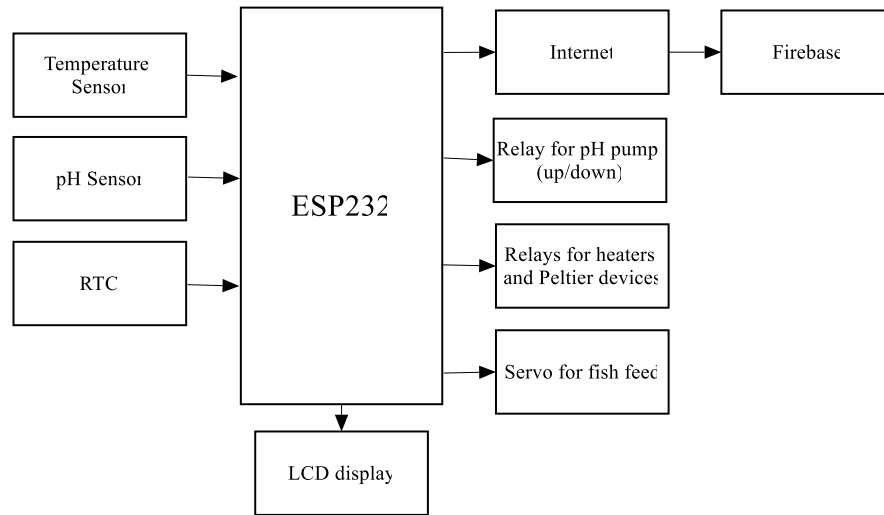


Figure 3. System Block Diagram

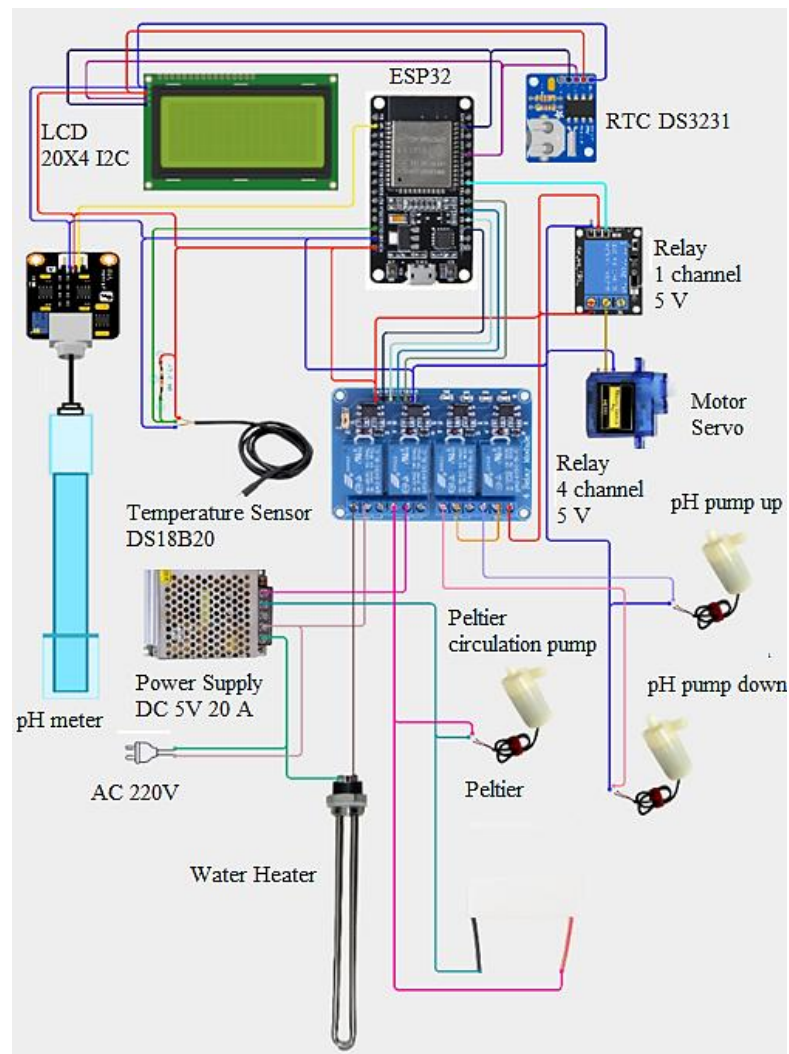


Figure 4. Circuit schematic

The aquarium automation system uses an ESP32 as a control center that is connected to various sensors and actuators, as shown in Figure 3. An important component of the system is the water pH control feature, which aims to maintain an ideal acidity level for fish. The analog pH sensor reads the voltage from the water solution and sends the data to the analog-to-digital converter (ADC) pin on the ESP32. The ESP32 then converts this voltage value into a pH value using a calibration formula based on the specified minimum and maximum voltages. Once the pH value is obtained, the microcontroller compares it to a preprogrammed threshold. For example, the threshold could be 6.5 to 7.5. If the pH value is too low and the pump has not been activated that day, the system turns on the pH-up pump relay for a few seconds to raise the water's pH. Conversely, if the pH is too high, the system will activate the pH-down pump to lower it. To prevent excessive correction, the system only allows one activation per day, which is controlled by the DS3231 real-time clock (RTC). The proposed system is designed for small-scale aquarium environments where system dynamics are relatively slow and stable. Threshold-based control was selected because it offers low computational complexity, is suitable for microcontroller-based embedded systems, has easier implementation for practical IoT devices, and has adequate performance for maintaining water pH within the acceptable range for goldfish (6.5–7.5). Furthermore, a time-based restriction using the DS3231 RTC was implemented to prevent excessive chemical dosing, which improves operational safety. Therefore, the chosen control strategy balances system simplicity, reliability, and practical applicability.

Additionally, the system includes an automatic water temperature control feature that uses a DS18B20 digital temperature sensor. The sensor operates via the OneWire protocol, providing digital temperature data that is processed directly by the ESP32. Based on the temperature reading, the microcontroller determines whether to activate the heater or the Peltier cooler. If the water temperature exceeds 26°C, the upper threshold, the system will turn on the Peltier relay for a certain duration and then turn it off for a rest period of several minutes. This cycle will continue if the temperature remains high. Conversely, if the temperature is below the minimum threshold of 24°C, the heater will activate. The control uses millisecond-based timing calculations to ensure the process runs efficiently without interfering with other system functions.

The ESP32 uses real-time data from the DS3231 RTC to determine when to activate the servo motor for automatic feeding. The feeding schedule occurs twice a day at 7:00 a.m. and 4:00 p.m. The daily feed volume information is retrieved from Firebase. The `servoSchedule()` function periodically checks the current time and compares it with the feeding schedule. If the time and feed amount are within the specified limits, the `feedFish()` function activates the servo relay for one second, moving the feed container and dropping food into the aquarium. Then, the servo stops, and the amount of feed given is recorded to prevent overfeeding. The amount of feed is converted based on a fixed ratio: one servo rotation represents ± 2 mg of fish feed. The experimental evaluation was conducted over a short-term testing period under controlled laboratory conditions. While the system demonstrated stable operation during this period, long-term performance aspects such as sensor drift, actuator durability, and extended system reliability were not fully evaluated. Future work will focus on long-term field testing and continuous monitoring experiments to further validate the robustness of the proposed system.

RESULT AND DISCUSSION

The developed smart aquarium system was evaluated through functional testing of its sensing, control, communication, and automation subsystems. The ESP32-based platform successfully integrated water temperature monitoring, pH sensing, automatic feeding, and real-time data transmission to the Firebase Realtime Database, as shown in Figure 5. Throughout the testing period, the system operated continuously without critical failures, indicating stable hardware–software integration for aquarium automation. The testing process was carried out on an

automatic aquarium system designed to monitor and control water quality, as well as feed the fish automatically, eliminating the need for manual intervention. Calibration results of the temperature sensor and pH sensor are shown in Tables 3 and 4.



Figure 5. Smart Aquarium

Table 3. Calibration Results of DS18B20 Temperature Sensor

Measurement No	Reference Thermometer (°C)	DS18B20 Sensor Reading (°C)	Error (°C)
1	24.0	24.3	+0.3
2	25.0	25.2	+0.2
3	26.0	26.4	+0.4
4	27.0	27.1	+0.1
5	28.0	28.5	+0.5

Average Error: $\pm 0.30^{\circ}\text{C}$.

The calibration results indicate that the DS18B20 sensor exhibits a small deviation from the reference thermometer with an average error of approximately $\pm 0.30^{\circ}\text{C}$, which is within the specified accuracy range of the sensor ($\pm 0.5^{\circ}\text{C}$). Therefore, the sensor is considered sufficiently accurate for monitoring aquarium water temperature.

Table 4. Calibration Results of PH-4502C pH Sensor

Measurement No	Standard Buffer pH	Sensor Reading	Error
1	4.00	4.12	+0.12
2	5.00	5.08	+0.08
3	6.00	6.10	+0.10
4	7.00	6.92	-0.08
5	8.00	8.14	+0.14

Average Error: $\pm 0.10 - 0.15$ pH units

Calibration was performed using standard buffer solutions (pH 4 and pH 7). The sensor output voltage was adjusted through calibration procedures to match the reference values. The resulting average measurement error of approximately ± 0.12 pH units indicates that the sensor provides adequate accuracy for maintaining the recommended aquarium pH range (6.5–7.5).

To evaluate sensor accuracy, calibration tests were conducted by comparing the DS18B20 temperature sensor with a laboratory digital thermometer and the PH-4502C sensor with standard buffer solutions. The results presented in Tables X and X show that the temperature sensor achieved an average error of approximately $\pm 0.30^{\circ}\text{C}$, while the pH sensor produced an average deviation of about ± 0.12 pH units. These values indicate that the sensing subsystem provides sufficient accuracy for monitoring aquarium environmental conditions and supporting the automated control mechanism implemented in the proposed system.

Water temperature was measured using the DS18B20 digital temperature sensor. Experimental results show that the sensor provided stable and repeatable readings with a resolution of 1°C . During testing, the recorded temperature ranged from 23.5°C to 29.5°C , reflecting changes in ambient conditions, as shown in Table 5.

Table 5. Temperature Sensor Measurement Results

No	Time	Temperature ($^{\circ}\text{C}$)	Relay Status	Description
1	08:00	27.3	OFF	Normal temperature
2	10:00	29.2	Peltier ON	Active cooling
3	12:00	28.5	Peltier ON	High stable temperature
4	15:00	25.1	Peltier OFF	Heater OFF
5	17:00	23.5	Heater ON	Active heating

When the temperature exceeded the upper threshold (26°C), the system automatically activated the Peltier cooling module via a relay. Conversely, when the temperature dropped below 24°C , the heater was activated. As summarized in Table 2, this closed-loop control mechanism successfully maintained the aquarium temperature within the desired range of 24 – 26°C for most operating conditions.

From an operational perspective, this result demonstrates that the temperature control logic implemented on the ESP32 is effective in responding to environmental fluctuations. Maintaining temperature stability is essential for goldfish health, as deviations beyond the optimal range were observed to influence fish behavior, including reduced activity at low temperatures and stress responses at higher temperatures.

Table 6. pH Sensor Measurement Results

No	Time	Voltage (V)	pH	Relay	Description
1	08:00	2.60	6.2	pH Up Pump	pH too low
2	10:00	2.45	7.0	Inactive	Normal pH
3	12:00	2.35	7.6	pH Down Pump	pH too high
4	14:00	2.48	6.9	Inactive	Normal pH
5	16:00	2.60	6.2	Inactive	Corrected today

The pH level of the aquarium water was monitored using an analog pH sensor calibrated with standard buffer solutions (pH 4 and pH 7). The measured pH values during testing ranged from 6.2 to 7.8, as presented in Table 6. The system was programmed to maintain pH within the target range of 6.5–7.5. When the measured pH fell below 6.5, the pH-up pump was activated for a short duration, while pH-down correction was applied when the pH exceeded 7.5. To prevent excessive chemical dosing, pump activation was limited to once per day using date information from the DS3231 real-time clock. The results indicate that this control strategy effectively corrected pH deviations without repeated or excessive actuation. From a system reliability standpoint, the use of time-based constraints via the RTC contributes to safer operation and reduces the risk of overcorrection, which is critical for maintaining water quality in small aquarium systems.

The automatic feeding mechanism was tested using a servo motor controlled by the ESP32 and synchronized with the DS3231 RTC. Feeding was scheduled twice daily at 07:00 and 16:00, with feed quantities configurable through Firebase. Experimental results (Table 7) show that the servo motor consistently dispensed feed according to the specified schedule and feed amount. The conversion ratio of approximately 2 mg per servo rotation enabled predictable feed dosing. Additionally, a safety mechanism prevented repeated feeding within a short time window, effectively reducing the risk of overfeeding. These results confirm that the feeding subsystem functions reliably and supports remote configuration, which is beneficial for users who require flexibility in feed management without direct physical access to the aquarium.

Table 7. Automatic Feeding Schedule and Amount

No	Time	Feed Amount (mg)	Servo Rotation	Status
1	07:00	6	3	Successful
2	16:00	4	2	Successful
3	07:00 (tomorrow)	0 (not yet entered)	-	Scheduled

Firebase is used for real-time data storage and access. It transmits various data, including pH values, temperature, heater relay status, Peltier status, pH Up/Down pump status, feed amount, and servo status. As shown in Figure 6, Firebase successfully receives data with an approximate transmission delay of 1 second between variables. It also serves as a reference source for configuration data, such as the daily feed amount, which is read every loop to allow for remote configuration flexibility.

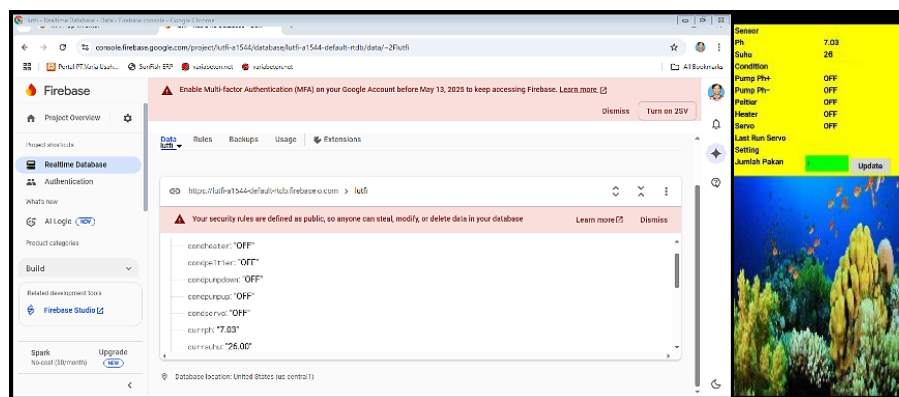


Figure 6. Firebase display

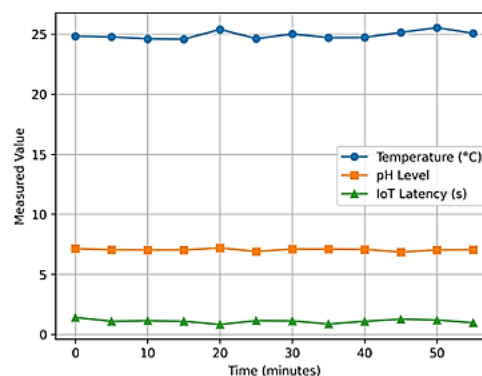


Figure 7. System Performance Evaluation of the IoT-Based Smart Aquarium.

Figure 7 shows the stability of temperature, pH level, and IoT communication latency during system operation. The temperature remained close to the target range of 24–26 °C, while the pH level was maintained around 6.5–7.5, indicating stable environmental control. The IoT

communication delay between the ESP32 device and the Firebase Realtime Database averaged approximately 1 second, demonstrating efficient real-time monitoring capability.

This level of latency is acceptable for aquarium monitoring and control applications, as the system does not require ultra-low-latency responses. Moreover, Firebase served not only as a monitoring platform but also as a configuration interface, allowing users to adjust feeding parameters remotely. This bidirectional communication enhances system usability and demonstrates effective implementation of IoT principles.

Table 8. System Performance Evaluation of the Proposed IoT-Based Smart Aquarium

Performance Parameter	Measurement Method	Result	Description
Temperature Sensor Accuracy (DS18B20)	Compared with a calibrated digital thermometer	± 0.30 °C average error	Accuracy falls within the sensor specification (± 0.5 °C), suitable for aquarium monitoring.
pH Sensor Accuracy (PH-4502C)	Compared with standard buffer solutions (pH 4 and pH 7)	± 0.12 pH units average error	Adequate precision for maintaining the recommended pH range of 6.5–7.5
System Response Time	Time between threshold detection and actuator activation	1–2 seconds	Includes processing time in ESP32 and relay switching
IoT Communication Latency	Time difference between sensor reading and Firebase database update	~1 second average	Measured using timestamp comparison between device transmission and database entry
Actuator Activation Time	Time required for the relay or servo to execute the control command	Relay: <1 s; Servo feeding: ~1 s	Ensures prompt environmental adjustment and feeding action
Control Stability	The duration the system maintains environmental parameters within the target range	Temperature: maintained within 24–26 °C for most operating time; pH maintained within 6.5–7.5	Demonstrates stable environmental regulation during testing

In addition to technical evaluation, qualitative observations of goldfish behavior were conducted to assess environmental suitability. When the aquarium conditions were maintained within the target ranges (temperature 24–26°C and pH 6.5–7.5), the fish exhibited active swimming behavior, normal feeding responses, and stable coloration. In contrast, temperatures above 29.5°C were associated with signs of stress, such as rapid breathing and surface swimming, while temperatures below 23°C resulted in reduced activity and appetite. Similarly, pH levels outside the target range led to erratic swimming or passive behavior. These observations support the importance of automated environmental control and indicate that the system contributes to maintaining conditions that are favorable for goldfish well-being.

To evaluate the operational effectiveness of the proposed smart aquarium system, several quantitative performance metrics were measured, including sensor accuracy, system response time, communication latency, and control stability. As shown in Table 8, the DS18B20

temperature sensor achieved an average error of approximately ± 0.30 °C, while the PH-4502C sensor showed an average deviation of ± 0.12 pH units when compared with standard reference measurements. The system response time between threshold detection and actuator activation was approximately 1–2 seconds, which is sufficient for aquarium environmental control, where parameter changes occur gradually. Communication latency between the ESP32 and the Firebase Realtime Database was approximately one second, indicating efficient IoT data transmission for real-time monitoring. Additionally, the implemented control logic successfully maintained water temperature within the target range of 24–26°C and pH levels between 6.5 and 7.5 during the testing period. These results demonstrate that the proposed system provides reliable sensing, timely actuation, and stable environmental regulation suitable for intelligent aquarium management.

Overall, the experimental results demonstrate that the proposed IoT-based smart aquarium system performs its intended monitoring and control functions effectively. Compared to manual aquarium management, the system reduces user intervention while providing continuous oversight of critical water quality parameters. The integration of ESP32, Firebase, and a mobile application enables real-time monitoring and remote configuration, aligning with current trends in smart home and IoT-based aquaculture systems. While the system shows reliable performance in a laboratory-scale aquarium, further work may include long-term stability testing, integration of additional water quality parameters (such as dissolved oxygen or turbidity), and evaluation across different aquarium sizes. Nonetheless, the present results indicate that the system offers a practical and scalable approach for intelligent aquarium management.

CONCLUSION

This research presented the development of an Internet of Things (IoT)–based smart aquarium system designed to monitor and automatically control water temperature, pH levels, and feeding schedules. The system integrates an ESP32 microcontroller, temperature and pH sensors, relay-based actuators, a real-time clock, and a cloud-based Firebase platform, enabling real-time monitoring and remote configuration via a mobile application. Experimental evaluation showed that the system operated reliably and was able to maintain water temperature within the range of 24–26°C and pH levels between 6.5 and 7.5 under the tested conditions. Scheduled feeding was executed consistently according to predefined time settings, and the implemented control logic effectively prevented excessive actuation, particularly in pH adjustment and feeding operations.

The use of IoT connectivity reduced the need for manual aquarium maintenance by allowing users to monitor system status and adjust operational parameters remotely. Qualitative observations further indicated that stable water quality conditions were associated with normal fish activity and feeding behavior. Despite its effective performance in a laboratory-scale setup, the system is currently limited to basic water quality parameters and short-term testing. Future work should include long-term reliability evaluation, the integration of additional sensors such as dissolved oxygen and turbidity, and adaptation for larger or more complex aquarium environments. Overall, the proposed system provides a practical and scalable foundation for intelligent aquarium management using IoT-based automation.

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