Smart IoT Aquarium Monitoring and Remote Lighting Control

Danish Haziq Bin Noor Izani1, a) and Mohana A/P Muniandy, 2, b)

*1,2Faculty of Computing and Informatics, Multimedia University, Persiaran Multimedia, 63100 Cyberjaya, Selangor, Malaysia*

*b) Corresponding author: mohana@mmu.edu.my  
a) 1211307542@student.mmu.edu.my*

**Abstract.** Using conventional manual methods to maintain ideal aquatic conditions in home aquariums can be time-consuming and prone to mistakes. This study introduces an ESP32 microcontroller-based smart internet of things aquarium monitoring and remote lighting control system. For real-time display and control, the system incorporates temperature, pH, and Total Dissolved Solids (TDS) sensors and links to a mobile app using the Blynk platform. It also uses Firebase to retain previous data and incorporates automation components to support the circadian rhythms of aquatic life. The system provides real-time monitoring, remote lighting control, alarm notifications, and data analytics. The implementation's outcomes demonstrate effectiveness, reliability, and usability.

# Introduction

Traditional aquarium maintenance, which includes manual water testing and preset lighting schedules, may be challenging and error-prone, especially for pet owners who are busy or on the go. IoT (Internet of Things) technology offers potential solutions by enabling automation, remote monitoring, and data-driven maintenance. This project introduces a Smart Aquarium Monitoring System that uses the Internet of Things to provide real-time water parameter tracking, automated alarms, and remote lighting control. Based on an ESP32 microcontroller, the system uses the Blynk IoT platform and a Firebase database to connect to the cloud.

## Literature Review

#### **Importance of Water Quality Monitoring**

Water quality monitoring is crucial for aquatic pets to be healthy, grow and survive. Other than that, consistent pH, the optimal temperature such as warm temperature for tropical aquatic pets or cool temperature for aquatics pets form cold climates, as well as Total Dissolved Solids (TDS) levels are essential for fish health and survival. It is highly possible that any significant changes in these factors could very easily lead to disease, stress, or even death in these aquatic pets [1]. Consequently, if aquatic pet owners can perform ongoing observation, they will be able to identify modifiable alterations early on. This will allow remedial measures to prevent negative ramifications.

#### **Limitations of Traditional Methods**

Manual aquarium monitoring techniques use portable meters or kits to test the water on a regular basis [2]. Despite being accessible and affordable, manual methods—which are often inaccurate and time-consuming—do not offer real-time monitoring. Temperature variations, biological waste buildup, and overfeeding can all cause major alterations in the water's quality very quickly [3]. Without constant observation, serious problems might not be identified until it is too late, and the situation is irreparable. Additionally, an aquarium owner's capacity to monitor trends or take quick action is limited by manual methods' lack of remote monitoring features and previous data visualization.

#### **Role of Lighting and Circadian Rhythm**

Aquatic pets are subject to circadian rhythms, which govern biological functions including feeding, sleeping, and reproduction, much like any other species. In order to keep these rhythms going, an aquarium's lighting and schedule are crucial. Uneven light cycles can stress aquatic species and have a detrimental effect on their health [4]. Controlled lighting systems that mimic natural light cycles can support steady biological rhythms, which will improve aquatic pets' behavior and overall health.

#### **IoT Applications in Aquatic Systems**

Aquaculture and aquarium management are currently using IoT technology more and more to enable automated data gathering, regulation of the environment, and real-time water quality monitoring [5]. The benefit of having an online mobile application that is connected to Wi-Fi is that it provides constant and remote monitoring for IoT-enabled systems. When parameters exceed safe thresholds, the app can notify users instantly, allowing for targeted maintenance and significantly lowering the chance of fish death.

## Main Components of the IoT System

The system includes several essential hardware components to ensure accurate and continuous aquarium condition monitoring. By detecting the number of dissolved solids in the water, the TDS sensor offers information on the water's overall cleanliness, which is essential for maintaining fish health. Contaminants such as waste products and nitrites may be detected by this sensor. The sensor for temperature helps to keep the water within species-specific optimum ranges because temperature fluctuations can stress or sicken aquatic life. The pH sensor assesses the acidity or alkalinity of the water, which is essential for maintaining a stable and healthy habitat for aquatic life. Central to the system is the ESP32 microcontroller, serving as the primary processing unit, gathering data from the sensors and sending it through Wi-Fi to the Blynk IoT platform for real-time monitoring and remote management.

## Mobile App Integration for IoT

Mobile apps such as Blynk provide customizable dashboards for users to monitor water quality parameters, receive alerts, and control lighting systems remotely. These platforms facilitate user engagement, allowing aquarium owners to manage their systems anytime and anywhere [8].

## METHODOLOGY

#### **Requirement Gathering**

Two fact finding methods were used which were questionnaires and interviews to identify user needs. The results revealed that users prioritize real time monitoring of water quality parameters, instant alerts for parameter deviations, and automated control of lighting systems to support circadian rhythms. These findings helped shape the definition of functional and non-functional system requirements.

#### **Hardware Development**

An ESP32 microcontroller was used due to its built-in Wi-Fi capabilities which is important for remote control and cost friendliness. TDS, temperature, and pH sensors were integrated to monitor critical water quality parameters. A 5V relay module was included to automate lighting control. The components were put together on an ESP32 extension board could later be integrated into a plastic casing to make sure the board stays away from water. The TDS sensor plays a vital role in assessing water purity by measuring the concentration of dissolved substances. Figure 1 shows the TDS sensor used in this system, which provides continuous readings to monitor water quality and detect contamination levels.

A white wire connected to a circuit board

AI-generated content may be incorrect.

**FIGURE 1.** Total Dissolved Solids (TDS) Sensor

Temperature regulation is crucial for maintaining a stable aquatic ecosystem. As shown in Figure 2, the temperature sensor ensures that the water remains within the optimal range for aquatic species by providing real-time temperature readings to the ESP32 controller.

A black wire with a piece of electronic equipment

AI-generated content may be incorrect.

**FIGURE 2.** Temperature sensor

Lighting control is automated using a relay module, which enables remote switching and scheduling through the mobile app. Figure 3 illustrates the 5V relay module integrated into the system to control the aquarium lighting based on programmed intervals or user input.

A close-up of a circuit board

AI-generated content may be incorrect.

**FIGURE 3.** Relay module 5v

#### **Software and Architecture**

The software was developed using Arduino IDE which made use of the relevant libraries for sensor integration and Blynk communication. The thresholds for pH, TDS and temperature were programmed to trigger alerts through the Blynk platform whenever a parameter has been exceeded. The mobile app was designed with separate widgets for real-time parameter display, historical data visualization, and remote lighting control.

The three sensors that make up the system architecture are linked to the ESP32 microcontroller, which processes the data before sending it over Wi-Fi to the Blynk cloud platform. The Blynk app allows users to remotely control lighting, analyze real-time parameter data, and get notifications. Automated warnings make sure that the parameters do not go beyond the predetermined threshold, and they notify the user right away if they do.

# System Implementation

To ensure a smooth and useful aquarium monitoring and control system, hardware and software components must be fully integrated as part of the system implementation. The first step is on finding the best locations for the sensors inside the aquarium to guarantee precise readings for variables like temperature, pH, and TDS as well as the remote lighting mounted on the aquarium's side. These sensors were connected to an Arduino IDE-programmed ESP32 microcontroller. Real time data from the sensors was processed and transmitted to the Blynk mobile app through Wi-Fi. The system also featured lighting circuit controlled by a relay to switch it on and off, allowing users to schedule or manually toggle the aquarium lighting. All components were housed in a waterproof enclosure to ensure durability in a moist environment. The implementation ensured not only functional monitoring and alerting but also enhanced usability and remote access for aquarium owners, fulfilling the project’s key objectives.

#### **Sensor Data Acquisition Module**

Sensors were strategically positioned inside the aquarium and are connected via jumper wires to the main processing board. Sensors collect temperature, pH, and TDS readings.The ESP32 was programmed to collect data at five-second intervals. The relay module was wired to a standard aquarium LED lighting system, allowing remote and automated switching. Data is processed using calibration equations and median filtering to reduce noise. The ESP32 transmits this data to both Firebase and Blynk.

**Real-Time Monitoring via Blynk**

Programming sensor reading intervals, Wi-Fi networking protocols, and warning circumstances were all part of the firmware development process. Secure online storage and continuous interaction between the ESP32 and the mobile application were made possible by the Blynk platform. Blynk virtual pins (V0-V3) are used for displaying live values and relay control. The app enables users to monitor readings and toggle aquarium lighting remotely.

**Cloud Integration with Firebase**

The Firebase Realtime Database organizes data in JSON format, stored under paths specific to each user, facilitating structured storage for individual users. Each entry contains a timestamp that is synchronized using an NTP client, ensuring precise monitoring of sensor data. This functionality allows for real-time updates and enables the analysis of historical trends across various devices.

**Automation and Notifications**

Thresholds are programmed to automatically activate alerts through Blynk log events whenever sensor measurements surpass predetermined safe limits. Real-time notifications are sent to the user’s mobile device when factors such as temperature exceed 30°C, pH falls below 6.5, or TDS goes beyond 500 ppm, enabling prompt corrective measures.

**Hardware Assembly**

Components are arranged on an ESP32 expansion board. Sensors are submerged safely, while the relay connects to the lighting system. All the hardware is enclosed to protect from moisture. The Blynk mobile app interface was designed with widgets for monitoring pH, TDS and temperature values. Additional features included historical trend graphs, light control toggles, and customizable alert notifications. Screenshots of the app interface demonstrate the real-time data visualization and ease of use for end-users.

# Discussion

The implementation phase successfully integrated hardware and software components to create a functioning IoT-based aquarium monitoring system. The system performed reliably under testing. Real-time updates were reflected instantly on the Blynk app. Alerts were accurately triggered for parameter deviations. Challenges encountered included sensor calibration and Wi-Fi connectivity, both resolved through iterative testing. The use of Firebase ensured secure cloud storage, and Blynk provided a user-friendly interface.

# Conclusion and Future Work

The implemented smart aquarium system achieves real-time monitoring, automation, and user interaction. It supports the well-being of aquatic pets by maintaining environmental stability and enabling remote control. Future improvements include multi-tank support, solar power integration, and predictive analytics using machine learning.

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