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Development of a Floating Beacon for Real-Time Water Quality Measurement

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ABSTRACT

Water quality is a critical determinant of agricultural productivity and environmental sustainability. This study addresses the challenge of real-time water quality monitoring in agricultural settings, specifically focusing on paddy fields in Perlis, Malaysia. The Jabatan Pengairan dan Saliran of Perlis (JPS) currently faces difficulties in continuously monitoring water quality parameters after water discharge from the Timah Tasoh Dam into the irrigation system. To overcome this, this research focuses on developing a Floating Beacon (FB), an Internet of Things (IoT)-based system for autonomous water quality assessment. The system integrates sensors to measure key water quality parameters, including pH, turbidity and temperature. Real-time data collected by these sensors are wirelessly transmitted to the Blynk cloud platform, enabling continuous data recording and visualization on a customizable dashboard. Furthermore, the system incorporates a feature for tracking the geographical location of the monitoring devices, providing crucial context for water quality measurements across the agricultural landscape. This research is anticipated to significantly enhance the efficiency of water quality management for the JPS of Perlis, thereby supporting optimal water supply to paddy fields and contributing to improved agricultural practices. Based on the result, the FB is capable provides real-time water quality data and display on the web and mobile devices using Blynk 2.0. Furthermore, the FB shows high accuracy for the location measurement with the maximum error at 0.000743% for latitude and 0.000037% for longitude.

Keywords: Agriculture, Floating Beacon, Internet of Things, Jabatan Pengairan dan Saliran of Perlis (JPS), Water Quality

1. INTRODUCTION

Water is an indispensable resource for all forms of life, and its effective management has become a paramount global concern, particularly in the industrial, agricultural, and domestic sectors, due to the escalating world population. Maintaining good water quality is crucial, especially for agricultural productivity and environmental health. In Malaysia, water quality assessment reveals a pressing need for enhanced monitoring; the Department of Environment's 2020 Annual Report indicated that out of 672 rivers, only 443 exhibited good water quality, while 195 were slightly polluted and 94 were significantly polluted [1]. This underscores the critical importance of ensuring water quality is consistently maintained at optimal levels.

The advent of Internet of Things (IoT) technology has revolutionized environmental monitoring, offering cost-effective and efficient solutions for water quality assessment [2]. IoT-based systems

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are increasingly recognized for their potential to mitigate issues such as water pollution and water scarcity [3][4], with multi-sensor platforms proving particularly effective for comprehensive water quality measurement [5]. Within the agricultural sector, especially in paddy cultivation, water quality is a foundational element for successful yields. State agencies are responsible for supplying high-quality water to paddy fields within their jurisdiction.

In Perlis, Malaysia, the Jabatan Pengairan dan Saliran of Perlis (JPS) is the primary state agency tasked with controlling and monitoring water quality for agricultural irrigation. However, JPS currently faces a significant challenge: while they can monitor water quality before its release from the Timah Tasoh Dam, continuous monitoring ceases once the water enters the paddy field irrigation system. To address this critical gap, this project developed a real-time water quality monitoring system based on a Floating Beacon (FB) design. The system utilizes a TTGO SIM7600, which integrates an ESP32 microcontroller with a SIM7600 GSM module, providing 4G connectivity essential for IoT operations. Key water quality parameters, including pH, turbidity, and temperature, are measured using dedicated sensors. For data storage, visualization, and remote access, the system leverages the Blynk 2.0 application, available on both mobile and web platforms. Therefore, the FB provides real-time data for JPS to monitor the water quality for agricultural use in Perlis.

2. MATERIAL AND METHODS

This section will detail the comprehensive hardware and software development, encompassing the Floating Beacon (FB) structural design, schematic connectivity, and the intricacies of application development.

2.1 The FB Monitoring and Operational System

The overall architecture of the FB monitoring system is illustrated in Figure 1. The core of the system is the TTGO SIM7600, which serves as the main processing unit, integrating an ESP32 microcontroller with a SIM7600 GSM module. This module provides essential 4G connectivity for IoT operations and incorporates a GPS module for accurate device localization. Three critical water quality parameters which are pH, turbidity, and temperature are measured using dedicated sensors interfaced with the microcontroller unit (MCU). For data aggregation, visualization, and remote control, the system leverages the Blynk 2.0 application, an intuitive IoT platform accessible via both mobile and web interfaces.

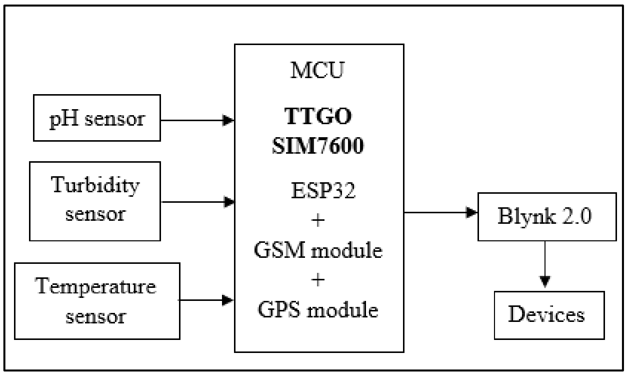

Figure 1. The FB system architecture

Next, the operational flow of the project is detailed in the flowchart presented in Figure 2. Upon system activation, both the GSM and GPS modules initiate their processes. These modules establish a connection with the ESP32 microcontroller via 4G connectivity to acquire cellular network access and location data. Once a successful connection is established, the microcontroller proceeds to collect data from the pH, turbidity, and temperature sensors. Subsequently, the acquired sensor data is transmitted to the cloud. The results obtained from these sensor readings are then updated and displayed on the dashboard of both the mobile and web applications via Blynk 2.0, providing real-time insights into water quality.

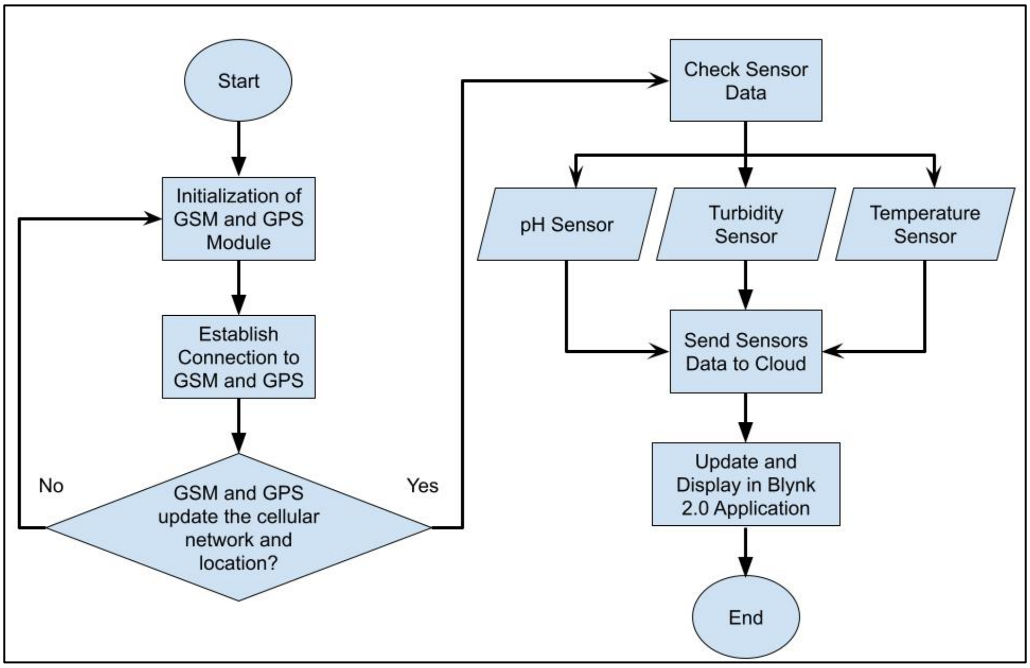

Figure 2. The FB flow process

2.2 The FB Hardware Development

The FB system's hardware comprises four primary components: the TTGO SIM7600, which embeds both GSM and GPS modules (Figure 3), a pH sensor (Figure 4), a turbidity sensor (Figure 5), and a temperature sensor (Figure 6).

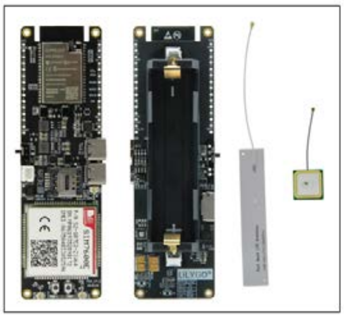

Figure 3. TTGO SIM7600

Figure 4. pH Sensor

Figure 5. Turbidity sensor

Figure 6. Temperature sensor

The detailed specifications for each of these components are provided in Table 1.

Table 1 The specification and functionality of the FB components

Component	Specification and Functionality
TTGO SIM7600 with GSM and GPS module	This component is compatible with 4G connectivity to transmit the live location and sensor data to the cloud.
pH Sensor	Detects the presence of the Hydrogen-ion in water-based solutions to determine the acidity or alkalinity.
Turbidity Sensor	Detects the turbidity parameter by measure light transmittance and scattering rate to detect suspended particles in water.
Temperature Sensor	Measure the temperature between -55°C to +125°C with ± 0.5°C accuracy [7]. This temperature sensor probe is waterproof so suitable to use for underwater.

Finally, the schematic diagram for these components is illustrated in Figure 7. The TTGO SIM7600 serves as the main microcontroller, combining an ESP32 with the SIM7600 GSM module for 4G IoT connectivity and a GPS module for satellite-based position tracking of the FB. Three sensors are connected to the microcontroller: the pH sensor is connected to pin A6, the temperature sensor to pin A13, and the turbidity sensor to pin A4. The entire FB system is powered by an 18650 battery, providing 3.3V for operation and activation.

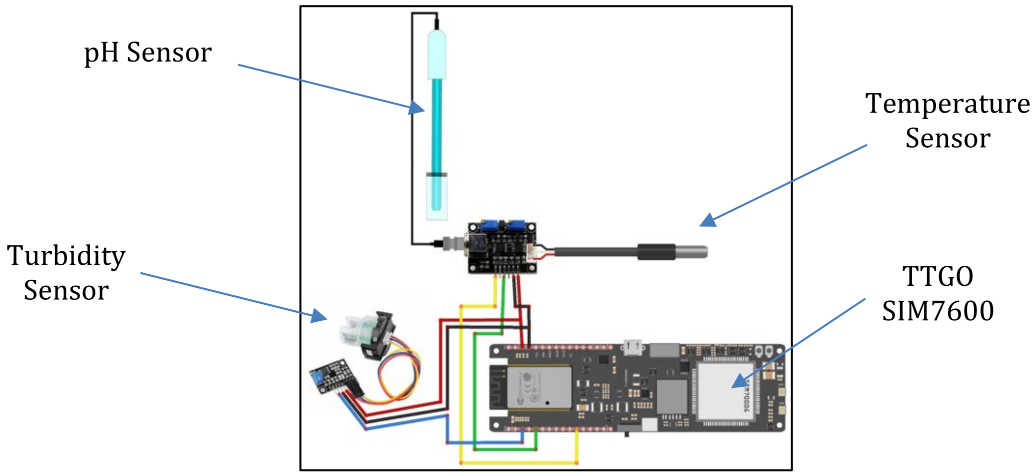

Figure 7. The FB schematic diagram

2.3 The FB Hardware Application Development and Connection

Blynk 2.0 is an Internet of Things (IoT) platform that facilitates connection to microcontrollers with Wi-Fi or cellular network functionality. This application is utilized to display remotely collected sensor data in a graphical format and provides an interface for controlling outputs or other parameters. The platform offers numerous features, including GPS integration and live charting, and is available in both mobile and web versions. Its user-friendly design makes it particularly accessible for newcomers developing new projects and customizing interfaces.

Notably, Blynk 2.0 operates using its proprietary Blynk Server, which manages all communications between smartphones, webpages, and hardware. This server can be run privately and locally, or users can leverage the Blynk Cloud. Being open-source, the Blynk Server is capable of handling thousands of devices and can be deployed on various platforms such as Arduino and Raspberry Pi over the internet [8].

2.4 The FB Structure Design

The physical design of the FB is based on a two-part concept, consisting of a main part and a cap part, as illustrated in Figure 8. The main part of the FB is designed to house the primary circuit board while the three sensors that consists of pH, turbidity, and temperature are attached to the FB device as shown in Figure 8. The final assembled product of this project is depicted in Figure 9.

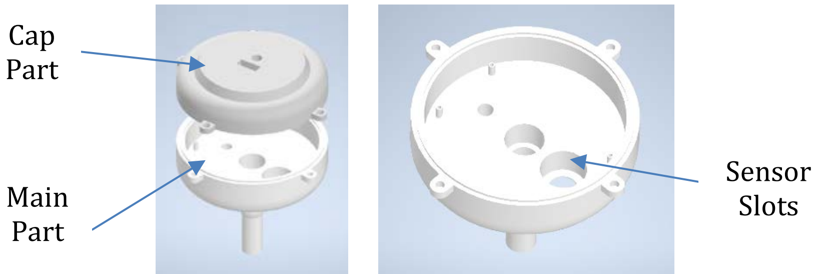

Figure 8. The FB design structure

Figure 9. The FB end product

3. RESULTS AND DISCUSSION

This section will detail the real-time sensor data acquired from pH, turbidity, and temperature sensors deployed at Dataran Santuari Ikan Air Tawar Timah Tasoh, located in Perlis, Malaysia. In addition to environmental parameter monitoring, the experiment also includes testing the accuracy of the FB (Firebase) location functionality and battery performances.

The core objective of this project is to showcase the capability of the ESP32 (or a comparable microcontroller with integrated Wi-Fi capabilities) to transmit this live environmental data to a cloud-based platform, specifically Blynk 2.0. This allows for convenient remote monitoring and visualization of the water quality parameters.

3.1 Analysis of Water Quality Parameters

Figure 10 presents the results obtained from the pH sensor. The recorded pH values range from a maximum of 9.00 to a minimum of 6.40. An observed increase in the water's pH value is attributed to heavy rainfall, which is hypothesized to have introduced significant levels of organic matter and suspended particulates into the river system. Despite these fluctuations, the average pH value recorded from the sensor data is 7.88.

According to the National Lake Water Quality Criteria and Standards (NLWQS), Timah Tasoh Lake is categorized as Category C. This classification signifies that the lake's primary purpose is for the preservation of aquatic life and biodiversity [9]. Based on the analysis of the pH sensor data, the observed pH values, particularly the average of 7.88 and the range of 6.40 to 9.00, fall within the compliant limits specified by the NLWQS, which typically ranges from pH 6.0 to 9.0 for Category C lakes. This indicates that, at the time of data collection, the pH level of Timah Tasoh Lake was suitable for supporting aquatic ecosystems as per the established national standards.

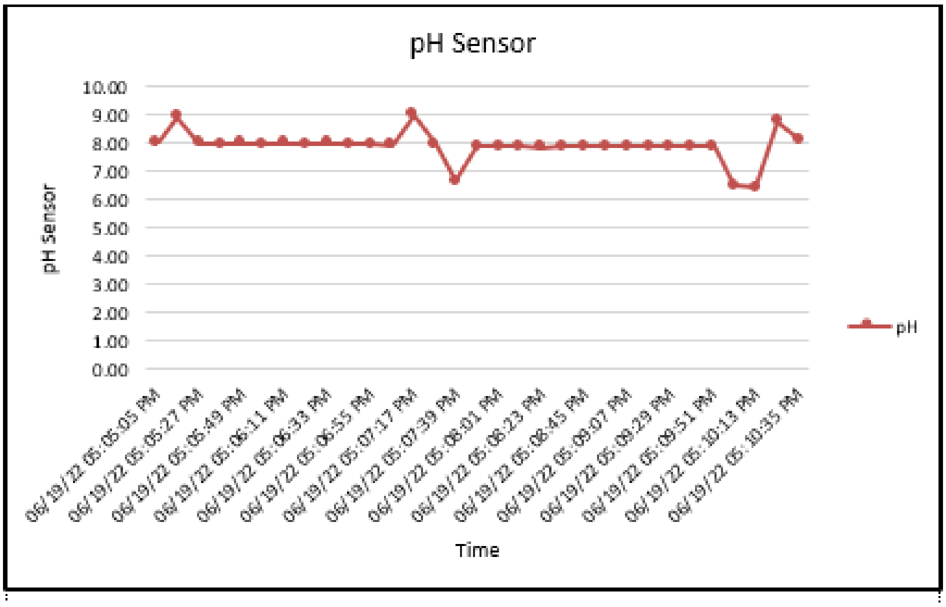

Figure 10. pH sensor's data reading

Next, Figure 11 illustrates the results of the turbidity sensor, which measures the cloudiness of the water. From the analysis, it is evident that the sensor data for turbidity exhibits inconsistency and instability. This is primarily attributed to strong wave action in the lake, causing the sensor to intermittently surface. This upward movement makes it difficult for the sensor to effectively reflect light and receive a reliable signal during data collection.

Despite these challenges in data stability, the average turbidity value recorded is 47 NTU. Based on the National Lake Water Quality Criteria and Standards (NLWQS) for Category C lakes (intended for the preservation of aquatic life and biodiversity), the turbidity limit is 70 NTU. Therefore, even with the observed instability, the average turbidity of 47 NTU is within the compliant limit set by the NLWQS. While the fluctuating readings highlight a data acquisition challenge, the overall average suggests that the water's clarity, in terms of turbidity, generally meets the standards for supporting aquatic life and biodiversity in Timah Tasoh Lake.

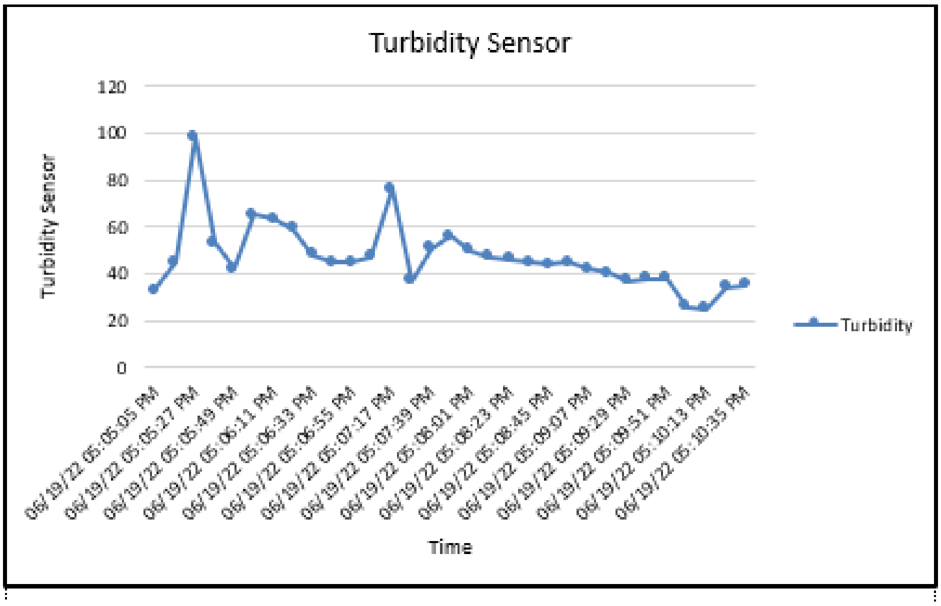

Figure 11. Turbidity sensor's data reading

Finally, the temperature sensor, an electronic device designed to detect and measure heat or coolness and convert it into an electronic signal, was employed in this project to ascertain the water temperature of Timah Tasoh Lake. As depicted in Figure 12, the water temperature of the lake was consistently recorded at 32°C.

According to the NLWQS, the ideal water temperature for the lake should be 28°C. The recorded temperature of 32°C exceeds this limit. This elevated temperature is likely a direct consequence of the hot weather conditions prevalent during the data collection period. Given that the current time is July, which is typically a warm month in Perlis, Malaysia, higher ambient temperatures can directly influence water body temperatures. This explains why the observed temperature surpassed the limit stipulated by the NLWQS.

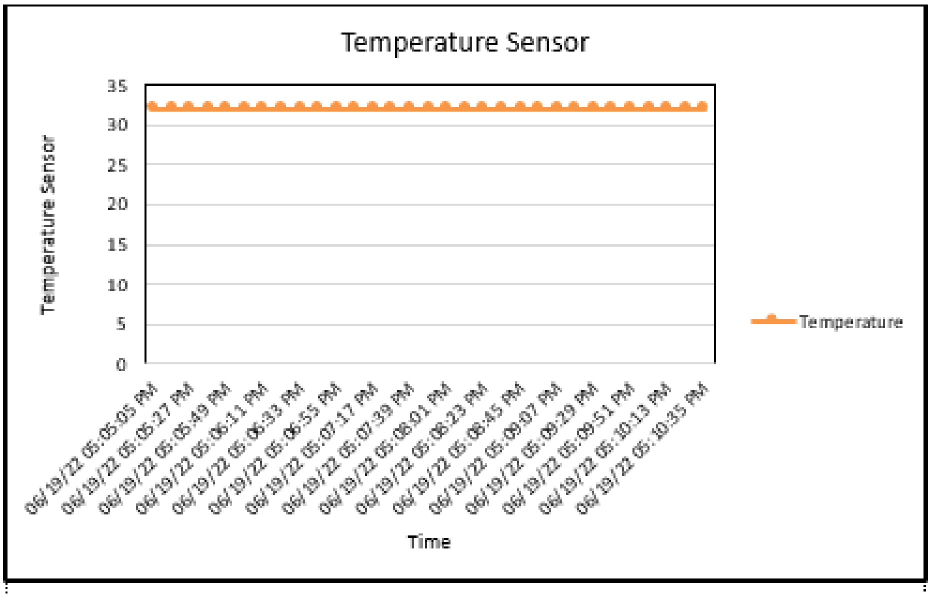

Figure 12. Temperature sensor's data reading

3.2 The FB Location Accuracy

To enhance the GPS accuracy of the FB device, a location accuracy test was conducted. This test took place at PFI2 Hostel, UniMAP and involved a comparative analysis with a different GPS-enabled device, specifically a smartphone.

Figure 13 visually represents the checkpoints recorded by both the smartphone's GPS and the FB device's GPS. The blue-colored route illustrates the checkpoints tracked by the smartphone's GPS, while the black-colored route denotes the checkpoints from the FB device's GPS. This visual comparison provides an immediate qualitative assessment of the congruence, or divergence, between the two tracking systems.

Figure 13. Location accuracy test path

Table 2 comprehensively details the quantitative data acquired during the test, presenting the latitude and longitude coordinates recorded by both the smartphone and the FB device across various checkpoints. The results indicate that the maximum observed error between the devices for latitude was 0.000743% at Checkpoint 1, while for longitude, it was 0.000037% at Checkpoint 2. The percentage of error, derived from these differences, is provided to offer a clear metric of the FB device's GPS accuracy relative to the smartphone's GPS. This meticulous analysis quantifies the current precision of the FB device's location capabilities, which will inform strategies for potential enhancements. These findings suggest a high degree of accuracy for the FB device's location measurements.

Table 2 The comparison of location accuracy between a smartphone and the FB device

Checkpoint	Smartphone Location (Latitude, Longitude)	FB Device Location (Latitude, Longitude)	Difference of Measurement (Latitude, Longitude)	Percentage of Error between Location (%)
1	6.460530, 100.359450	6.460578, 100.359458	0.000048, 0.000008	0.000743, 0.000008
2	6.460710, 100.358880	6.460746, 100.358917	0.000036, 0.000037	0.000557, 0.000037
3	6.460950, 100.358220	6.460942, 100.358184	0.000008, 0.000036	0.000124, 0.000036
4	6.460400, 100.358020	6.460443, 100.358024	0.000043, 0.000004	0.000666, 0.000004
5	6.459840, 100.357820	6.459834, 100.357826	0.000006, 0.000006	0.000093, 0.000006
6	6.459610, 100.358460	6.459611, 100.358467	0.000001, 0.000007	0.000015, 0.000007
7	6.459420, 100.359040	6.459440, 100.359046	0.000020, 0.000006	0.000310, 0.000006
8	6.459940, 100.359250	6.459967, 100.359275	0.000027, 0.000025	0.000418, 0.000025

3.3 Mobile and Web Application Dashboard Display

Figures 14 and 15 illustrate the interfaces of the developed mobile and web applications, respectively. These applications serve as the primary platforms for displaying and monitoring the real-time output from the pH, turbidity, and temperature sensors. Continuous monitoring of sensor data is facilitated through these applications. All collected sensor data are stored in a cloud-based CSV format for subsequent analysis in Microsoft Excel. Furthermore, the applications integrate GPS functionality, enabling real-time viewing and tracking of location data.

Figure 14. Web application interface

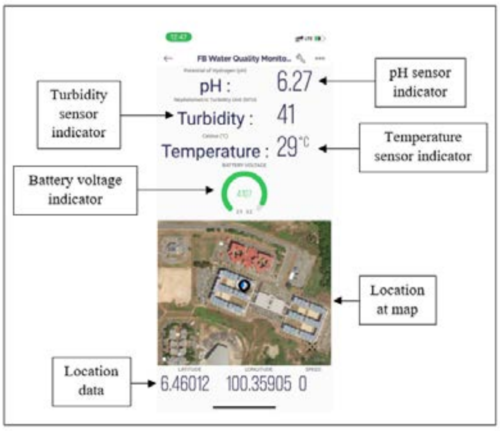

Figure 15. Mobile application interface

3.4 Battery Management and Performances

Battery life is a critical consideration for portable devices such as the FB device, necessitating careful selection based on capacity and operational duration. A robust and sufficient battery life is paramount for the FB device to function effectively throughout its intended operating period. Interruption of power during operation would prevent data communication to both the user and the server, compromising the system's utility. For this project, an 18650 rechargeable battery with a capacity of 3500 mAh was selected to power the device.
The battery's voltage was monitored using the Analog-to-Digital Converter (ADC) pin 35 of the microcontroller. According to the 18650 rechargeable battery datasheets, its nominal voltage is 4.2V, with a cut-off voltage of 2.9V [10]. Figure 16 illustrates the gradual voltage drop observed during testing, demonstrating that the battery sustained operation for approximately 12 hours before fully discharging from an initial 4.07V to the 2.9V cut-off.

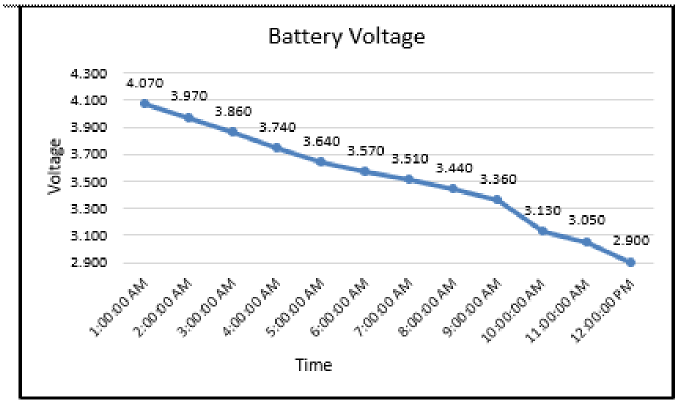

Figure 16. Battery performance on the FB

4. CONCLUSION

This project successfully developed and implemented the FB that effectively accomplished all specified tasks. It demonstrated real-time water quality monitoring capabilities, seamlessly transmitting and storing data to the Blynk Cloud, and high accuracy for the location measurements. Furthermore, the mobile and web applications, developed using the Blynk 2.0 IoT platform, were successfully deployed, providing users with a clear interface to view water quality parameters.

To enhance the current system, several areas for future development are proposed:

- Enhanced Mobility: The FB device's functionality could be expanded beyond static water quality monitoring and location tracking by incorporating mobility features. Currently, the device requires manual retrieval by boat after operation. Integrating two DC motors, similar to those found in remote-controlled (RC) boats, would allow users to remotely control the device's return upon completion of its operational period.
- Expanded Sensing Capabilities: To provide a more comprehensive assessment of water quality, additional sensors could be integrated into the FB device. Specifically, the inclusion of Dissolved Oxygen (DO) and Electrical Conductivity (EC) sensors would broaden the range of measurable water quality parameters. Additionally, to improve device discoverability, a buzzer sensor could be implemented to alert users to the device's last known position.
- Optimized Power Management: Battery capacity and sustained operation are critical for portable devices like the FB device. Future research should focus on selecting the most suitable battery type to maximize operational longevity. A promising suggestion to extend battery life is the implementation of solar charging. Given that the TTGO SIM7600 microcontroller features built-in solar charging capabilities, this could be leveraged in future iterations to significantly prolong the battery's operational duration.

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