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Conceptualising flood warning system for connected vehicles

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ABSTRACT

Floods are a common natural hazard in Malaysia during the monsoon season. It affects millions of people each year that leads to severe deaths and infrastructure destruction. In recent time, flood warning system (FWS) has been a notable topic but it has not been extensively implemented in Malaysia. In this study, we developed a FWS that can interface with connected vehicles in order to provide alerts to drivers while also sending warnings to end users. This type of FWS enables vehicles to connect with one another within a particular radius to broadcast flood information via long range (LoRa) communication technology. When the water level rises over a certain point, the system sends a warning to drivers indicated through a mobile application. Drivers have the option to take alternative route, reducing the likelihood of damage when driving into or near a flooded area. The developed application demonstrates that the warning was able to be instantly displayed to the driver if there is a significant increase in water level. Experimental evidence shows that the driver was able to receive the water level alert and a visual interpretation of the immediate area affected by flood through the application.

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1. INTRODUCTION

Floods are among the most frequent and destructive natural disasters that may occur worldwide. Every year, it has an impact on the lives of millions of individuals. Floods and heavy rain are unexpectedly destructive natural occurrences that have the potential to result in a considerable number of fatalities as well as the destruction of property [1], [2]. One of the states that make up Malaysia, Kedah, was struck by a flash flood in August 2021. There were around 965 households adversely impacted (approximately 4,825 people). In addition, occurrences of a similar nature surfaced in other states of Malaysia in September 2021, including Sabah, Sarawak, and Johor. The Association of Southeast Asian Nations (ASEAN) disaster information network (ADINet) estimated that 255 individuals had to evacuate their homes due to the flash flood; 75 in Sabah, 84 in Sarawak, and 96 in Johor. These floods resulted in some damage being done to the homes and the roads, and as a result, the victims had to shift to an evacuation centre in order to find a safe place to live [3]–[5].

Although a dam monitoring system in Malaysia can determine how much water is retained behind a dam's walls, there is currently no viable flood warning system (FWS) that can be put into place in the state's more populated areas [6]. In certain nations, such as the Philippines, for example, the government has invested in the development of a monitoring system in order to minimize the severity of the damage that may be caused by floods, especially in the region of Manila. The national operational assessment of hazards (NOAH), responsible for creating the monitoring system, incorporated the Senix ToughSonic sensor into the design. This has undoubtedly aided in appropriately monitoring floods on Philippine urban roads [7], [8]. As a direct consequence, the floods have had major effects on society. Thus, it is necessary to set up a FWS to warn people ahead of time, allowing individuals to take preventative measures and keep an eye out for ways to lessen the damage caused by floods [9]. In most countries, FWS was first used only to monitor the height of dam water in order to predict and assess the likelihood of flooding [10], [11]. This approach is neither efficient nor particularly accurate because the topography of each location will be different. Consequently, with the development of a technology known as the internet of things (IoT), it will be possible to improve the current FWS by putting IoT devices in suburban, urban, and rural locations.

In this study, the water level is detected by the server system and stored in the local and cloud databases for further processing. In addition, the server's location will be logged to ensure that the exact location of the flood may be discovered. The system allows the client and the end user to check the water level using a mobile application. This is particularly useful for those who drive or walk on roads since they can observe the water's height while they are on the road and have access to real-time information on the places that are being impacted by flood. In this approach, both drivers and pedestrians may remain vigilant by changing their routes around the affected area since they will have advance notification of the road's condition.

The paper is being organised according to the following structure. Section 1 comprises the introduction. Following this, section 2 provides the theoretical review. In section 3, the research method is deliberated. Section 4 presents the results of the experiment. In section 5, the conclusion is presented.

2. THEORETICAL REVIEW

2.1. Connected vehicles

Recently, governments and the automotive industry have been investigating methods to make use of the monitoring of potential hazard data for drivers in real time. The data gathered by various sensors inside or outside of a connected vehicle would allow crowdsourcing approaches to let drivers, emergency services, and other public agencies know about potentially hazardous circumstances ahead on the road [12]. On a separate note, [13] emphasised that knowing what lies beyond the next corner may be helpful in various situations but can be especially important for drivers. In previous iterations of emergency alert systems for road users, drivers were responsible for providing the information that was used to create alerts. At this juncture, road hazards may be represented without the need for any input from the driver to gather information and convey warnings. It is indeed worth mentioning that the advantage will be available to all vehicle owners regardless of type and model.

2.2. Flood

Malaysia is not the only country affected by floods; other countries are also affected by floods due to river overflow. India, Bangladesh, and China are the top three countries worldwide that are most at risk from flash floods [14]. In a case reported in July 2021, China was exposed to the heaviest rainfall in 1,000 years, which resulted in devasting floods. The flood affected the citizen of Zhengzhou city and caused at least 25 people, including 12 subway passengers, have been killed in the downpour. The flood, which occurred from Saturday through Tuesday, was caused by a combination of factors, the most significant of which was the 617.1 mm of rainfall that fell during that time period. Another contributing factor was that Zhengzhou is located on the banks of the Yellow River, China's second-longest river, making it more difficult to manage floods there. Although the country has developed some projects for flood mitigation, with extreme rainfall, the dam and the riverbank cannot hold during high rainfall [15], [16].

2.3. Long range communication (LoRa)

Long-range communication, or LoRa technology, is an emerging wireless protocol optimised for long-distance and low-power communication. The technology has been used extensively in a variety of settings [17]–[19]. For instance, South Korean Telecom, a mobile operator company in South Korea, recently launched a nationwide low power wide area networking (LoRaWAN) network. This network is effective at connecting millions of devices, such as controllers, sensors, and other devices, and it will be utilised to implement a new infrastructure in the healthcare industry, renewable energy, and self-driving automobiles. Moreover, South Korean Telecom has planned to use LoRaWAN in the project for urban street lighting networks to minimise the amount of energy consumed. This will be accomplished by collecting data about the current state of the road and the surrounding environment, which will then allow the lighting intensity of the road to be adjusted appropriately [20], [21]. In urban areas, LoRa can support distances of up to 5 kilometres; in the suburbans, it can support distances of up to 15 kilometres; and in rural areas, it can support distances of up to 45 kilometres. The LoRa technology has shown the potential to be used for connected vehicles and the capability to establish connections with IoT devices [22], [23].

Abana *et al*. [24] proposed a water management system to help alert the citizen of flood occurence. With IoT technology, different types of sensors were used, such as rain and ultrasonic sensors, and the microcontroller was integrated using the Blynk application. When the water level increased to a certain level, an alarm will be triggered, and the data will be sent to the application to alert the citizen. Similarly, Hassan *et al*. [25] presented a system that uses sensors to detect the water level. The sensor was connected to Raspberry Pi to receive the data, and a global system for mobile communication (GSM) module was integrated to broadcast short message service (SMS) alerts to the resident when the water level rises.

Along these ideas, Shah *et al*. [26] proposed a flood warning system built using Raspberry Pi. The Raspberry Pi is connected with several sensors such as an ultrasonic sensor, camera and rain gauge to determine the water level of the station every 10 microseconds and capture the condition of the station every 5 minutes. The information was displayed to the user through a web and mobile application where the user could view the readings and the station's condition. After the system's data is analysed using the parse library, the system automatically generates the alert message and push notification to mobile applications.

From a different perspective, Wang and Liu [27] designed a framework for a flood warning system that uses cellular network technologies and general packet radio service (GPRS). The information, such as the water level and flow, was obtained from the sensors and data loggers located at the station using GPRS. In addition, the data is analysed to build a real-time graph, which is uploaded to the web server. When a flood is forecast to surpass the threshold, users will get an alert through text messages. The SMS message would function in a dual manner, allowing users to send messages to the server to seek information and receive messages from the server. In addition, the flood forecast was also published on the web servers, where it is accessible to be seen using any device.

3. SYSTEM DESIGN

The FWS system proposed in this study was implemented in a controlled environment. The proposed system was tested in lab scale to evaluate the performance of sensors and interconnection modules. The proposed FWS system has three main subsystems: server, client and end user. The proposed FWS system has three main subsystems: server, client and end user. Each system is attached to a communication module to transfer data to each other. Meanwhile, the detection sensor is placed to detect the water level at the server, which was proposed to be the primary detection tool for flood occurrence. If the water level threshold is classified into a certain category, the system will send a warning message through a communication medium to parties involved (client or end-user) within the geo-location. The warning will be triggered to an application that the client or end users would be able to view. The proposed use case diagram of the FWS system is shown in Figure 1.

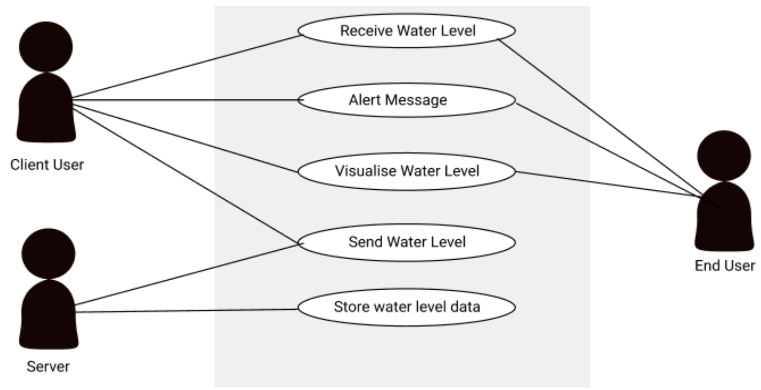


Figure 1. FWS flow chart

Figure 2 shows the block diagram of the FWS system. Each sensor is linked to an ESP 32 microcontroller, which is a device that enables the IoT elements. The ultrasonic sensor attached to the server system will capture the water level and then pass it to the application using Bluetooth every one second. The system's communication between server, client and end-user is employed using LoRa technology. The server will broadcast the data to the client, where the information is propagated to the nearby end-user. This information will be received through a warning triggered in the application.

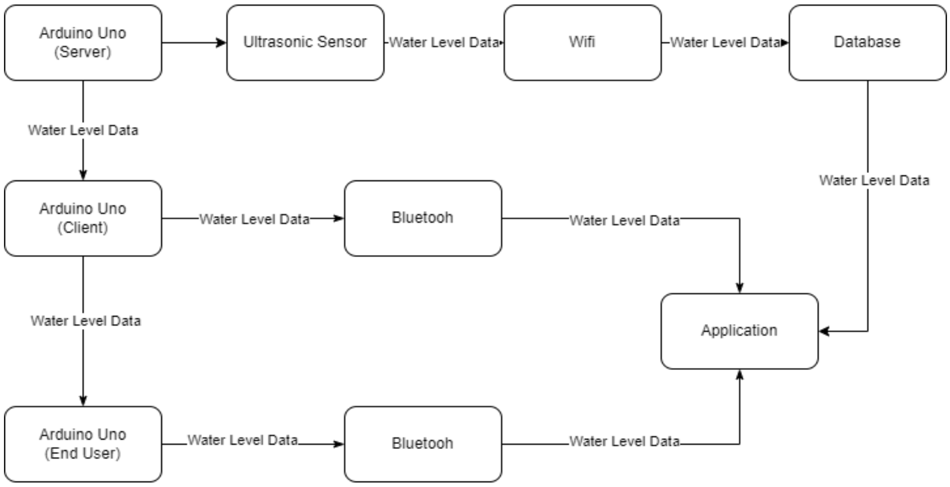
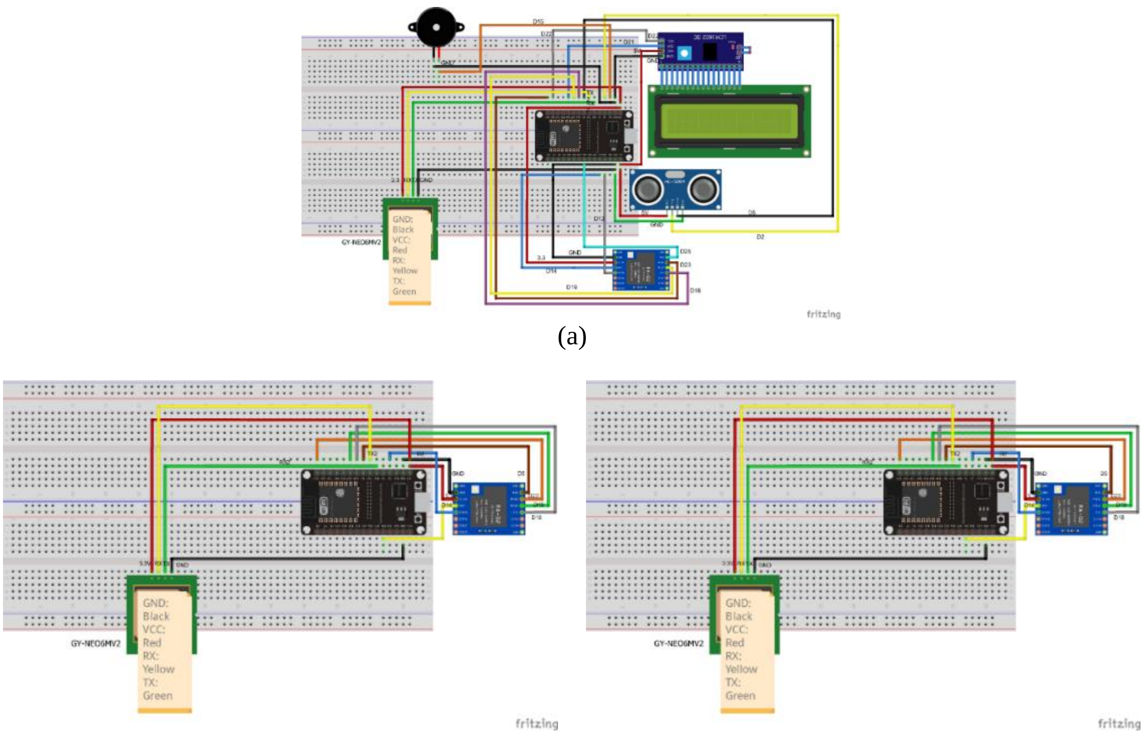


Figure 2. FWS block diagram

3.1. Schematic diagram and prototype

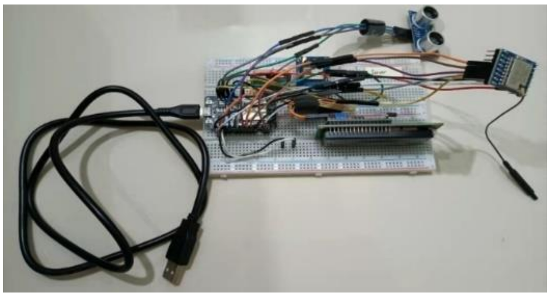
The breadboard diagram of the FWS system is shown in Figure 3. In Figure 3(a), the FWS system consists of an ultrasonic sensor, an ESP 32 microcontroller, a buzzer, a global positioning system (GPS) module, an liquid crystal display (LCD) screen, a breadboard, a Bluetooth module and an SX1278 LoRa module. The ultrasonic sensor is connected to the ESP 32 microcontroller, and the resulting water level measurement will be transmitted in a centimetre (cm) unit. In Figures 3(b) and 3(c), the FWS system consists of only an ESP32 microcontroller, a GPS module, a Bluetooth module and an SX1278 LoRa module for both client and end user. The ESP32 The developed prototype of the FWS system can be seen in Figures 4. Figure 4(a) depicts the prototype of the server, which serves as the central component in the system. In Figure 4(b) and 4(c), we can observe the client and end-user prototype, representing the users in vehicle or pedestrian to interact with the system.



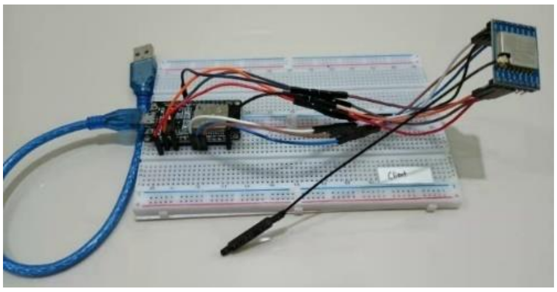
(a)

(b) (c)

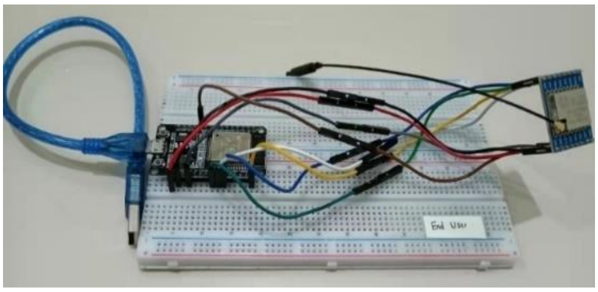
Figure 3. FWS schematic diagram (a) server, (b) client, and (c) end user



(a)



(b)



(c)

Figure 4. FWS prototype design (a) server, (b) client, and (c) end user

3.2. Application

The developed FWS has incorporated a mobile application for the client and end-users. Figure 5 shows the interface design of the mobile application. The application lets client and end-users to track the real-time and historical data as soon as the application is connected through Bluetooth.

Figure 5. FWS application interface (client and end user)

4. EXPERIMENTAL SETUP AND RESULTS

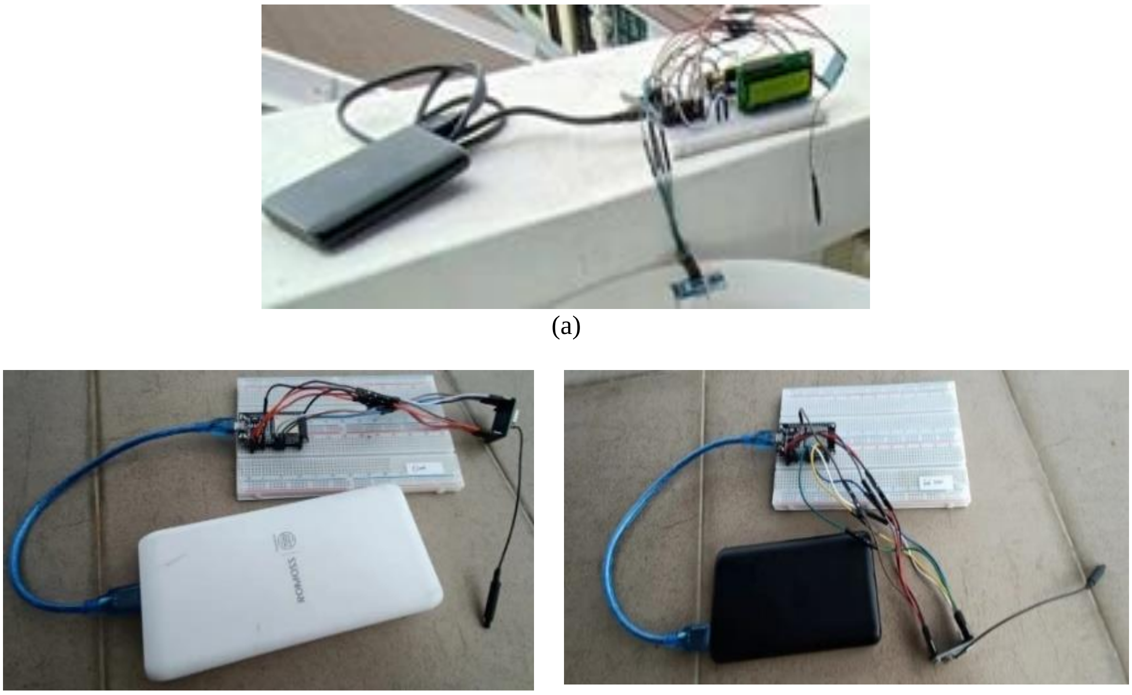
The FWS is demonstrated with the use of a large container, and an ultrasonic sensor located on the server would determine the amount of water in the large container, as shown in Figure 6. The system categorised the threshold into a few categories, such as safe, alert, danger, and critical, as indicated in Table 1. This was accomplished by adjusting the water level threshold based on a flood gauge acknowledged in [28]–[30].

Figure 6. FWS with water container (server)

Table 1. Categories of water level warning

Water level (cm)	Status
< 25	Safe
> 25 and < 33	Precaution
> 33 and < 65	Danger
> 65	Critical

The FWS was tested to assess the functionality of the system. During the testing phase, the results were recorded following each test item and respective modules or components. In Figure 7, all three units were successfully activated to demonstrate the outcome of Test 1. Figure 7(a) shows the server, Figure 7(b) shows the server and Figure 7(c) shows the end-user. The verification of the outcome for Test 2 can be seen in Figures 8. Figure 8(a) and Figure 8(b) shows the Wi-Fi and Bluetooth capabilities enabled on the server system, respectively. Subsequently, the results of Test 3 are shown in Figure 9, which presents the state of a functional LoRa module.

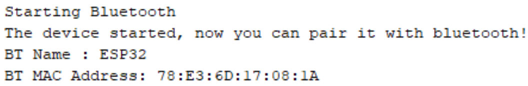


(a)

(b) (c)

Figure 7. FWS (Test 1) (a) server, (b) client, and (c) end user

(a)



(b)

Figure 8. FWS (Test 2) (a) Wi-Fi and (b) Bluetooth

Figure 9. FWS with LoRa (Test 3)

Figure 10 depicts the results of Tests 4 and 5, in which an ultrasonic sensor could determine the amount of water in the container and activate a buzzer when the connection was lost, or the water level was higher than the predetermined threshold for that level of water. The results of Test 6 are shown in Figure 11, which indicates that when the GPS module was turned on, the longitude and latitude coordinates were successfully displayed.

Figure 10. FWS with ultrasonic sensor and buzzer (Test 4 and Test 5)

Figure 11. FWS with GPS (Test 6)

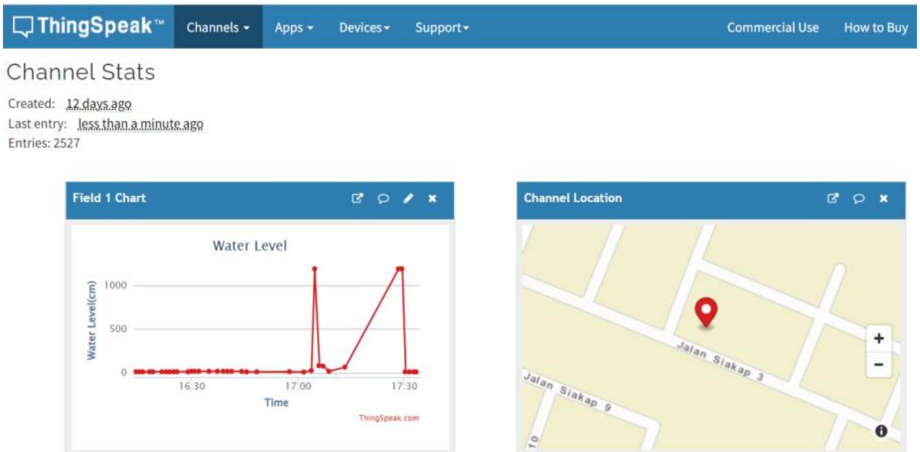
The results of Test 7 are shown in Figure 12. Figure 12(a), demonstrates that the server information was transferred to the local database. The water level data is seen in Figure 12(b) being saved to a local database and Figure 12(c) being uploaded to the ThingSpeak cloud platform.

```
Sending server info to local databases . . .
httpRequestData: board_id=Server-FYP1-002&server_name=Water Level Server 1&server_info=Detect water level
Server info for Server-FYP1-002 updated successfully
```

(a)

```
16:57:40.407 -> httpRequestData: board_id=Server-FYP1-002&water_level_cm=8.87&water_level_m=0.09&water_level_inch=3.49
16:57:42.406 -> New record save successfully
16:57:43.282 -> Channel update successful.
```

(b)



(c)

Figure 12. FWS server information (Test 7) (a) local databse (1), (b) local database (2), and (c) ThingSpeak

As shown in Figure 13, the results of Test 8 demonstrate that the LoRa communication system successfully established two-way communication between the server and the client to transmit water level data. Tests 9 and 10 are shown in Figure 14. In these tests, the client and end-user were successful in obtaining the water level data and receiving the warning message through the application; however, only on the condition that they permitted Bluetooth connection with the system as shown in Figure 14(a). On the other hand, Figure 14(b) demonstrates that end users could see historical data generated by the application during Test 11. Table 2 shows the summary of test items and status that were conducted to check the functionality of the proposed system.

COM5

```
16:56:10.119 -> 9.35
16:56:11.135 -> 8.87
16:56:12.149 -> 8.87
16:56:13.152 -> 8.87
16:56:14.150 -> 8.87
16:56:15.181 -> 8.87
16:56:16.181 -> 8.87
16:56:17.182 -> 9.35
16:56:18.198 -> 9.35
16:56:19.198 -> 9.35
16:56:20.167 -> 8.87
16:56:22.255 -> 8.87
16:56:23.256 -> 9.35
16:56:24.256 -> 8.87
```

COM4

```
16:56:09.165 -> 8.87
16:56:10.166 -> 9.35
16:56:11.182 -> 8.87
16:56:12.196 -> 8.87
16:56:13.214 -> 8.87
16:56:14.197 -> 8.87
16:56:15.238 -> 8.87
16:56:16.239 -> 8.87
16:56:17.228 -> 9.35
16:56:18.198 -> 9.35
16:56:19.198 -> 9.35
16:56:20.213 -> 8.87
16:56:22.302 -> 8.87
16:56:23.303 -> 9.35
16:56:24.303 -> 8.87
```

Figure 13. FWS with LoRa involving server and client (Test 8)

(a)

(b)

Figure 14. FWS Application involving end user (Test 9 and 11) (a) water level status (café) and (b) hisotical data

Table 2. Summary of test items and status

No	Test Items	Status
1	The microcontroller is successfully powered up in server, client, and end user system.	Successful
2	The Wi-Fi and Bluetooth module able to function with the microcontroller.	Successful
3	The LoRa Module is successfully powered up	Successful
4	The ultrasonic sensor in the server are able to function to detect the water level of the container.	Successful
5	The Buzzer are able to alert when the connection loss or water level exceed the water level threshold in critical conditions (water level > 65cm)	Successful
6	The GPS module in the server successfully powered	Successful
7	The data capture from the sensor is successfully deliver to the server and cloud using Wi-Fi module.	Successful
8	The server are able to transmit data to the client via LoRa communication and the end user are able to receive data from the client.	Successful
9	The mobile application able to display the water level data correctly via Bluetooth communication from client and end user system.	Successful
10	The users are able to receive the alert message based on the water level conditions.	Successful
11	The historical data in the mobile application are able to fetch data from thingspeak and displayed.	Successful

5. CONCLUSION

In this paper, an FWS system was developed to broadcast flood information to clients and end-users with LoRa technology. The client refers to drivers, and end-users refer to pedestrians or the public. The experimental results show that the detection of flood levels based on the scenario placed using sensors could be conveyed to the client and end-users via a mobile application. The flood level indication was classified based on the Metro Manila development authority (MMDA) flood gauge, widely applied in many research studies. The involvement of connected vehicle was able to prove the functional concept to propagate the flood information for better reach with the use of LoRa technology. Nevertheless, this study has several ways in which it may be enhanced, such as by improving the functionality for further testing to achieve reliable operation for the system. Besides, the study could also focus on precise location data by determining the nearest server to the client and end-user and transmitting the flood information from the particular geo-location. However, this would need a higher-quality GPS module to identify the location more quickly, leading to a better experience for the client and end-user.

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