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Solar Powered Water Level Monitoring System for Flood Management in Rural Area using GSM Module

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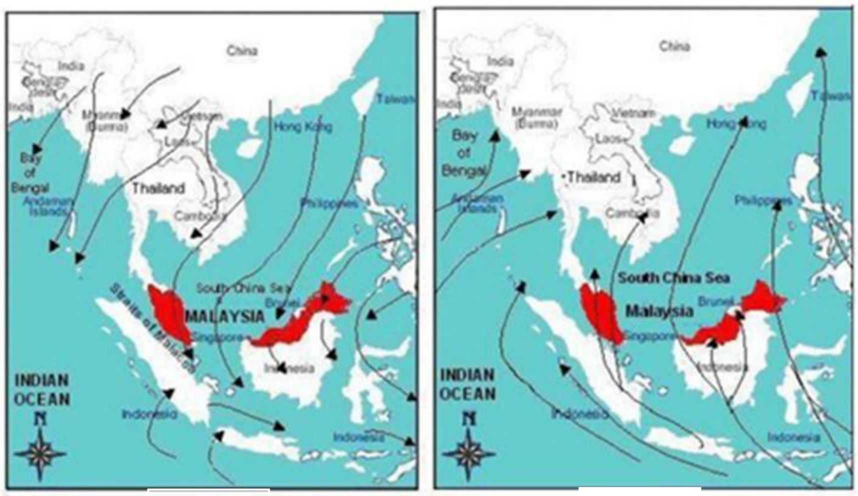
Abstract

The present natural disasters such as floods cause loss of life, property, devastation of livestock and agriculture. Flood is known as yearly disaster in Malaysia because of the monsoon season that will cause heavy rain in certain states, especially at Sabah. Therefore, the system develops a solar powered water level monitoring system for flood management and notify the user by using the GSM module. The notification messages will be sent to cellular of logged user that are head of village and people at the affected areas. The system uses three Ultrasonic Sensors, Buzzer, Solar power, Buzzer, Arduino UNO, ESP32 and GSM shield as the main components in the prototype. Arduino UNO and the ESP32 act as micro-controllers of systems to perform various actions such as observe height of water and perform calculation and send SMS through GSM shield. This system successfully measured the water level with 99.58% success accuracy for the first sensor, 99.59% success accuracy for the second sensor and 99.53% success accuracy for the third sensor. With a few hours, the solar also managed to charge the battery for the system. Moreover, with 96.67% accuracy of GSM test success rate, it successfully sends SMS to the user if the water level is in danger condition. However, data collection for flood management involving message transmission time and sensor reading distance is one of the scope systems. Thus, with the availability of this effective SMS flood notification system, people can take immediate action and take more precautions to save lives and reduce damage due to flood disasters, especially in low-lying areas in rural villages that are far from internet access.

1. Introduction

Floods are amongst the most common and devastating of all-natural hazards. Malaysia is susceptible to flooding just like any other nation because of this natural hazard. Floods are defined as high water flows that are greater than the capacity of natural or man-made barriers and can happen anywhere along the river system (Ajit Singh et al., 2023). Consequently, water overflows the flood plain when a riverbank is overtopped, posing a threat to civilization that may result in a large number of fatalities, the spread of disease, destruction of property, and financial loss. In Malaysia, floods are the most severe natural disaster (Buslima et al., 2018). Two important types of floods that have occurred in this country are flash floods and monsoon floods. The Northeast monsoon flood, which lasts from October to March, brings intense rains to the east coast states of the Peninsula, the northern portion of Sabah, and the southern portion of Sarawak (Akasah & Doraisamy, 2015). Fig. 1(a) and Fig. 1(b) show the Southwest monsoon and Southeast monsoon, respectively.



(a) (b)

Fig. 1 *Movement of (a) Southwest monsoon and (b) Southeast monsoon (Akasah & Doraisamy, , 2015)*

Based on the Fig. 2 and Fig. 3, Sabah is a state located in the northern part of Borneo, Malaysia, experiences a tropical rainforest climate characterized by high humidity and substantial rainfall throughout the year. The distribution of rainfall in Sabah is influenced by its geographical location, topography, and the monsoon winds. For example, Sabah's topography ranges from coastal plains to mountainous interiors, including the Crocker Range and the famous Mount Kinabalu. These variations in elevation significantly impact rainfall patterns. With that, following the prolonged rains will cause flooding problems in this state (Goh & Monteuuis, 2009).

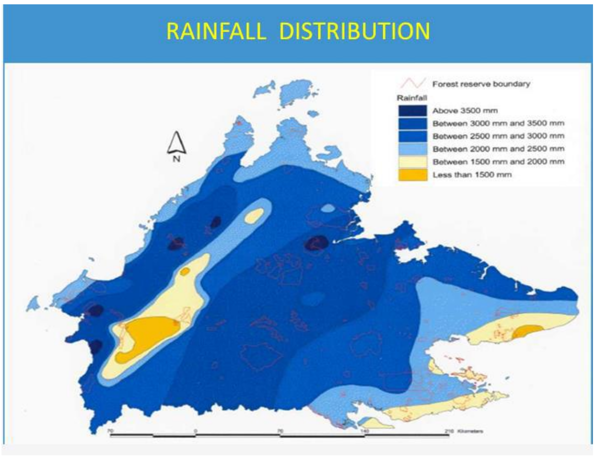


Fig. 2 *Rainfall distribution at Sabah (Goh & Monteuuis, 2009)*

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Sabah flood situation worsens after persistent rain

BY RUBEN SARIO

Beaufort flooded.

Department of Irrigation and Drainage Sabah

Fig. 3 *Sabah flood situation worsens after persistent rain (Sario, 2014)*

The study location, at rural areas at Sabah where one of the famous state related floods. The current flood warning system implemented in Sabah is not widely use. The point of monitoring is focused on one location per river and the low areas at rural areas at Sabah. Several areas still pending to receive early flood notification due to ineffective and unsuitable alert tools of communication channels. Moreover, existing warning system lacks the basic abilities to monitor water level. The proposed system focuses on designing system that overcomes the existing flood system based on comparison study on previous system (Keoduangsine et al., 2014). The system is simulated to determine the accuracy and reduce system errors by using prototype of this system.

This work focused only for detection and early warning alert system via cell phone text messages that alerts local subscribers of potential flood events. This system is provided with the actual water level, of the desired area location. A water level for flood monitoring system has been developed to help the villagers, especially in the rural areas. This system uses the mobile phone as output which is Short Message Service (SMS) to inform users. This will help users to prepare for the early evacuation process and move their valuable belongings to safe place.

2. System Design

At initial stage of the process of implementing this project, ultrasonic sensor served as the head or major input for the overall system. Ultrasonic sensor captures all the data required such as the distance of the current water level based on the reflection wave from the sensor to the surface of water and back again to sensor. The process of the system takes place for the microcontroller ESP32 and Arduino Uno, the value displayed on the OLED display and the GSM module to send the date if the rising water level in DANGER condition. After the process stage, and if the desired value is reached which is the water level is below than 20 cm, the piezo buzzer will be triggered and at the same time the GSM Module will send an early warning notification to the user's mobile device. All the main process as shown in the Fig. 4.

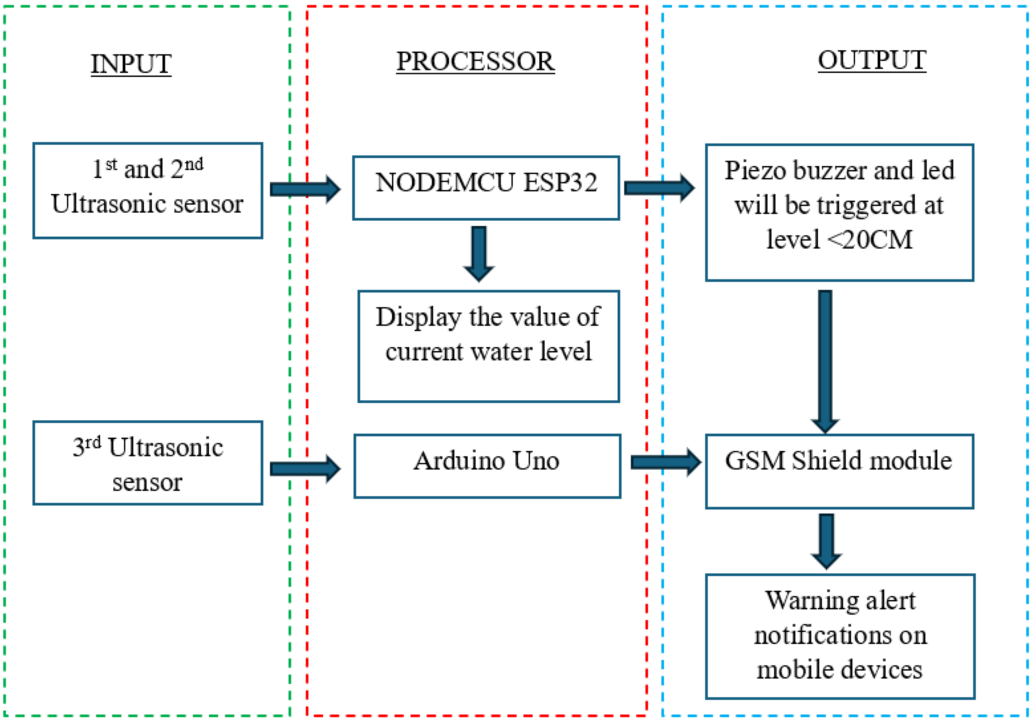


Fig. 4 *Block diagram of the designed process*

Based on the flow chart in Fig. 4, the ultrasonic sensor has been successfully triggered by ensuring the correct circuit construction between the electronic components and the microcontrollers. The first and second sensors (HC-SR04) were properly interconnected with the main microcontroller, the NODEMCU ESP32, while other components such as the piezo buzzer and 12C OLED display were also connected to the NODEMCU ESP32. The VCC and GND of these components were linked to the positive and negative rails of the breadboard using wires. The third sensor was connected to the second microcontroller, an Arduino Uno, for the purpose of sending notifications to the user. The ultrasonic sensors successfully measured the water level, with their data being displayed on the OLED screen. When the water reached a critical level, the piezo buzzer emitted an audible warning, and the OLED displayed the critical water level. Simultaneously, the Arduino Uno transmitted the critical water level to the user via the GSM module. The flowcharts in Fig. 5 and Fig. 6 outline the designed processes using the ESP32 and Arduino, respectively, reflecting the successful implementation of the project.

Based on Fig. 6, Arduino used for GSM to process the data from the sensor then send the data to the users. By using the GSM module to notify the phone user by warning alert notifications. The phone user could also monitor the current water level, for them to be prepared before the flood gets more worse. However, if the water level is still in a safe range, there won't be any notifications to be alert for the users.

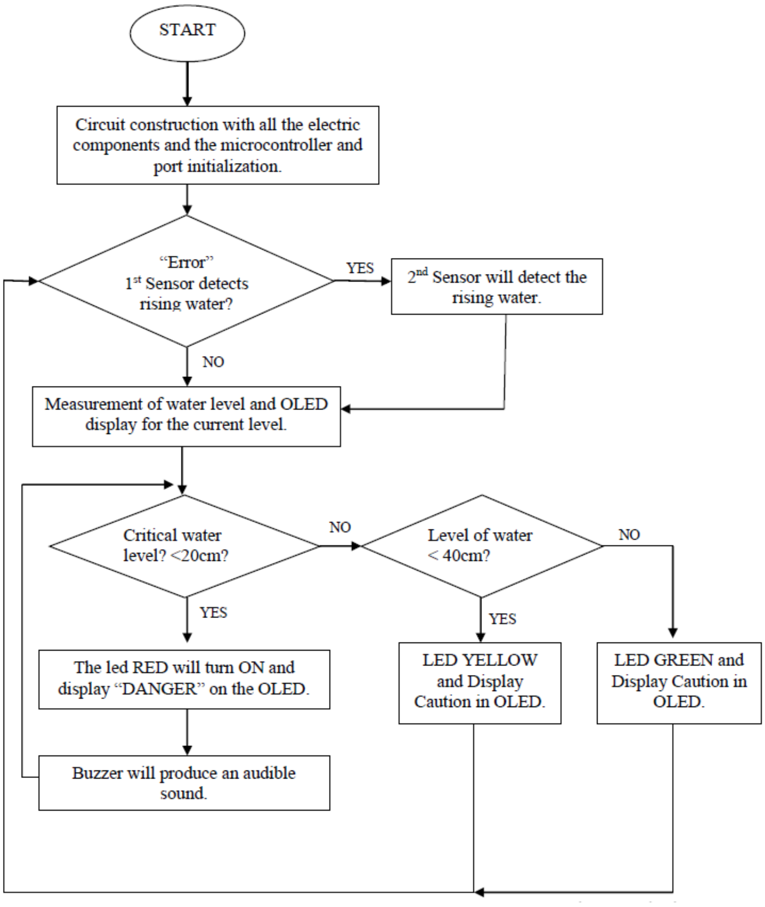


Fig. 5 *Flowchart of the designed for ESP32 process*

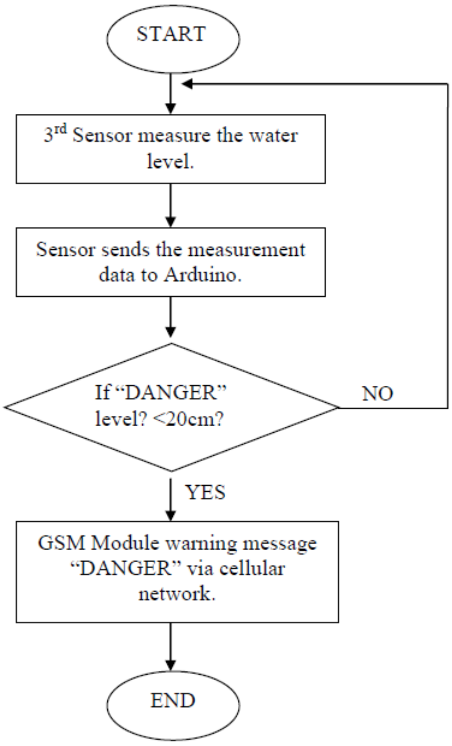


Fig. 6 *Flowchart of the designed for Arduino process*

The system design involves designing the circuit and prototype of system. For circuit design, simulation of circuit needs to be done by using software and for prototype coding needs to be written and uploaded to the ESP32 and Arduino then test the system. Debugging expected to occur because of error that may arise from the coding design. Fig. 7 and Fig. 8 show schematic circuit for flood monitoring using Esp32 and Arduino, respectively.

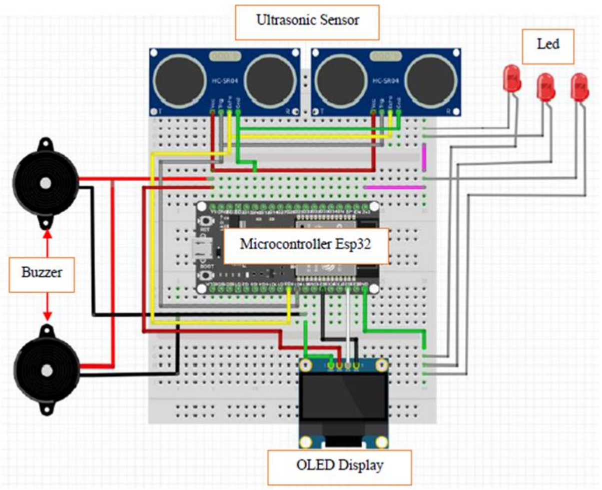


Fig. 7 *Schematic circuit in Esp32 part for flood monitoring*

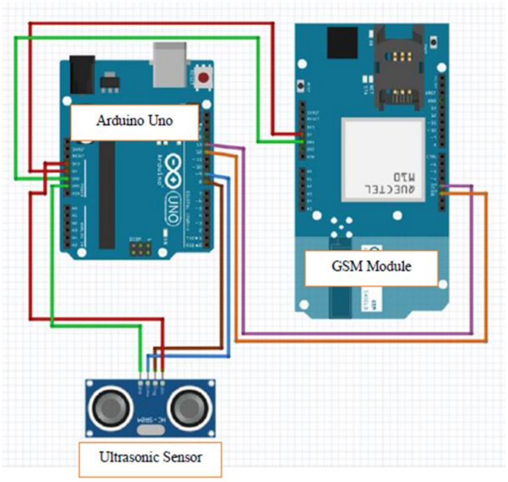


Fig. 8 *Schematic circuit in Arduino part for flood monitoring*

The most important thing in this system is to measure the distance or height of water. In order to measure the height of the water, three Ultrasonic sensors used to measure distance water relative the height of sensor, it means that the distance measure is from ultrasonic sensor to the height of water. Ultrasonic sensors will act as the references point for the system where the initial value is zero (0) and increase until the sensor reflect the signal from height of water to be store in the system. Fig. 9 shows a water level indicator that measures the distance between ultrasonic sensor and water surface.

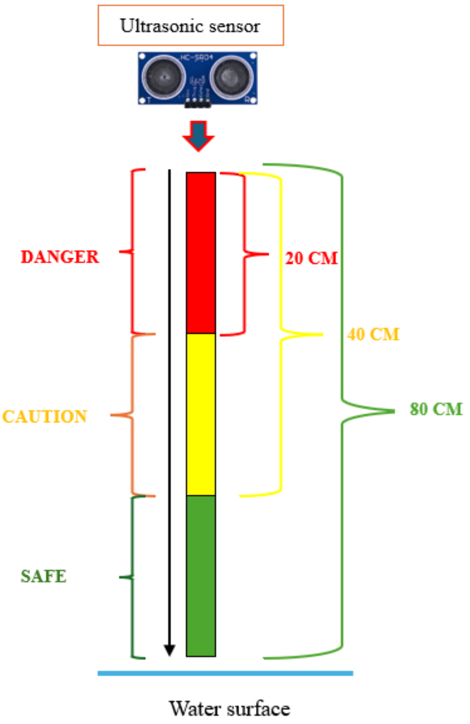


Fig. 9 *Distance relative to sensor*

Fig. 10 and Fig. 11 show the final project design with different views. Fig. 11 shows the bottom view of the system, and all the sensors are ready to monitor the level of water. At the front view system, there are three types of LED, ON and OFF button and OLED to monitor the danger water level.

Fig. 10 *Final project design*

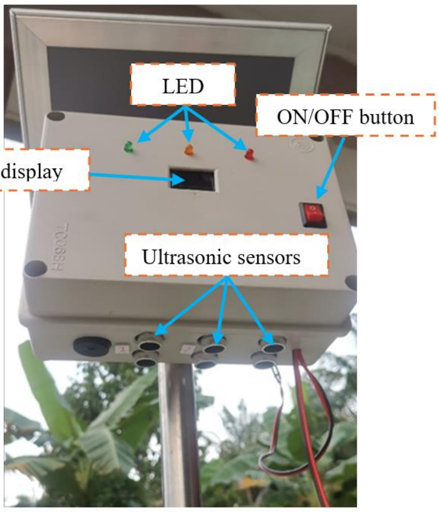


Fig. 11 *Final project design (bottom view)*

3. Result and Analysis

3.1 Sensor Calibration

Fig. 12 shows ultrasonic sensor 1 has been tested at a distance of 40 cm (Caution). Each sensor has been tested by measuring the distance from 10 cm to 100 cm. Based on the result of each sensor, there are slight change in the reading for each sensor for each distance and causes the percentage of accuracy for each sensor to be different. Meanwhile, Table 1, Table 2 and Table 3 show the reading of each sensor and the successful percentage accuracy sensor.

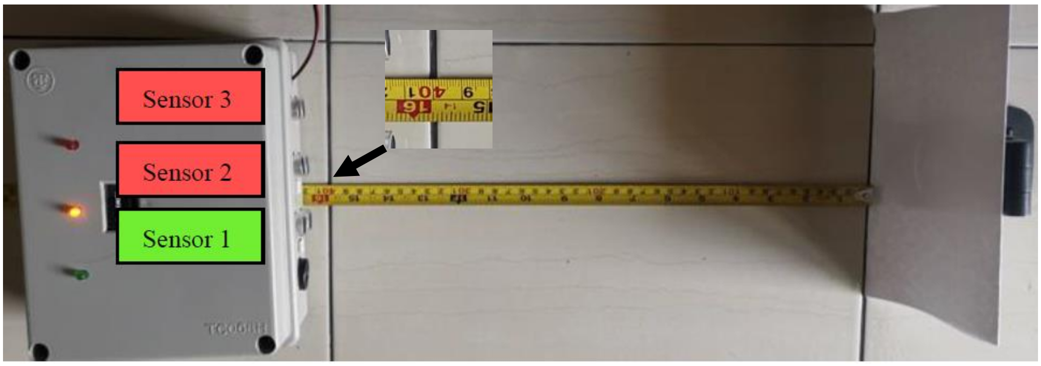


Fig. 12 *Ultrasonic sensor 1 test within 40cm (CAUTION)*

Table 1, Table 2, and Table 3 show the reading of each ultrasonic sensor testing. By using Equation (1),(2) and (3), the average reading and error percentage of ultrasonic sensor was measured. From Table 1, we can conclude that the first sensor is successful with 99.58% accuracy, and Table 2 shows the second sensor is successful with 99.59% accuracy. For Table 3, the third sensor was successful with 99.3% accuracy. Based on the percentage of error with these sensors, we can conclude that these sensors are still in good condition and still function in this system. Meanwhile, Fig. 13 shows the graph of error percentage of each sensor.

$$\text{Error Percentage, \%} = \frac{\text{1st sensor reading} - \text{Actual reading of sensor}}{\text{Actual reading of sensor}} * 100 \tag{1}$$

$$\text{Error} = 1^{st} \text{ sensor reading} - \text{Actual reading of distance} \tag{2}$$

$$\text{Average of error percentage, \%} = \frac{\text{Total Error Percentage \%}}{\text{Amount Testing}} \tag{3}$$

Table 1 *Distance and calculation of 1st sensor height (Accuracy: 99.58%)*

Actual reading of distance	1st Sensor reading	Error	Error Percentage, %	Average of error percentage of distance measurement, %	Accuracy of the sensor, %
10 cm	10.1 cm	0.1 cm	1	0.42%	**99.58%**
20 cm	20.9 cm	0.9 cm	0.45		
30 cm	30.12 cm	0.12 cm	0.4		
40 cm	40.17 cm	0.17 cm	0.43		
50 cm	50.11 cm	0.11 cm	0.28		
60 cm	60.23 cm	0.23 cm	0.46		
70 cm	70.25 cm	0.25 cm	0.36		
80 cm	80.13 cm	0.13 cm	0.16		
90 cm	90.27 cm	0.27 cm	0.3		
100 cm	100.33 cm	0.33 cm	0.33		

Table 2 *Distance and calculation of 2nd sensor height (Accuracy:99.59%)*

Actual reading of distance	2nd Sensor reading	Error	Error Percentage, %	Average of error percentage of distance measurement, %	Accuracy of the sensor, %
10 cm	10.07 cm	0.07 cm	0.7	0.414%	**99.59%**
20 cm	20.11 cm	0.11 cm	0.55		
30 cm	30.22 cm	0.22 cm	0.73		
40 cm	40.15 cm	0.15 cm	0.38		
50 cm	50.20 cm	0.20 cm	0.4		
60 cm	60.18 cm	0.18 cm	0.3		
70 cm	70.26 cm	0.26 cm	0.37		
80 cm	80.16 cm	0.16 cm	0.2		
90 cm	90.23 cm	0.23 cm	0.26		
100 cm	100.25 cm	0.25 cm	0.25		

Table 3 *Distance and calculation of 3rd sensor height (Accuracy:99.53%)*

Actual reading of distance	3rd Sensor reading	Error	Error Percentage, %	Average of error percentage of distance measurement, %	Accuracy of the sensor, %
10 cm	10.05 cm	0.05 cm	0.5	0.472%	**99.53%**
20 cm	20.14 cm	0.14 cm	0.7		
30 cm	30.28 cm	0.28 cm	0.93		
40 cm	40.20 cm	0.20 cm	0.5		
50 cm	50.16 cm	0.16 cm	0.32		
60 cm	60.21 cm	0.21 cm	0.35		
70 cm	70.32 cm	0.32 cm	0.46		
80 cm	80.24 cm	0.24 cm	0.3		
90 cm	90.25 cm	0.25 cm	0.28		
100 cm	100.38 cm	0.38 cm	0.38		

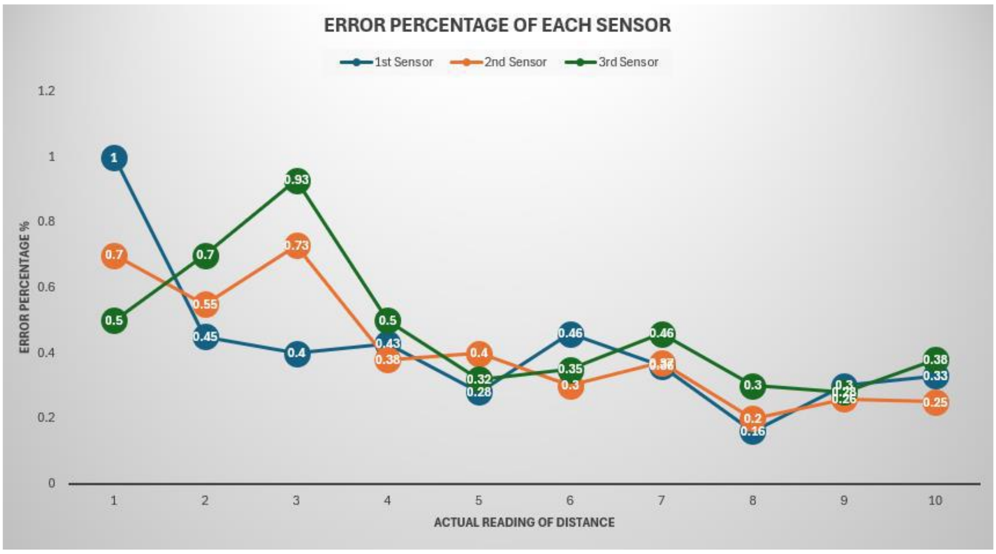


Fig. 13 *Error percentage of each sensor*

3.2 GSM Output Danger Water Level

Based on the Fig. 14, the water level of 12 cm inside the bucket has been used to test the ultrasonic sensor. The ultrasonic sensor will sense the distance of water inside the bucket and can monitor the level at the OLED display. When the ultrasonic sensor senses the distance below than 20cm, the OLED display the DANGER condition, and the LED red will turn ON. At the same time, the buzzer will turn ON with beep. It is apparent that the ultrasonic sensor effectively detects the presence water and display it on the OLED display.

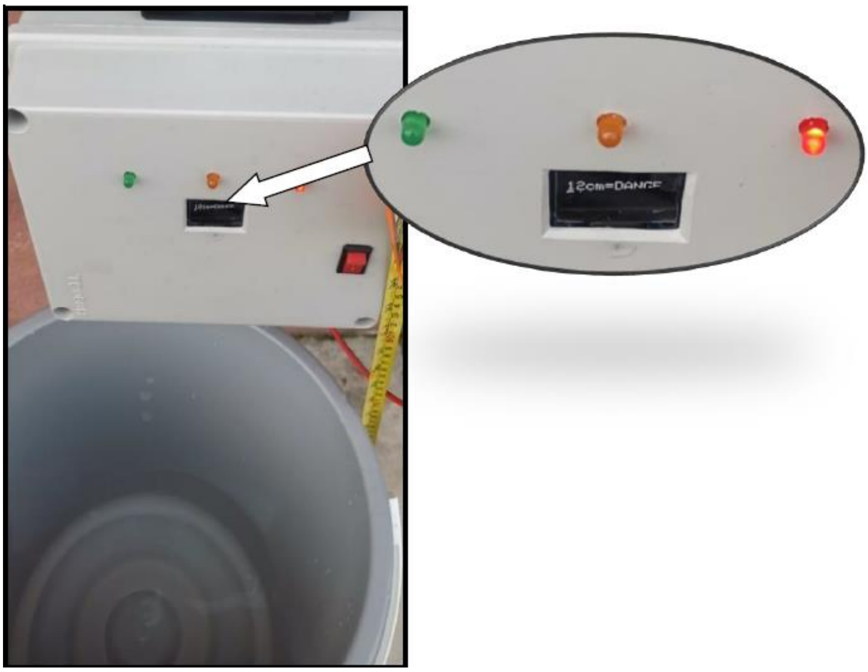


Fig. 14 *Water level in 12cm level (DANGER)*

The GSM output testing for danger water level was conducted for distance of 10 cm, 15 cm and 20 cm. Based on the Table 4, the error percentage sensor for 20 cm distance is 3.33 % shows 96.67 % of successfully rate of accuracy. Meanwhile, the distance of 10 cm until 15 cm is also tested due to very danger level water to be monitored. From Fig. 15 shows that the percentage of error is small as 20% for this GSM output testing for all distances. Thus, shows that the GSM module successfully sending the message when the system detects the danger water level which the distance is 20 cm and below.

Table 4 *GSM Testing*

Testing \ Actual value distance	**10 cm**	**15 cm**	**20 cm**
Testing 1	9 cm	13 cm	19 cm
Testing 2	10 cm	12 cm	20 cm
Testing 3	8 cm	14 cm	20 cm
Average distance	9 cm	13 cm	19.67cm
Error percentage (%)	**10%**	**20%**	**3.33%**

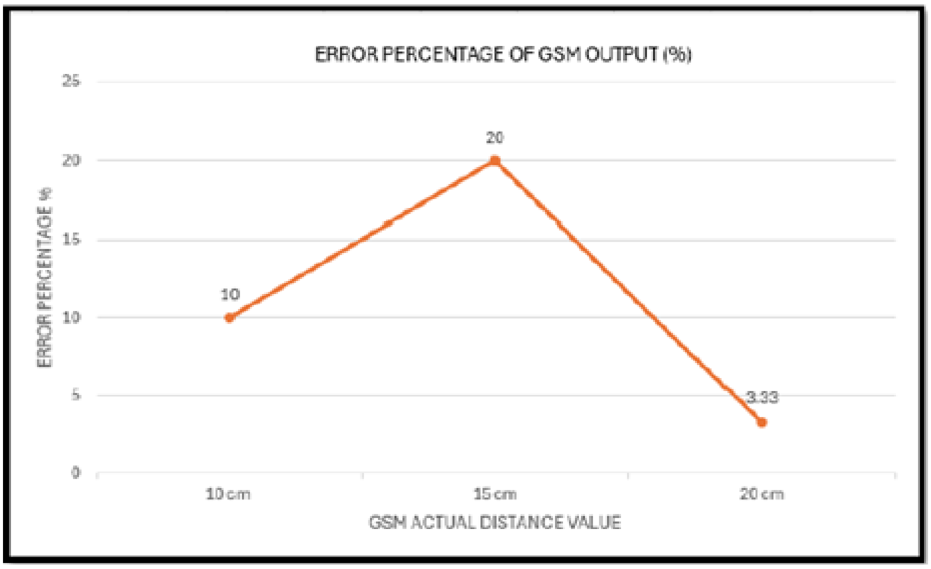
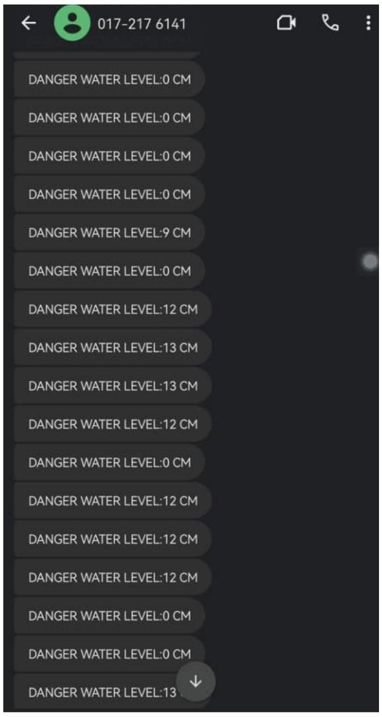


Fig. 15 *Error percentage of GSM output*

Fig. 16 and Fig. 17 show the message 'DANGER WATER LEVEL" from the GSM module for several distance testing between 0 to 20 cm. However, the sensor sends the certain error to the user but overalls, the GSM module successfully notified the user by sending the SMS of danger water level.



DANGER WATER LEVEL:0 CM
DANGER WATER LEVEL:0 CM
DANGER WATER LEVEL:0 CM
DANGER WATER LEVEL:0 CM
DANGER WATER LEVEL:9 CM
DANGER WATER LEVEL:0 CM
DANGER WATER LEVEL:12 CM
DANGER WATER LEVEL:13 CM
DANGER WATER LEVEL:13 CM
DANGER WATER LEVEL:12 CM
DANGER WATER LEVEL:0 CM
DANGER WATER LEVEL:12 CM
DANGER WATER LEVEL:12 CM
DANGER WATER LEVEL:12 CM
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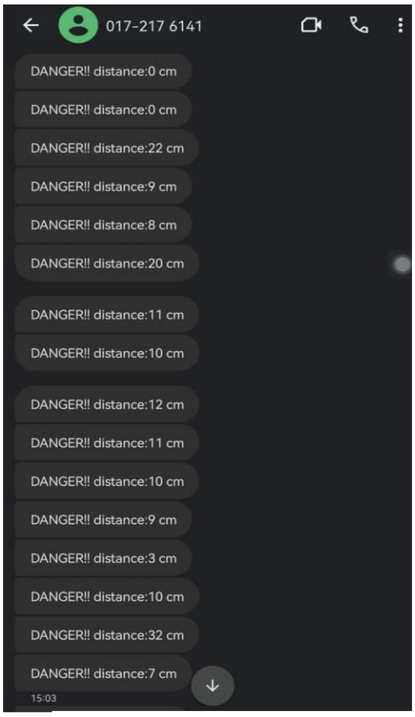
DANGER WATER LEVEL:0 CM
DANGER WATER LEVEL:13

Fig. 16 *DANGER Message 1*



DANGER!! distance:0 cm
DANGER!! distance:0 cm
DANGER!! distance:22 cm
DANGER!! distance:9 cm
DANGER!! distance:8 cm
DANGER!! distance:20 cm
DANGER!! distance:11 cm
DANGER!! distance:10 cm
DANGER!! distance:12 cm
DANGER!! distance:11 cm
DANGER!! distance:10 cm
DANGER!! distance:9 cm
DANGER!! distance:3 cm
DANGER!! distance:10 cm
DANGER!! distance:32 cm
DANGER!! distance:7 cm
15:03

Fig. 17 *DANGER Message 2*

4. Conclusion

The development and implementation of the solar-powered water level monitoring system have demonstrated significant potential for improving flood management in rural areas. The system's integration of ultrasonic sensors, GSM modules, and solar power ensures a reliable and sustainable solution. Testing revealed high accuracy and efficiency in water level detection and SMS alert notifications. This technology provides a critical tool for early warning and response, helping to mitigate the impact of floods on vulnerable communities. The success of this project underscores the importance of innovative approaches to disaster management, especially in remote regions with limited infrastructure.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Eldievant Daminon;* ***data collection:*** *Eldievant Daminon;* ***analysis and interpretation of results:*** *Eldievant Daminon;* ***draft manuscript preparation:*** *Eldievant Daminon, Maslina Yacoob. All authors reviewed the results and approved the final version of the manuscript.*

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