River Monitoring System for Headwater Phenomena Using Long Range (LoRa) Communication(BUOY ONE)

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River Monitoring System for Headwater Phenomena Using Long Range (LoRa) Communication (BUOY ONE)

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Abstract: *The unpredictable force of nature, occasionally poses a threat to human beings and the environment. The headwater phenomena are one of the most frequent life-threatening events at river and waterfall spots. In order to reduce the risk, the research aims to create waterfall alarm system for headwater phenomena or named Buoy ONE. The research consists of two systems which are monitoring and data collection communicate through LoRa-RFM communication. The system consists of three sensors which are water flow sensor, ultrasonic sensor and piezo vibration sensor. All these sensors will produce the data when the behavior of river changes in flow speed and debris vibration in the river. The whole system will be control by Arduino UNO R3 as a microcontroller of this project. The data collected will be save in the SD card for further research. Based on the carried-out test, this alarm system has met the objectives set out in the project.*

Keywords: Headwater, Vibration, Speed, Level, LoRa

1. BACKGROUND

The National Hydraulic Research Institute of Malaysia (NahRIm) director-general, Datuk Dr. Nasir Md Noh, stated that "the climate change issue plaguing the whole world, including our country, has led to the occurrence of extreme weather events that are difficult to predict." [1]. According to what he said, every natural disaster may strike at any time or place, and headwater phenomena are no exception. They also can arise outside of rainy seasons.

Headwater phenomena are now a frequent natural catastrophe that invariably happens around waterfalls that receive tremendous amounts of rain [2]. When the water flow in a small stream increases and contributes to a larger stream, headwater phenomenon takes place. When headwater events affect our lives, the effects are terrible and unpredictable [3]. For example, on February 7, 2024 at Sungai Kenjur, Ipoh, a mother and her three children were drowning by the headwater during their camping time. The mother was washed 100 meter from the camping site and the children still missing at that time. Based on the news, headwater phenomena have not occurred in Sungai Kenjur in a long time [4]. The development of a waterfall alarm system for headwater phenomena serves as a safety measure for the surrounding environment. The alarm system will sound when the headwater begins to occur. A microcontroller that serves as the alarm system's brain, sensor, alarm, and other operational components will be included.

2. PROBLEM STATEMENT

Despite the early warning signs, not everyone is capable at reading the environment. The water level can rise quickly in five minutes. Although there is a manual alert system and a safe guard at the top of the waterfall, is this enough time for an evacuation for every guest who is still having a good time [5].

The automated waterfall alarm system for headwater phenomena is suggested as a solution to this problem. Based on the motion of the river and environmental factors, such as loud bird sounds, scattered branches, and large rocks slamming into one another, this method will identify the headwater early. Since this system is entirely automated, it won't need human monitoring for a long period of time. This system is completely automated and does not require human supervision for an extended duration.

3. RELATED WORK

Fatimah et.al proposed a research on Real Time Flood Monitoring and Prevention Using IoT Sensors in Developing Countries. This research present Flood Alert a real time intelligent monitoring system using Internet of Things (IoT) water level sensors powered by the Rasberry Pi board as microcontroller. The flood information will display in mobile app and website [6]. Diogo et al. monitor and notify the Vale do Itajai basin's flood system. The three major cities of Vale do Itajai are connected to the alert system's telemetric network: Low, Medium, and High. Its 17 hydrometeorological stations feed precipitation and river level data by GPRS to a central computer system, where it is processed and stored in the database of Vale do Itajai. Every 30 minutes, the telemetric network is set up to collect data at each location on the bowl and make calls at least once every four hours. [7]. Yoshiyuki et al. designed an architecture that combines off-the-shelf river flood monitoring with MQTT brokers operating in parallel connections to create a low-cost Internet of Things-based river flood monitoring system. The MQTT publisher sends a message to the local broker that is configured in bridge mode. The message is then sent to the subscriber via the remote broker. [8]. Liu Yan et al. intended to design an early warning system based on IoT and analyse the rainfall-induced slope disaster. The project is creating a low-cost, sustainable EWS that uses IoT and solar energy for data gathering, monitoring, and alerting, enabling for early detection of risk levels and potential movement. This project uses a soil moisture sensor, an accelerometer sensor, and an image sensor [9]. Mowen et al's study aims to develop early warning systems and reinforcement methods by assessing landslip risk, analysing stability, and monitoring [10].

4. METHODOLOGY

The main focuses of this chapter incorporate the design of alarm system with monitoring system. This system is embedded with two module of transmitter. First transmitter module which is buoy module is equipped with water speed sensor, piezo vibration sensor and LoRa-RFM module. The second is water level transmitter equipped with temperature sensor, ultrasonic level sensor and LoRa-RFM. The data collected by the sensor will be transmitted to the receiver module through technique derived from chirp spread spectrum (CSS) technology known as LoRa-RFM. As a backup, SD card Arduino module will be used to store the raw data. Figure 1 depicts the project design block diagram that must be highlighted in order to accomplish the goal.

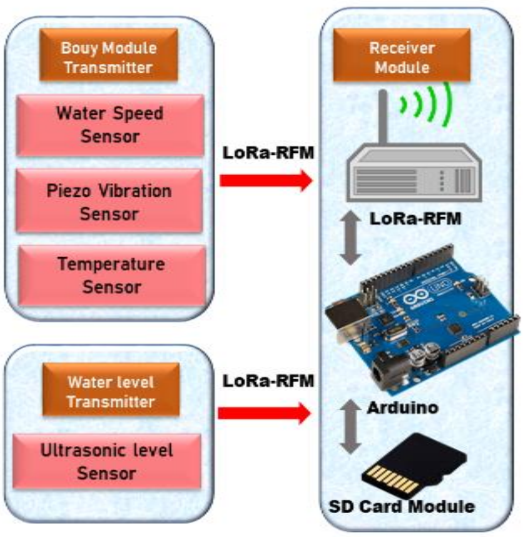

Fig.1. System block diagram.

Both of the transmitter and receiver use Arduino Uno R3 as the main microcontroller equipped with ATmega328P-based. It features a 16 MHz ceramic resonator, 6 analogue inputs, 14 digital input/output pins (six of which can be used as PWM outputs), a USB port, a power jack, an ICSP header, and a reset button. It comes with everything needed to support the microcontroller; all you need to do is power it with a battery or an AC-to-DC adapter or connect it to a computer via a USB cable to get going [11]. These three module also use individual LoRa-RFM SX1278 module as a communication platform. Both transmitter acting as a slave and receiver as their master. Each of them as designated address to prevent data losses or unknown data. The SX1278 is wireless transmission module, based on SEMTECH's SX1278 transceiver, offers advanced LoRa spread spectrum technology, a 10,000-meter communication distance, anti-jamming capabilities, air wake-up, and high sensitivity, making it ideal for long-range communication [12]. Figure 2 show the LoRa-RFM SX1278 use in this project.

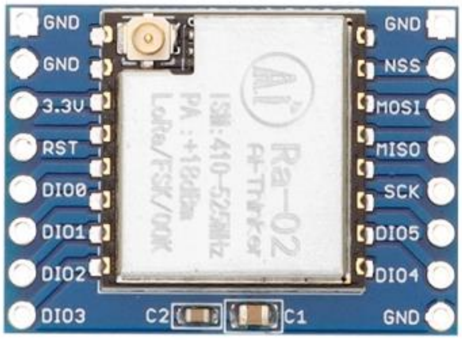

Fig. 2. LoRa-RFM SX1278.

4.1 Receiver module

This module is the most crucial part of the system. This module consists no sensor but it has three module interfacing each other in order to receive, record and display the data received from both transmitters. The main brain of receiver is Arduino Uno R. In order to receive the data, the receiver is equipped with LoRa-RFM SX1278 as a master to receive data from the both salve transmitters. Meanwhile, the data receive will be stored in the sd card shield data logger. This data logger shield is easy to use with its hardware connection, SD card socket, Real Time Clock, and level shifter for Arduino. It allows data to be saved to files on FAT16 or FAT32 formatted SD cards and includes a Real Time Clock IC, DS1307, which timestamps data with the current time for precise tracking [13]. Figure 3 shows the data logger use in this project.

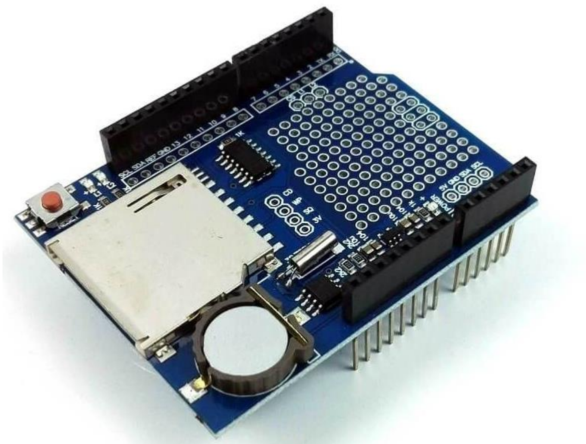

Fig. 3. Shield data Logger.

To display the data, receiver module has 16x2 liquid crystal display to display the data receive from the transmitters. Figure 4 show the receiver module build up using black plastic hard case.

Fig. 4. Receiver module

4.2 Buoy module transmitter

This module is equipped with two sensors which is water flow sensor and piezo vibration sensor. The water flow sensor consists of a plastic valve body, water rotor, and hall-effect sensor. The sensor has a 20mm diameter, a water pressure of less than 1.75Mpa, and a flow rate of approximately 30 L/m [14]. The piezo vibration sensor uses piezoelectric ceramic chip analog vibration, generating electric signals through an anti-conversion process, allowing the sensor's signal terminal to generate electrical signals [15]. Figure 5 (a) show the water flow sensor and figure 5 (b) show the piezo vibration sensor use in this project.

Fig. 5 (a). Water flow sensor.

Fig. 5 (a). Piezo vibration sensor.

Both of this sensor attached to the Arduino UNO R3 that works as the microcontroller. Both sensors will produce the data based on the condition of the river flow and the debris in the water. The data recorded will be sent to the receiver module through LoRa- RFM SX1278 module. Figure 6 (a) and (b) show the buoy module device build up using the emergency buoy as the platform and polyvinyl chloride pipe as the exoskeleton of the device.

Fig. 6 (a). Top view buoy module.

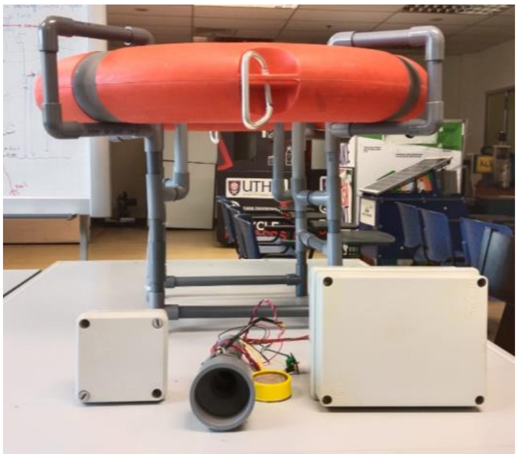

Fig. 6 (b). Front View buoy module.

4.3 Water level transmitter.

This module consists with JSN-SR04T waterproof ultrasonic sensor, LoRa-RFM and lipo battery. Waterproof ultrasonic is rangefinder module functions as both a transmitter and receiver, attached to a printed circuit board using a 2-meter cable. Its accuracy is comparable to the HC-SR04, with a maximum distance of 6 meters, making it easy to carry and suitable for various environments [16]. The reading of water level change is send through LoRa- RFM SX1278 module. Figure 7 (a) show the JSN-SR04T waterproof ultrasonic sensor use in this project and figure 7 (b) is the transmitter.

Fig.7 (a). JSN-SR04T.

Fig.7 (b). Water level transmitter.

4.4 Hardware mechanism.

The site testing is located at the floating house on Sungai Kahang, Kluang Johor. This site is chosen due to minimal risk of headwater occur to avoid any damage or loses to the hardware or life threating event. The river behavior is enough to get the reliable data. The location coordinate is 2.310475,103.645135. The buoy module is tied to the horizontal wood facing the stream flow and the water level transmitter is attached to the vertical pole at the river bank. Figure 8 shows the setup of the project.

Fig.8. Setup of the hardware.

The water flow rate and piezo vibration is placed underwater. The water flow rate will read the volume of water flow through the valve body each second but the data will be send to the receiver in every three second same goes to the piezo vibration sensor. Every time the debris underwater hit the piezo surface, electric pulse will be generated and send to the receiver.

5. RESULT AND ANALYSIS

5.1 Effect of distance on receiver signal strength indicator RSSI

RSSI is a measure of the power level received by a receiver from a transmitter. It is crucial in assessing the quality and performance of a wireless link in LoRa (Long-Range Access) technology. RSSI is typically measured in decibels relative to a milliwatt (dBm), with values closer to zero indicating stronger signals. Good signal quality often leads to better data transmission rates and lower error rates. RSSI values for LoRa typically range from -30 dBm to -120 dBm. A signal at RSSI = -30 dBm is extremely strong, whereas one at -120 dBm is extremely weak. However, it should be considered alongside other metrics like Signal-to-Noise Ratio (SNR) and packet error rate. The signal-to-noise ratio (SNR) in decibels (dB) is calculated by taking 10 times the base-10 logarithm of the ratio of the signal power to the noise power. The formula is:

$$SNR(dB) = 10log10\,\frac{Psignal}{Pnoisse}$$

Where Psignal is the power of the signal and Pnoise is the power of the noise [17]. LoRa SNR values typically range from -20 dB to +10 dB. The received signal is less distorted when the value is closer to +10 dB. In fact, transmissions that are -7.5 dB to -20 dB below the noise floor can be demodulated using LoRa. LoRa is designed to work over long distances, and it can be affected by obstacles like buildings, trees, and terrain. Monitoring RSSI aids in network planning, ensuring reliable communication and identifying areas with poor coverage that may require additional gateways or repeaters. In LoRaWAN networks, RSSI is used to determine the best gateway for data transmission. Three setup have been carried out to the the RSSI of LoRa- RFM SX1278 module. The setup is line-of-sight (Los), non-line of sight and elevation. Figure 9 show the transmitter and receiver setup for the experiment.

Fig. 9. Receiver (left) and transmitter (right) of LoRa-RFM SX1278

5.1.1 Line-of-sight RSSI

LoRa line-of-sight (LoS) testing entails assessing the communication performance between a LoRa node and a gateway in the absence of any obstacles. This procedure aids in comprehending the optimal signal quality and maximum range. In this setup, the transmitter is place at one point and the receiver moved to one and another point in incremental distance. Table 1 shows the result of LoS testing.

Table 1. Distance against RSSI value LoS testing.

Distance (m)	RSSI (dBm)
50	-95
100	-100
150	-101
200	-104
250	-101
300	-106
500	-105
600	-110

From table 1, we can see the value of RSSI signal quality and strength decrease with distance. Reliable communication is maintained up to 600 meters. Beyond 600 meters, the SNR drops below 0 dB, indicating reduced signal quality and potential communication issues. Figure 10 show the map of LoS LoRa RSSI testing.

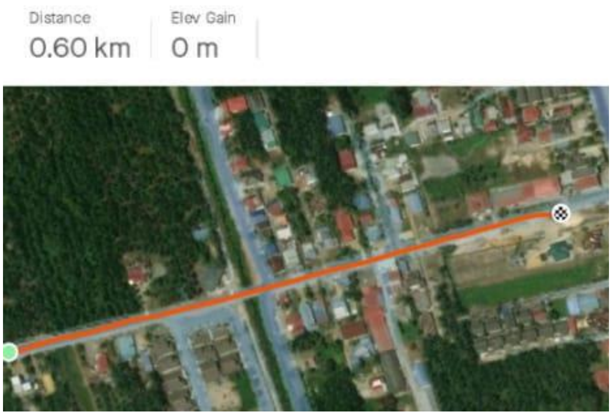

Fig. 10. Distance of LoS testing.

5.1.2 Non-line-of-sight RSSI

Non-line-of-sight (NLoS) testing for LoRa entails assessing the network's coverage and performance in the presence of obstructions separating the gateway and the LoRa node. Understanding how geography, trees, buildings, and other obstacles impact signal strength and quality depends on this kind of testing. In this setup, the transmitter is place at one point and the receiver is move to random obstructed locations. Table 2 show the data obtain from NLoS testing at urban area with houses and river.

Table 2. Distance against RSSI value LoS testing.

Point	Distance (m)	RSSI (dBm)	Obstruction
1	50	-98	1 house
2	70	-98	Cross river
3	150	-104	1 house
4	200	-110	1 house
5	210	-110	4 house
6	480	-105	3 house

From table 2, we can see we can see the value of RSSI signal quality and strength decrease with distance and obstruction. Reliable communication is maintained up to 480 meters. Figure 11 show the map of LoS LoRa RSSI testing at urban area with houses and river. The red point is the location of transmitter and the yellow points are the location of receiver.

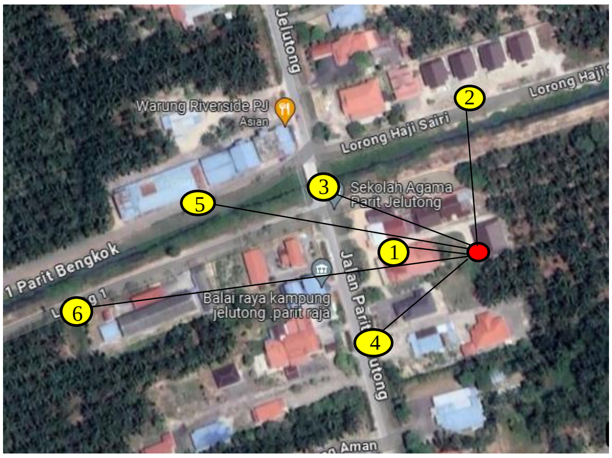

Fig. 11. Distribution of receiver location.

5.1.3 Elevated non-line-of-sight RSSI at forested hilly terrain

Elevation testing is a technique used in LoRa (Long Range) networks to assess the network's coverage and performance at various elevations. Because of variations in line-of-sight, obstructions, and atmospheric conditions, the elevation of LoRa nodes and gateways can have a substantial influence on the range and signal strength (RSSI). Table 3 shows the data obtain from NLoS testing at forested hilly terrain.

Table 3. Distance against elevated RSSI value NLoS testing.

Elevation (m)	RSSI (dBm)
Initial 0	-33
28	-98
35	-101
38	-102
55	-102
62	-114

From table 3, we can see we can see the value of RSSI signal quality and strength decrease with elevation due to elevation at the forested area. Reliable communication is maintained up to 62 meters from the sea. Figure 12 show the elevation of NLoS LoRa RSSI testing at forested hilly terrain.

Fig. 12. Max elevation recorded for RSSI.

5.2 Device testing on river

5.2.1 First testing without water level transmitter

There are three set of data collection during testing at Sungai Kahang. This is because varies of sensor placement is tested. Figure 13 show the first placement of buoy module under the floating house. The blue arrow shows the facing of vibration and flow sensor. Table 4 shows the data collected from the first setup on 16 November, 2023.

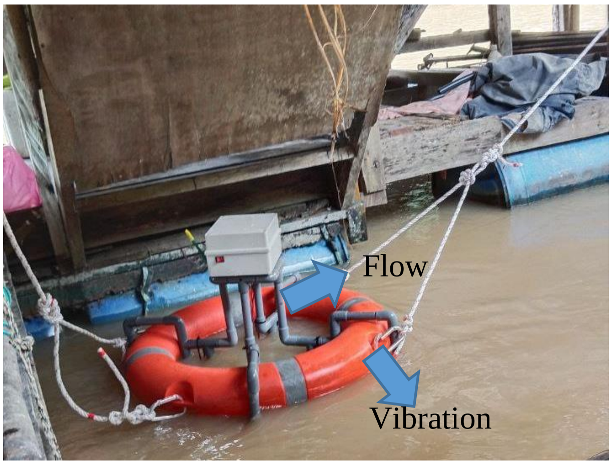

Fig. 13. First position of testing

Table 4. Data collected from the first setup on 16 November, 2023.

Time, pm	Temperature, ◦c	Vibration, Hz	Flowrate, m^3/s	RSSI dBm
3.01	29.56	1	4051	-51
3.47	28.94	2	1763	-49
4.40	28.31	1	2339	-54
4.52	27.75	5	2139	-50
4.53	27.63	0	3275	-69
5.00	27.38	0	2051	-43
5.10	27.13	0	2715	-37
5.15	27.06	0	3459	-37
5.57	26.44	2	2219	-28
6.00	26.38	3	1483	-40
6.05	26.44	1	1123	-43

From the table above, the temperature value is acceptable since the device is place under shading area. The reading of water flowrate is acceptable. The median flowrate of water is 2419 m^3/s. The RSSI value of Lora communication is comprehensive. This is because the distance transmitter and receiver is only three meter. The median flowrate of water is 2419 m^3/s. The value of vibration is misleading due to not suitable placement of vibration sensor. Second test have been conducted to overcome this issue.

5.2.1 Second testing without water level transmitter

Figure 14 (a) show the placement of vibration sensor in second position. Figure 14 (b) show the vibration sensor is facing the flowing water same with water flowrate sensor. Table 2 show the second data set after the position of vibration sensor have been alter.

Fig. 14 (a). New position of vibration sensor.

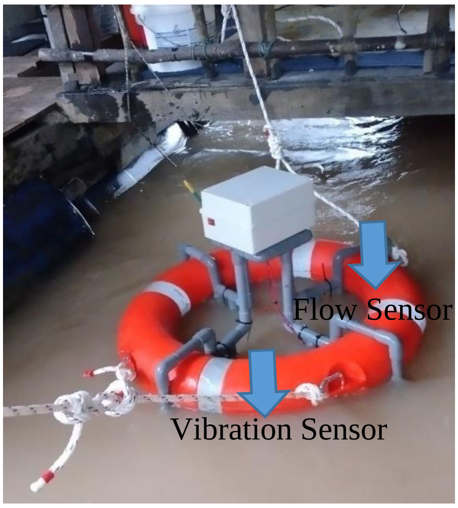

Fig. 14 (b). Direction of sensor facing to the water flow.

Table 5. Second data set after the position of vibration sensor have been change.

Time, pm	Temperature, ◦c	Vibration, Hz	Flowrate, m^3/s	RSSI dBm
6.28	26.00	12	3317	-55
6.31	26.00	10	3381	-50
6.50	25.56	9	3819	-33
7.08	25.56	8	1507	-52
8.03	25.06	31	3285	-35
9.05	25.19	16	1853	-35
9.20	25.25	15	2675	-30
9.47	25.25	14	2939	-40
Time, am	Temperature, ◦c	Vibration, Hz	Flowrate, m^3/s	RSSI dBm
6.23	24.81	38	3440	-35
6.47	24.63	41	2587	-48
7.10	24.56	42	3817	-41

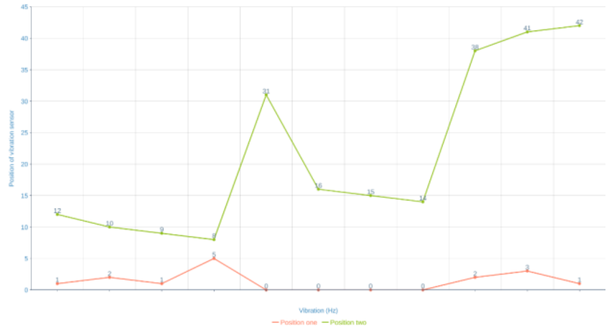

Fig. 15. Comparison of vibration reading.

Figure 15 show the comparison of data captured when the position of vibration sensor is change. After the position of vibration sensor is change, the value of vibration become more reliable since the piezo get hit from the debris flowing in the water. The temperature value is decreasing because the day already at night. The RSSI value still strong because the position of transmitter and receiver still same with last experiment. The median flowrate of water is 2618 m^3/s. This show the flowrate of river 199 m^3/s higher on that night.

5.2.1 First device testing with water level transmitter

Figure 15 shows the third setup of this experiment. This time, the device is place outside the floating house near the river bank.

Fig. 15. Third setup of this experiment.

Figure 16 shows the depth of water using sonar wave to get the initial value of water level which is 170cm. The distance of node 1 to the water surface is 80cm makes the total height of sensor to the bottom is 250cm.

Fig. 16. The depth of water obtains with fish finder sonar.

Water level (Wl) sensor will calculate the different between the distance of sensor to the river bed (1) and the initial depth of river (2).

$$Wl = 1 - 2$$

Figure 17 shows illustration how water level getting the value of water level and able 6 show the data collected for third setup on 9.40 morning until 3.40 afternoon of 17 November, 2023.

Temperature, °c	Vibration, Hz	Distance, cm	Water level, cm	RSSI dBm
26.75	45	80	170	-80
26.75	44	80	170	-79
27.69	43	85	165	-75
28.06	43	88	162	-85
27.69	42	89	161	-77
27.50	43	91	159	-79
28.25	44	94	156	-83
28.38	45	95	155	-85
28.56	44	96	154	-84
28.75	43	96	154	-73
28.81	45	97	153	-72

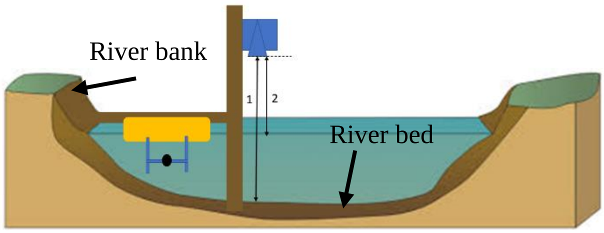

Fig. 17. Hardware setup illustration

Table 6. Data collected for third setup on 17 November, 2023.

From table 6, the value of temperature is higher than the first testing is because node 2 is expose to the sunlight. The value is rising from the morning until afternoon. The vibration is higher since more debris flowing at river bank. The RSSI value is reliable since the distance both transmitters from the receiver about 70 meters. Figure 8 show the data plot of the experiment.

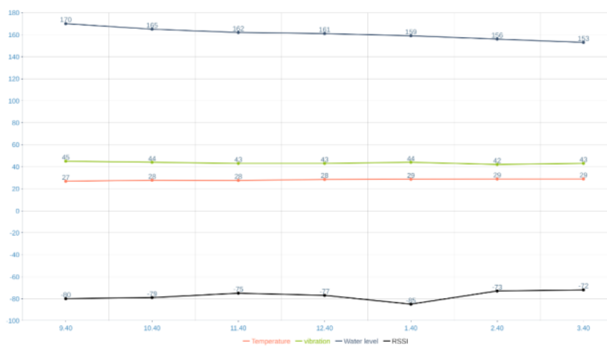

Fig. 8. Data plot of the experiment

Figure 8 show that in the morning, the water level is at 170cm and decreasing 17 cm until late afternoon. This show the water level decrease about 2.8cm per hour. There are four thresholds for Sungai Kahang water level which is alert, warning and danger [17]. Based on this experiment, the normal water level is 1.7 meter. The alert water level is 5.5 meter, the warning level is 5.8 meter and the danger level is 6.2 meter. If direct assumption calculation from the data, 26 hours will be needed to achieve danger level. However, the level of water change to several factors such as heavy rain can cause rapid increases and seasonal changes such as monsoon and el nino seasons.

6. CONCLUSION

In conclusion, this project was executed simply, making use of inexpensive sensors and easily accessible materials. The study's design of experiments effectively illustrated how environmental conditions affect both the accuracy of the sensors and the LoRa communication protocol. The prototype passed its functionality test with satisfying every prerequisite. Still, there's space for improvement in the testing facility. In order to overcome the constraints imposed by the existing testing facility, moving to a genuine area of effect would offer headwater phenomena scenario. Overall, this project emphasizes how easy and affordable the solution for monitoring system is, but it also acknowledges that there is need for improvement in order to maximize performance in real-world operational conditions.

7. ACKNOWLEDGMENT

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