Development of IoT Real-Time Groundwater Monitoring System

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Abstract. Internet of Things (IoT) Real-Time Groundwater Monitoring System is a system built to monitor groundwater extraction and consumption. Groundwater scarcity has become a major threat to the government especially water utility company. Water theft, inaccuracy meter reading & lock out access are some problems contributing to water scarcity. In this research, data obtained from the groundwater consumption using flow sensor will be sent to the server where all this data will be recorded for future analysing by respective authorities. The system has been tested thoroughly using Long Range (LoRa) communication module together with Thingspeak cloud and mobile application. The results showed promising coverage with Line of Sight (LOS) is tested at 900m maximum while for Non-Line of Sight (NLOS) is at 600m. A very small standard deviation up to 4.93 was observed for received Signal Strength Indicator (RSSI) value for LOS and NLOS. Compared with the existing manual method, the proposed IoT system will water authority to monitor water consumption effectively through real time and better coverage.

1. Introduction

Fresh water is a very precious resource. It is vital for human survival and health, the production of food and energy, industrial activity, and the functioning of the entire global economy, as well as for the survival of other animals, plants, and natural ecosystems [1]. However, water scarcity has become a main issue in certain areas of our country due to various growth in economics, population, urbanization and also includes the human growth. The demand for fresh water has been increasing for the past 100 years [1].

As we look into Malaysia’s current status, there are reports suggested that five trillion cubic metres of groundwater reserves in Malaysia. There are many cases also being reported of inaccurate manual or abuse meter reading, lacking in policy making and supervision [2]. Thus, all these major problems conclude in ground water exploitation increasing in many cities. This has resulted in millions of payment delinquencies to the authorities. The government could not overcome these loses without stopping this problem and as a result, all these illegal water smuggling has resulted in increasing Non-Revenue Water (NRW).

In Malaysia, according to the Eighth, Ninth and Tenth Malaysia Plan, the federal government has invested about RM 2.6 billion from the year 1996 to 2010 for NRW cutting program [2]. However, Malaysia still suffers from NRW rate remaining very high in some states, standing between 20 to 60 % with the overall average of 36.8 % from the year 2000 till now [2]. If we look deeper into this issue, there are certain states in our country which are facing a major NRW issue reaching the 50 % stage.
This indicates that half of the state’s ground water has been consumed due to illegal exploitation. In 2014 until 2017, Kedah, Kelantan, Perlis and Selangor have always reached the 50 % mark of NRW [4]. Such high rates of NRW jeopardize Malaysia’s water security in the long-term, potentially leading to negative effects on the country’s social, environmental and economic well-being [3].

IoT is defined as internetworking physical objects embedded with electronics, sensors, network connectivity and actuators which can be used to collect and exchange the data [4,5]. In this proposed IoT system, collected sensor’s data will be sent to a base station where it will be analyzed accordingly. The final output will be updated to cloud and a developed mobile application for real time monitoring. Moreover, the communication module used in this project is LoRa which is also known as Long Range (LoRa) which would allow monitoring remote areas with no internet or line coverage. Therefore, this research offers potential opportunity for local water utility agency to collect and analyze data in real time through cloud portal together with mobile application by using a wireless long-range communication.

2. System Design and Testing

2.1. Sensor Unit

For this project, Ultrasonic Clamp on Flow Meter was selected for the flow sensor. There are few advantages in ultrasonic method being used because it has a very high accuracy, and it will not be affected by any external environmental factors especially outdoor environment. Furthermore, ultrasonic sensors are also a non-invasive technique which makes it more interesting for this project.

2.2. Communication Module

Cytron LoRa communication and ESP8266 Wi-Fi module were selected for this project as it has a good coverage, energy efficient and can be easily modified to integrated to Arduino Uno which is the controller used for the project.

2.3. Cloud Computing and Mobile Application

All data collected in the microcontroller are stored in the database through cloud computing system. The cloud used for this project is Thingspeak which provide simple IoT implementation in cloud computing system. To enhance the portability and mobility of data monitoring system, mobile application for tablets and smartphones is designed to capture those data stored in the cloud and visualized in charts and gauges representation for water quality monitoring purposes. Real time data will be measured and saved in the cloud to produce historical data for certain period. Due to fast development time required for the mobile application development, MIT APP Inventor was selected.

2.4. Underground Water IoT System Architecture

The Groundwater Monitoring System consist of two parts which is the client system which will be placed on the pipe and the server system which will be placed further away for online monitoring. As in Figure 1, the client system consists of the Arduino Uno, Ultrasonic Sensor, LoRa module, LCD Display & Battery.

![Figure 1. Block Diagram of the Client System](image-url)
The Ultrasonic sensor will be attached on the groundwater pipeline to read information of the water flowrate. Then, the flow rate data will be sent to the Arduino Uno by the analog input. Arduino will perform calculation to get the volume of the liquid flowed by multiplying with the time taken. The flow volume information of the groundwater will be sent to the server system through a LoRa communication module. On the other hand, the server system only consisting of an Arduino Uno, LoRa module and ESP8266 Wi-Fi module. The server system will receive data through the LoRa Module in a long range and send the information through the ESP8266 to the internet. The ESP8266 will update all the data to the Thingspeak cloud portal and Mobile Application continuously to view real-time data. Figure 2 shows the working mechanism for the server system.

![Figure 2. Block Diagram of the Server System](image)

2.5. LoRa Communication testing
For the LoRa communication testing, due to the Covid-19 Movement Control Order, all testing was conducted inside University Technology Petronas campus. The testing was done in two different locations in the campus due to Line of Sight (LOS) and Non-Line of Sight (NLOS) testing. as in Figure 3, the LOS testing was performed at the open area of 1 km range whereas the NLOS testing was performed near hostel area, where it has a lot of hostel building thus creating a NLOS situation. The testing was conducted under a radius of 1 km. Every 100 m, three Received Signal Strength Indicator (RSSI) values are observed and recorded, and the packet losses are observed. The client system was placed permanently on a spot and the server system is moved every 100 m.

![Figure 3. UTP Testing Location (a) LOS Testing Radius (b) NLOS Testing Radius](image)
3. Result and Discussion

3.1. Flowrate Sensor Testing
For the first testing, the water flow meter with the transducers will be placed on the pipe to receive different speeds of tap water, interpret and finally display data on the flow meter. As in Figure 4, the data shows that there is a steady rise of flowrate and velocity with increasing speed of water into the pipe. Three trials were repeated to observe the data consistency. The standard deviation of the result collected is very low at speed 1 and rises a bit when the speed is at maximum. In overall, the standard deviation is still considered low. There is a small standard deviation of 0.03. This shows that the data received is very accurate and precise.

![Flowrate vs Speed](image)

**Figure 4.** Testing Location (a) LOS Testing Radius (b) NLOS Testing Radius

3.2. Line of Sight Testing Result
As for LOS testing, the whole testing was conducted on a ground without any major distraction or reflection for the LoRa module between the transmitter and the receiver. The testing was conducted between a 1 km radius within UTP campus. Three RSSI values and packet received data are recorded for each distance until the signal is lost. This test is repeated for different TX powers. Figure 5 shows the graphs for the tabulated graph of the RSSI compared the LOS distance coverage. It shows a steady and smooth curve for the RSSI values plotted. In terms of power saving, lower TX power applied, the more power saving it is.

![RSSI vs Distance](image)

**Figure 5.** LOS RSSI vs Distance chart
For the LOS testing results, the results for TX power 23 which is the strongest signal power is first discussed. For TX power 23, the total distance that can be achieve by the LoRa module is 900 m. As in figure 5, after 900 m, the signal will not be available. The RSSI value starts -22 at 50 m and reaches -101 at 900 m which is very weak. Between 50 m to 400 m the signal looks strong but after 500 m the signal strength is becoming weaker. The standard deviation for the RSSI values is also very low, which is only between 2 to 4. This shows that the RSSI values are steady and without major fluctuation. There were 22 packet data sent during testing. There are no packet losses at this stage.

For TX power 14, the total distance that is able to achieve by the LoRa module is only 700 m. TX power 14 is the moderate signal power. The signal could not detect after 700 m. The RSSI value starts -31 at 50 m and reaches -91 at 700 m. The distance between 50 m to 300 m the signal looks strong but after 400 m, the signal strength is becoming weaker. The standard deviation for the RSSI values also stays low between 2 to 4 which indicates that the RSSI values are still steady and there is no major fluctuation. All the 22-packet data were able to be received as well. There are still no packet losses found at this stage of testing which is a very positive result.

Finally, for TX power 5, which is the weakest signal power of all, the total distance that is able to achieve by the LoRa module is only 100 m. This signal becomes lost after 100 m. This shows a very poor result in terms of distance. The RSSI value also starts at -77 at 50m and reaches -95 at 100 m. The signal strength is very weak even at the shortest distance. The standard deviation for the RSSI values stays between 3 which indicates that the RSSI values are still steady and there is no major fluctuation. There are still no packet losses found at this stage as well with all the packet data being received.

Overall, the best results are obtained with TX Power 23 in terms of distance and RSSI. TX power 14 is still applicable for shorter distances but TX power 5 is not applicable at all for field usage. TX power 5 does not really fulfil the requirement of Long-Range requirement as it can only cover up to 100 m. All three TX powers do not have any packet losses during testing which indicates a very good sign. The standard deviation also stays within 4 which is a very good sign.

3.3. Non-Line of Sight Testing
As for NLOS testing, the whole testing was conducted on a regular spot of which the area has building. Therefore, there will some distraction or reflection of the LoRa signal between the transmitter and the receiver. This testing was also conducted between a 1 km radius within UTP campus. Three RSSI values and packet received data are recorded for each distance until the signal is lost. This test is repeated for different TX powers. The graph in Figure 6 shows a steady and no abrupt changes for the RSSI values plotted. In this case, TX power 23 is the only conditions satisfies requirement of long range and it is the only one applicable.

![Figure 6. NLOS RSSI vs Distance chart](image-url)
First as we look at TX power 23 the strongest signal power, the total distance that is able to achieve by the LoRa module is only 600 m. As in Figure 6, the signal was observed to be lost after 600 m. This shows that in NLOS, the distance achieved is short even with the strongest signal power. At 50 m, the signal strength is at -55 and slowly rises and finally reaches -108 at 600 m. At 50 m to 200 m, the signal is strong but after 300 m the signal strength is becoming very weaker. The standard deviation for the RSSI values is also very low between 1 to 4.93. The RSSI values fluctuate slightly more than LOS testing, but still within acceptable range. For the packet losses, there was 1 packet loss observed during 400 m range with an existing RSSI value of -96. This is due to the reflection distractions of buildings and other materials between the transmitter and receiver. This packet loss happened only once during this testing.

For TX power 14, the total distance that is able to achieve by the LoRa module is only 300 m which is very short. The signal could not be detected after 300 m. The RSSI value starts at a very weak strength of -78 at 50m and reaches -98 at 700 m. The whole signal was very weak. The standard deviation for the RSSI values was between 1 to 4 which indicates that the RSSI values are still steady and there is no major fluctuation. There was 1 packet loss observed during testing at 300 m. 300 m was the last received signal before the signal was lost. Overall, with TX Power 23, better results were obtained in terms of distance and RSSI compared to TX power 14.

For NLOS, TX power 14 itself is not applicable for field usage as it only covers a very short distance of 300 m. This does not fulfil the requirement of long range. TX power 5 was not tested since there were no signal even at 50 m. Therefore, it is not applicable. There were two packet losses observed during this testing which indicates that there might be some error in results sometimes due to packet losses. The overall standard deviation also stays within 4.93 which is still acceptable.

3.4. Thingspeak Cloud Portal

The data that has been collected by the flow meter will be transferred through LoRa communication to the server system. Then, after performing some calculation on the server system to obtain the flowrate, the total amount of water consumption per day, per week and per month in (RM). The total water consumption will be multiplied by RM 0.05/m³ as per mentioned in the Lembaga Urus Air Selangor (LUAS) company official webpage for commercial use [6].

![Figure 7. Thingspeak Cloud Sample Results](image-url)
For the per day calculation, the data will be renewed every day at 12:00 am. For the per week calculation, the data will be renewed on every Sunday 12:00 am. Finally, the per month calculation will be renewed on the 1st of every month on 12:00 am. All these four data will be sent to the Thingspeak Cloud portal to be recorded and observed. Figure 7 illustrates the results on the Thingspeak cloud portal.

3.5. Mobile Application
The mobile application was developed with MIT Application. The application is designed to be a user-friendly interface. Every user will not have any difficulties in using the application. The application will be able to display the flowrate of the pipeline, per day water consumption, per week water consumption and per month water consumption. There will be a button with an option to view the graph of the displayed data. At the bottom of the application there will be a Google Map which will indicate the location of the pipeline being measured. All the data displayed will be updated every 20 seconds. Figure 8 shows the display of the mobile application.

![Figure 8. Mobile Application Sample Display](image)

4. Conclusion
Nowadays, underground water monitoring system is very important as water scarcity has been a developing problem in our society. Several state water utility companies in Malaysia have been facing various issues on ground water monitoring such as water theft, meter tampering, lock out access & inaccuracy meter reading. All these issues have leaded to NRW. This IoT real-time groundwater monitoring system will be the best solution to the government for all the issues they are facing. This system utilizes ultrasonic sensors for water monitoring as it provides accuracy, precision and feasibility. Cloud portal & mobile application will also be accessible for easier monitoring. For the communication module, the results on the RSSI, distance, TX power and packet losses shows a good and accurate result even in long distance of LOS and NLOS. Therefore, the proposed system shows its effectiveness in monitoring underground water monitoring through wider LoRa coverage compared to the conventional wireless systems. For further recommendations, this underground water monitoring system can be further improved by including solar powered battery to automatically recharge so that this system will last longer and be more efficient instead using a LiPo battery.
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