Water Quality Monitoring with Internet of Things (IoT)

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***Abstract* - The paper suggests an Internet of Things (IoT) based system implementation by embedding the Radio Frequency Identification (RFID) system, Wireless Sensor Network (WSN) platform and Internet Protocol (IP) based communication into a single platform for water quality monitoring (WQM) purpose. The suggested radio frequency for the proposed WSN communication to be deployed in vegetation area is 920MHz. The measured water parameter in this proposed system is pH level by using an analog pH sensor. The ambient temperature is captured during pH measurement by using an analog temperature sensor. All the WSN nodes are deployed in a real environment at the lake in the campus area of Universiti Sains Malaysia (USM) for performance evaluation. Instead of using 2.4GHz ZigBee protocol, the 920MHz Digi Mesh protocol is proposed to be implemented for water quality monitoring in vegetation area due to its ability to surpass the signal attenuation. This novel proposed system prototype was evaluated in a real environment to ensure that the main functionality on pH measuring process is following the design requirements. Several experimental analysis were conducted including the energy analysis and communication read range analysis to study the overall performance of the proposed system.**

***Index Terms* - IoT, RFID, WSN and WQM.**

I. INTRODUCTION

In general, the water quality monitoring process is a specific task carried out by the respective authorities to measure the water parameters whether it can be safely consumed by human, animals and plants or not. The basic observed water parameters for water quality determination are pH level, Dissolve Oxygen (DO), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Suspended Solid (TSS) and Ammoniacal Nitrogen (NH3N). All these water parameters will be measured to determine the water quality before can be safely consumed. The ignorance of a few respective authorities in implementing proper water monitoring technique had caused serious health problems to human due to the dirty water consumption [1]. Therefore, an automated system with different wireless technologies embedment for water quality monitoring including the RFID system, WSN platform and IP-based communication is proposed in this study.

The IoT keyword is very synonym with the latest wireless monitoring system in our daily life. From the healthcare to the environmental surveillances, the IoT system is widely used for a reliable data acquisition in a real-time monitoring process. There are several approaches of IoT communication available. According to [2], device-to-device and device-to-cloud are the two types of communication that applied in IoT system. Most of the developed IoT-based systems utilize the second approach which is device-to-cloud for data storing and online monitoring. By employing the cloud storage, there will be no more hassle in managing the data storage facility which is requiring a highly skills person in ICT background.

WSN as a component in the proposed IoT ecosystem allows machine-to-machine (M2M) communication in transmitting information through UHF band frequency of 902MHz to 928MHz with the utilization of 920MHz transceivers. Most of the WQM spots are located in vegetation areas with high radio signal attenuation whereas the Line-of-Sight (LoS) communication is almost impossible to be established there. The WSN platform in the proposed system enables the RFID tags to communicate with dedicated system gateway in a simplified network topology, Digi Mesh instead of typical IEEE 802.15.4 ZigBee that is often used in wireless monitoring system. There is no parent-child relationship in Digi Mesh network. Thus, all WSN nodes can be turned into sleep mode, resulting an efficient wireless monitoring system with ultra-less energy consumption throughout the WQM operation.

II. LITERATURE REVIEWS

This section reviews the relevant works of environmental monitoring system using the WSN platform and RFID system.

A. Wind Speed Sensing

The work of [3] studied the win speed sensing with WSN platform. This system consists of two main parts which are the sensor node and host node. The sensor node design including ZigBee-Pro transceiver, ATMega microprocessor, memory card, anemometer, temperature and humidity sensors SHT-10 and independence power system. While the host node consists of Raspberry Pi board, Central Processing Unit (CPU) and ZigBee Pro transceiver. The developed system was evaluated at University Siliwangi in West Java Indonesia at coordinates 7 ° 21'1 "S 108 ° 13'22" E. The data of wind speed, temperature and humidity were captured. The sensor node was transmit 26

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bytes of ZigBee packet payload to the host node in each of transmission. As the final results, this developed system managed to 100% transmit data at only 18m distance and significantly drop to 69% at 107m distance.

B. Evaluation of XBee-Pro Transmission Range under The Forested Environments

Iswandi et al. [4] studied the maximum range of WSN node under forested environment based on Receive Signal Strength Indicator (RSSI). The IEEE 802.15.4 ZigBee protocol was used in this work. This range test was conducted in forestry area with various distance of the transmitter and receiver to get the maximum communication range. Both transmitter and receiver are configured with below parameters.

- Transceivers are XBee-Pro S2B
- Transmitting and receiving power at 18dBm
- Receiver sensitivity at -102dBm
- Antenna gain at 3dBi
- Baud rate at 9600bps
- Height of antenna pole at 1.5m
- Occurrence of packet transmit at 500 packet
- Inter-packet interval at 200ms

And the results shows that 330m of maximum communication range was achieved for homogeneous forest and 290m was the best communication range for heterogeneous forest without the presence of network router. The results from this work is better than work of [3] in term of communication range.

C. Water Monitoring System using Wireless Sensor Network

Another work [5] implemented the WSN platform in water monitoring process. The SquidBee which is a typical IEEE 802.15.4 ZigBee based motes were used as the WSN nodes. All sensor nodes were floated on the beach and deployed in a wide study area. It monitored the water pH level, DO and water temperature of the studied beaches.

This developed system consists of three main parts; the sensor node, cluster head node and network gateway. It employing the typical parent-child relationship of ZigBee protocol. This ZigBee protocol relationship is illustrated in Figure 1. The algorithm of gateway was written in C programming language to receive the data from sensor nodes for every 5s of time interval. The authorized user can monitor the real-time captured data of pH level, DO and water temperature by using PC at the base station.

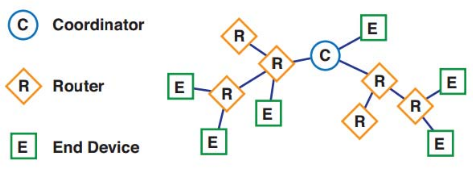


Fig. 1. ZigBee Parent-Child Relationship Nodes

D. Discussion

The use of IEEE 802.15.4 ZigBee or similar mesh protocol in wireless monitoring system is demanding but limited with the read range capability in outdoor NLoS communication. A network router should solve this read range limitation but it is not an economical solution when involving too many routers in the same network. In addition, the complexity of a network will increase due to the use of many network routers. Therefore, the UHF 920MHz transceiver which is XBee-Pro S3B with Digi Mesh network is proposed for wireless WQM in this study.

III. System Architecture

There are two main parts in the proposed system which are the sensor node and network gateway. Figures 2 and 3 illustrate the hardware functional flow for these two types of proposed node. The end node which is an active RFID tag is powered by high power density 9.6V of Nickel Zinc (Ni-Zn) rechargeable batteries. While the network gateway is powered by 9V of power adapter from mains supply. We proposed a new circuitry design of sensor node that is based on Arduino Uno board. A new double layers PCB layout design is proposed with the embedment of RF module circuit. The parameters to be measured in this proposed system are the pH level and ambient temperature.

The 9.6V from batteries input will be regulated down to 5V output by the voltage regulator. The temperature sensing module, pH sensing module and microcontroller are supplied by this regulated 5V output. However, the RF module circuit can only be supplied by 3.3 V input. Therefore, an additional 3.3V of voltage regulator where the input is supplied from regulated 5V is required to power up the RF module. The network gateway components also supplied by the similar regulated voltages of sensor node.

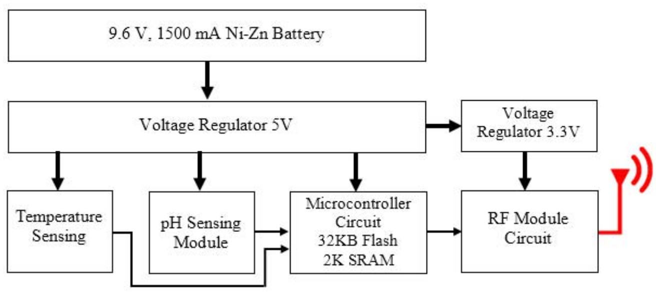


Fig. 2. Proposed Sensor Node Design Block Diagram

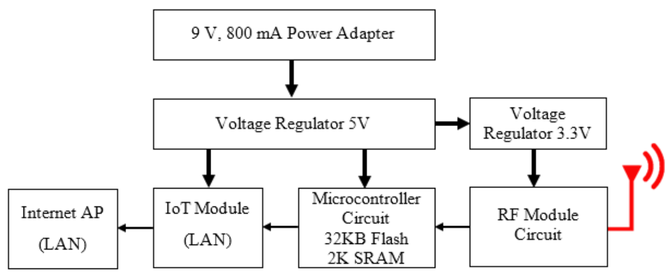


Fig. 3. The Proposed Network Gateway Design Block Diagram

This proposed network gateway is connected to the internet connection by using the IoT module; Arduino Ethernet Shield. It will utilize the available internet bandwidth through the internet Access Point (AP). The AP could be fixed or wireless type depends on the available of IT infrastructure at the base monitoring station. Finally, the obtained data from sensor node will be pushed to the cloud storage by using the integrated IoT module onboard the network gateway. This IoT module communicates with cloud storage infrastructure through TCP/IP communication by requesting the HTTP Get command. Once the TCP/IP communication established, the cloud database will store all the received data from the network gateway of the proposed system.

As the mobile platform provides portability, we proposed a mobile application to enable online monitoring tool with alert triggering system. The proposed mobile application is developed based on an Android OS platform. The GUI of this mobile application is developed by using the mobile hybrid programming technique. On the other hand, the algorithm of alert triggering system is written in PHP programming language to detect the certain pre-determined pH threshold value and then produces the beeping alert sound at the user's mobile device.

IV. IMPLEMENTATION

The Atmega328p microcontroller is proposed for both sensor node and the network gateway. It provides low energy consumption which consume only 0.1 µA during power down sleep mode [6]. While the Xbee Pro is proposed for the WSN communication due to low energy consumption during sleep mode which is rating at 2.5µA [7]. This transceiver capable to communicate up to 6.5km of outdoor communication and up to 305m of indoor communication [7] in Digi Mesh network protocol. According to official document [8], it also has a good signal attenuation surpassing in vegetation area than the typical 2.4GHz transceiver. This network protocol is proposed due to less complexity than the IEEE 802.15.4 ZigBee protocol where no parent-child relationship involves in the Digi Mesh network (see Figure 4).

The proposed system is designed with double layers PCB for a mobility feature. The small form factor of this proposed system design ensures the fast system installment at the field and easy to be moved to other monitoring area. Figure 5 shows the top-view and bottom-view of the proposed system prototype. The pH sensing module and temperature sensor are attached to this proposed prototype by using analog input connectors (see Figure 6). This pH sensing module, from DFRobot [8] is capable to measure between 0 and 14 of pH values. It has ±0.5 accuracy at 25°C temperature.

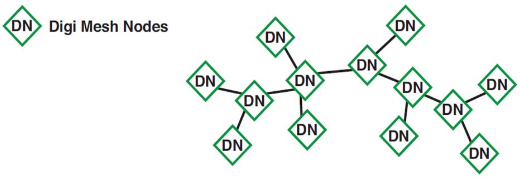
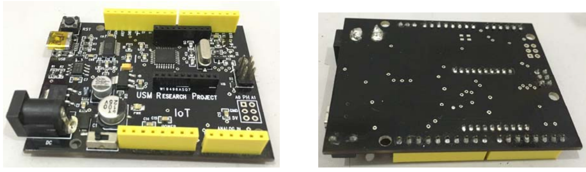


Fig. 4. Digi Mesh Homogeneous Network



(a) (b)

Fig. 5. The Proposed System Prototype; (a) Top-view; (b) Bottom-view

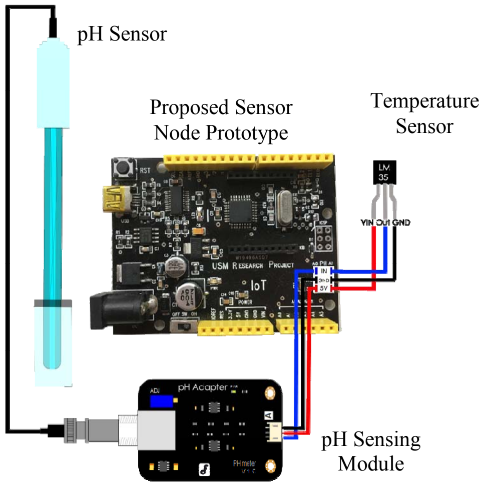


Fig. 6. Sensors Configuration for the Proposed Sensor Node

The microcontroller of the proposed sensor node prototype is embedded with pH sensing algorithm by using an Arduino Integrated Development Environment (IDE). Based on the pH sensing module manual operation [9], an ideal pH probe output is in between -412.12mV to 412.12mV but may slightly different from the actual measurement due to the tolerance of regulated input voltage. Back to the proposed sensor node, it can measure an analog input between 0 and 5V. Therefore, equation 1 maps the analog input from the probe output between 0 and 5V into integer values between 0 and 1023. Thus the equation 2 is written in the developed algorithm for this proposed pH sensing to map the pH value between 0 and 14 as the final pH measurement result.

$$V_{Actual} = V_{probe} * 5 / 1024 \quad (1)$$

$$V_{Ref} = V_{ph} / S \quad (2)$$

$$\text{pH value} = S - [(V_{ph} - V_{Actual}) / V_{Ref}] \quad (3)$$

Where V_{Actual} denotes the analog input voltage, V_{probe} denotes the pH probe output, V_{Ref} denotes the analog input voltage reference, V_{ph} denote the analog input voltage during the pH calibration and S denotes the pH buffer solution value that is used in pH calibration. In this study, we used pH 7.01 buffer solution for pH calibrating process.

As the result of IoT based system implementation, the proposed mobile application is installed in the mobile device to display the real-time data as the first trial run. This trial run is important to ensure the functionality of the proposed mobile application has meet the design requirements. The GUI shows the latest captured pH value, sensor node ID and timestamp (see Figure 7). It also provides the visualization of the past data represented in line chart. Once the anomaly of pH level is detected, this mobile application will beep a frequent sound to alert the user.

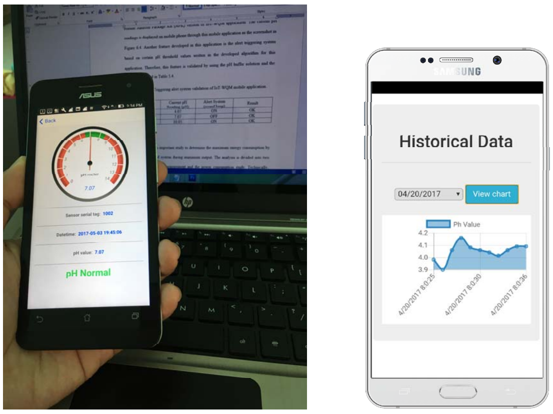


Fig. 7. The Proposed Mobile Application GUI

V. RESULT AND DISCUSSION

This section will discuss the experimental results of our proposed system in term of the performance evaluation in the real environment deployment.

A. pH Measuring

We analyzed the pH measuring by comparing the obtained results from the proposed system with standalone RFID system. The analog pH meter which is an Arduino based system is used as a reference output to ensure the reliability and stability of the pH measurement during the analysis.

The pH measurement was conducted from 8.00A.M. until 7.00P.M. at the studied area (lake near the USM Staff's Clubhouse) in Engineering Campus of USM. The distance between the sensor node and the network gateway is about 120m. Both of them were configured to transmit and receive data at maximum power level by using the XCTU software. The sensor node transmit data within 10 minutes period and then turned into sleep mode for 50 minutes. The collected data of all three systems are tabulated in Table I. We found that the average percentage deviations for the proposed system and the RFID system are in a good tolerance within 10% range. The proposed system provides stable pH measurement as similar as the standalone RFID system. As observed from the Table I, the recorded average water pH level indicates that the normal water condition without the presence of pollution substances.

TABLE I: PH MEASUREMENT ANALYSIS

Time	Ambient Temperature (ºC)	Average pH Data of pH Meter	Average pH Data of IoT-WQM System	Average pH Data of RFID System	% Δ for IoT-WQM	% Δ for RFID
8.00	26.24	7.42	7.40	7.43	2	1
9.00	27.87	7.48	7.48	7.48	0	0
10.00	28.63	7.49	7.48	7.47	1	2
11.00	29.75	7.45	7.46	7.45	1	0
12.00	31.41	7.48	7.54	7.49	6	1
13.00	31.66	7.44	7.53	7.47	9	3
14.00	31.89	7.52	7.53	7.47	1	5
15.00	31.93	7.52	7.52	7.45	0	7
16.00	32.09	7.44	7.47	7.44	3	0
17.00	32.22	7.35	7.37	7.34	2	1
18.00	32.08	7.00	6.99	7.05	1	5
19.00	31.77	7.00	6.98	7.01	2	1
Average Percentage Deviations					2.33	2.17

B. Energy Analysis

The energy analysis involving the current consumption measurement and power consumption analysis. The sensor node is powered by 9.6V from AC-DC voltage generator. Tables II and III tabulates the result of calculated and measured current consumption on different operation modes. The sleep mode is calculated based on hourly usage where the proposed sensor node transmits data one time in an hour. The Shunt resistor 10Ω is used to calculate the load current of the proposed system. The measured current consumption is calculated based on the Ohm's Law V = IR. Therefore, the measured voltage (V) is divided by the Shunt resistor value (R) to obtain the load current value (I).

As we observed the results in Table III, the total average current consumption in one hour is 32mA. It is almost identical with the calculated current consumption which is 33mA. In addition, the results shows the proposed system consumes less energy during sleep mode. Most of the operation time in real system deployment is utilized by the sleep mode, thus benefits all homogeneous nodes in the Digi Mesh network to operate with ultra-less energy consumption. On the other hand, transmit and receive mode consume the most supplied energy with identical result at average 230mA.

Based on the results of Table III, the power consumption is calculated by applying the equation P = IV. Therefore, by substituting I with 0.0032A which is obtained from Table III and V with 9.6V which is the input supply voltage from AC-DC voltage generator, the maximum power consumption of the proposed system based on hourly usage is 310mW.

TABLE II: THE CALCULATED CURRENT CONSUMPTION

Mode	Average current (mA)	% of time	Current Consumption
Transmit	248.27	1.5556×10^{-4}	0.39µA
Receive	62.27	1.8333×10^{-4}	0.1µA
Idle	62.27	0.0132	8.2µA
Sleep	33.0726	99.9865	0.033A
Total			0.033A

TABLE III: THE MEASURED CURRENT CONSUMPTION

Mode	Average current (mA)	% of time	Current Consumption
Transmit	230	1.5556×10^{-4}	0.36μA
Receive	229	1.8333×10^{-4}	0.42μA
Idle	45	0.0132	5.94μA
Sleep	32	99.9865	0.032A
Total			0.032A

C. Maximum WSN Read Range

The 920MHz Digi Mesh network performance of the proposed WSN is evaluated in LoS and NLoS outdoor communication. The maximum transmit power level of Xbee Pro with 2.1dBi antenna gain of whip antenna is configured by the XCTU software. The average RSSI data in every 100m distance are collected. The proposed system reader is placed at fixed location with antenna height from the ground is 1m while the sensor node is fixed on top of the moving vehicle where the antenna height is 1.5m from the ground (see Figure 8). During the read range test, the coordinates for the proposed system reader and the sensor node are 5°36'08.5"N 100°32'31.0"E and 5°36'10.3"N 100°31'58.2"E respectively. The vehicle move forward in LoS range from the fixed position of the system reader until the maximum value of RSSI and distance can be recorded. The minimum receiver sensitivity of the Xbee Pro is -101dBm [7]. The NLoS range test is configured by blocking the communication path with two vehicles in between of the sensor node and system reader. The Range Test tool from XCTU software is used to measure the maximum RSSI value with 100 bytes payload of packet transmission. The serial communication was established at 9600bps between the interfacing PC and the proposed system nodes.

Table IV shows the maximum read range of the proposed WSN platform. This analysis shows the RSSI value at 1000m is -74dBm with 100% data efficiency which is still in good read range for LoS communication environment. The RSSI value of NLoS communication environment is -81dBm, showing that the read range is in acceptable tolerance. Due to the space limitation, the estimated maximum read range is obtained from the extrapolated data as shown in Table V. Thus, the logarithmic equations 4 and 5 are derived from the obtained data of Table IV to extrapolate the maximum WSN read range.

RSSI for LoS outdoor communication:

$$y = -15.12\ln(x) + 31.68 \quad (4)$$

RSSI for NLoS outdoor communication:

$$y = -18.64\ln(x) + 49.268 \quad (5)$$

And assume that the data efficiency percentage for LOS and NLOS communication = 100%.

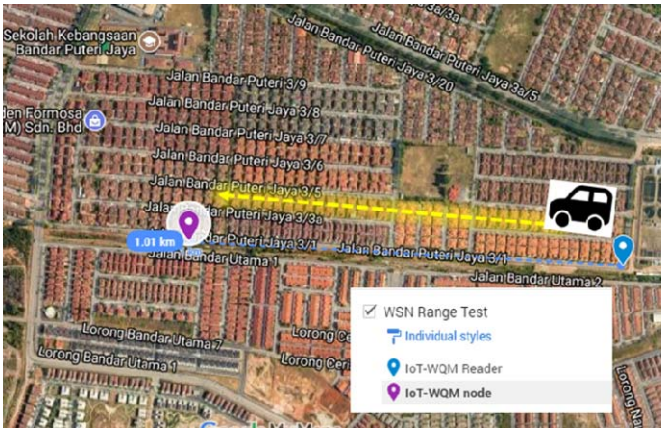


Fig. 8. The Proposed WSN Outdoor Read Range Setup

As we observed the Table V, the 6500m distance of maximum WSN read range is achievable as mentioned in [7]. By considering the 20% signal loss of specific signal attenuation in vegetation area based on [8], the RSSI value at 3000m of NLoS communication which is -100dBm decreased to -80dBm. Therefore, the new maximum range of the proposed WSN is 900m. Figure 9 illustrates the relationship between the RSSI value and distance based on the Table IV results.

TABLE IV: THE MAXIMUM WSN READ RANGE

Distance (m)	LOS			NLOS		
	Data Efficiency (%)	RSSI (dBm)	pH	Data Efficiency (%)	RSSI (dBm)	pH
100	100	-40	7.07	100	-40	7.10
200	100	-47	7.09	100	-48	7.07
300	100	-54	7.07	100	-55	7.07
400	100	-58	7.09	100	-60	7.09
500	100	-61	7.08	100	-65	7.05
600	100	-65	7.05	100	-69	7.09
700	100	-67	7.06	100	-73	7.10
800	100	-70	7.08	100	-77	7.07
900	100	-72	7.06	100	-79	7.05
1000	100	-74	7.09	100	-81	7.08

TABLE V: THE EXTRAPOLATED WSN READ RANGE

Distance (m)	LOS		NLOS	
	Data Efficiency (%)	RSSI (dBm)	Data Efficiency (%)	RSSI (dBm)
1500	100	-78.9	100	-87.1
2000	100	-83.2	100	-92.4
2500	100	-86.6	100	-96.6
3000	100	-89.4	100	-100
3500	100	-91.7	100	-102.8
4000	100	-93.7	100	-105.3
4500	100	-95.5	100	-107.5
5000	100	-97.1	100	-109.5
5500	100	-98.5	100	-111.3
6000	100	-99.9	100	-112.9
6500	100	-101.1	100	-114.4

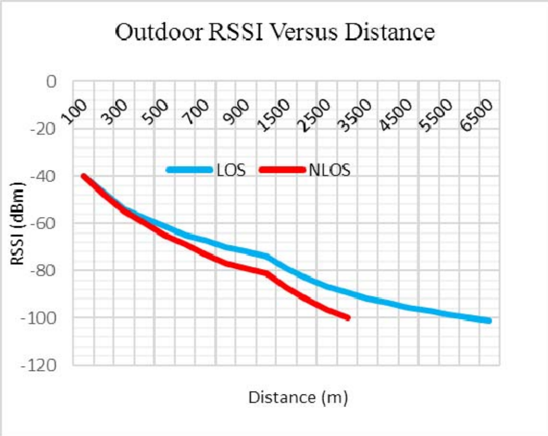


Fig. 9. Relationship between Outdoor RSSI and Distance

VI. CONCLUSION

Sensor selection is suitable and adequate to measure the water parameter based on this proposed system for water quality monitoring purpose. The proposed system prototype is evaluated in a real world environment thus provides the reliable performance data. An average percentage deviations comparison of pH measurement between the proposed system and standalone RFID system shows below than the maximum 10% of acceptable tolerance where each systems average at 2.33% and 2.17% respectively. Therefore, this proposed system is reliable for a real environment deployment. The maximum current consumption from the energy analysis is 32mA with 310mW power consumption at one time per hour usage basis. The maximum WSN read range is up to 6.5km based on the extrapolated data for LoS communication while the NLoS communication is able to transmit at maximum 900m distance in vegetation area. As another decent enhancement, a router can be implemented at each 900m distance for network extending purpose. In addition, the mobile application was successfully installed and ran on Android mobile device. Instead of Android, a mobile application for other mobile device OS could be developed for wide usage of the proposed system. In this study, the primary objective for environmental monitoring especially in WQM was successfully designed and implemented.

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