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Emerging Advances in Integrated Technology

A LoRa-Cloud Based Water pH and Air Temperature Sensor Hub

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Abstract: Water pollution has become one of the important issues in Malaysia which occurs frequently especially in the rivers of Selangor. One of the indicators of pollution is the pH of the water. Thus, the main purpose of this study was to design a LoRa-Cloud-based water pollution sensor hub to monitor the real-time water quality. Sensor devices for pH (SEN0161-V2), and temperature and humidity (DHT11) were used to accurately detect water pH, and air temperature and humidity, respectively. REYAX RYLR896 Long Range Low Power (LoRa) transceiver module enabled the transmission of sensor data from the sensor node to the gateway node, while NodeMCU ESP8266 enabled transmission of sensor data to the Cloud. Ubidots IoT platform was used to monitor the real-time sensor data. A 3 W power supply was continuously supplied to the prototype and autonomy was guaranteed with the addition of monocrystalline solar cells. The performance of the prototype device was tested based on the monitoring function, and the overall pH level of Taman Metropolitan Batu Park Lake was slightly alkaline as the pH of the lake water ranged from 7.32 to 9.08 with data updating every 5 minutes on the Ubidots dashboards. The LoRa-Cloud-based water pollution sensor hub was successfully developed to monitor the real-time water quality through the Ubidots IoT platform.

Keywords: Water quality, Real-time, LoRa, Cloud, Ubidots

1. Introduction

Water is indeed essential to human life. It covers more than 70% of the Earth's surface and is a significant asset for individuals and climate. Water pollution affects drinking water, streams, lakes and seas anywhere in the world. This subsequently has negative effects to human health and general habitat. In Malaysia, there are many water pollution cases reported especially in rivers. The Department of Environment (DOE) stated that there was a total of 579 rivers monitored in 2008 of which 58% of the rivers were classified as clean and the rest were slightly polluted (34%) and polluted (8%) [1]. According to the Malaysian Environmental Quality Report (2016), of the 477 rivers monitored, only 47% of the rivers were classified as clean and the rest were slightly polluted (43%) and polluted (10%) [2]. These sources of contamination are mostly caused by industrial areas, residential areas, and animal husbandry activities.

In one case, water pollution occurred in Sungai Gong, Rawang, in September 2020 which flowed into Sungai Sembah and Sungai Selangor. This incident was caused by a machinery maintenance factory in Rawang that

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deliberately discarded oil waste into the river [3]. It has greatly affected the residents in the areas such as Petaling, Klang, Gombak, Kuala Lumpur, Hulu Selangor, Kuala Langat, and Kuala Selangor. The sudden cut-off water supply to the residential areas has caused great panic to the residents and also affected the industrial areas as there was no water supply for the factories to operate. Therefore, the development of research and technology to control water pollution is important to maintain water quality. According to the National Integrated Water Resources Management Plan, there are 14 research themes which include water quality and pollution. Six research topics related to the themes are water quality modelling, terrestrial atmospheric pollution and water quality, marine pollution, ground water quality, water quality information management and modelling, and finally, technologies for controlling and monitoring non-point source pollution [4].

Many studies on water quality monitoring systems have been conducted by previous researchers [5-10]. All these studies involved Internet of Things (IoT)-based continuous water quality monitoring systems aimed at monitoring real-time water quality using different wireless sensor technologies such as Sigfox, LoRa, Wi-Fi and GSM. The parameters measured were water pH and temperature. A Sigfox-compliant prototype for water monitoring was proposed where the water quality data were successfully obtained from the IoT platform and completely self-sufficient in energy consumption [5]. Water quality measurement station coupled with real-time data visualization platform was successfully designed and implemented at the Botanical Garden Basin for a longer distance of 500 meters however it has consisted of many interfaces, namely LoRa, Wi-Fi, Ethernet and 3G/4G [6].

In this paper, a LoRa-Cloud-based water pollution sensor hub was used to monitor real-time water quality as it was able to connect sensors to the Cloud and real-time communication data between low-power remote devices. The data collected from this study displayed in Ubidots can be used to analyse the pH level of the water and the temperature of air surrounding the water source. Water quality can be monitored and controlled to detect or prevent water pollution from occurring, thus minimizing the threat of pollution.

2. Research Method

2.1 Design of Lora-Cloud-Based Water Pollution Sensor Hub

The LoRa-Cloud-based water pollution sensor hub consisted of two interfaces, namely LoRa and Wi-Fi. At the sensor node, it mainly consisted of two sensors, which were pH sensor (SEN0161-V2), and temperature and humidity sensor (DHT11), a microcontroller (NodeMCU ESP8266), and a wireless REYAX transceiver module (RYLR896). The water pH was detected by SEN0161-V2 where it was an analog sensor while the air humidity and temperature were detected by DHT11 where it was a digital sensor. Both sensors were then connected to the analog and digital pins (A0 and D5) of NodeMCU ESP8266.The data signal was amplified and fed to an analog-to-digital converter (ADC) to convert the signal into digital form. The NodeMCU ESP8266 was then connected to the RYLR896 and encoded to allow signals at frequency of 896 MHz to be transmitted to the appointed RYLR896 at the gateway node with specific AT (attention) commands address. The transmission of data signals was performed through the connection of antennas from RYLR986 at the sensor node and gateway node as shown in Fig. 1.

Next, sensor data were received through the antenna in RYLR896 at the gateway node by demodulating the data signal to recover the information. The microcontroller (NodeMCU ESP8266) was encoded to split the received string data into substring to be converted into floats so that the data could be uploaded to the Ubidots IoT platform through Wi-Fi for water quality monitoring purposes. The raw data recorded with the timestamp in Ubidots was saved in .CVS format and plotted using Microsoft Excel software. Monocrystalline solar cells with output voltage of 6 V and current supply of 500 mA were connected to the lithium battery shield modules to ensure a constant 3 W power supply to both sensor and gateway node.

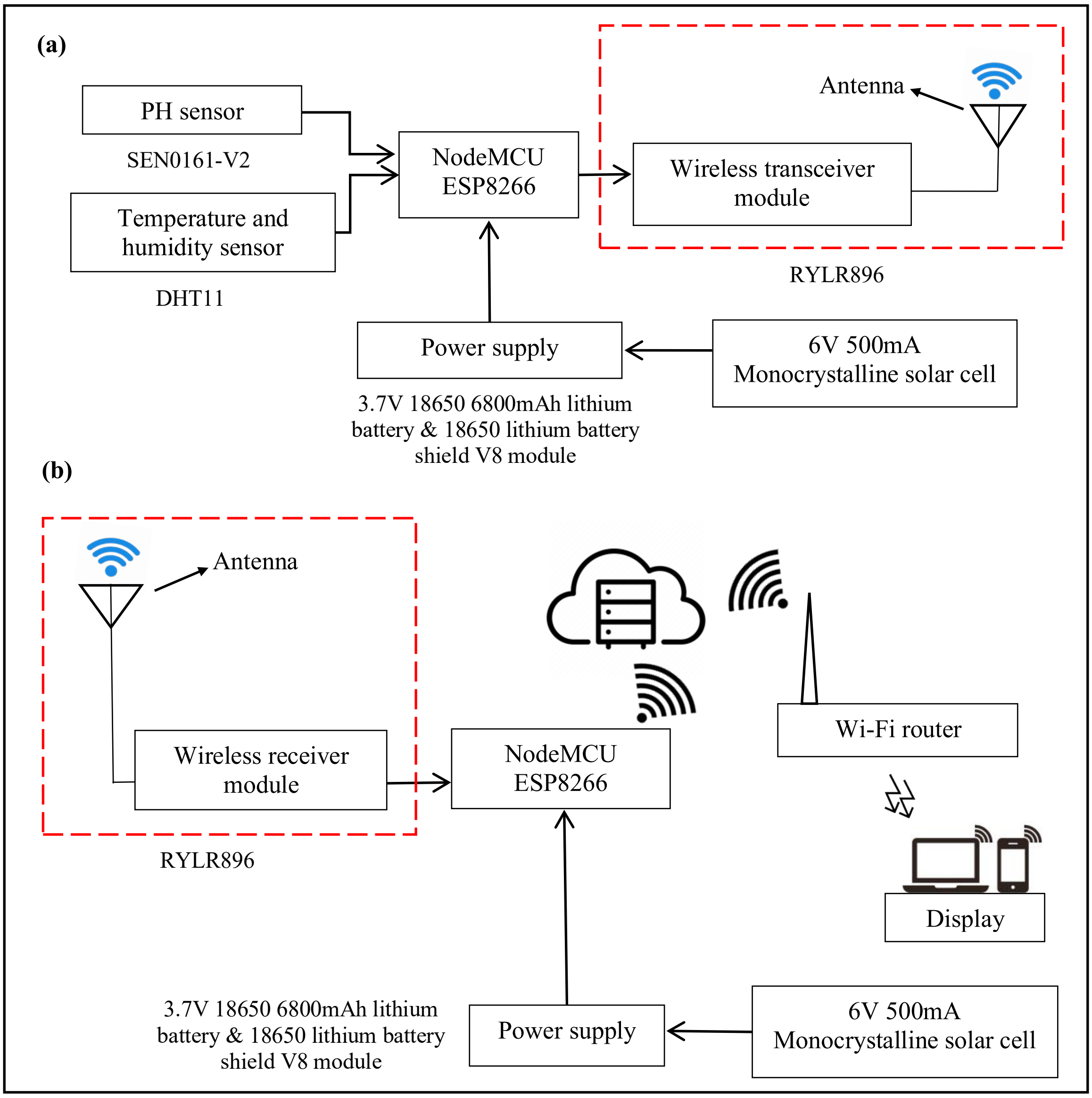

Fig. 1 - Block diagram of (a) sensor node and (b) gateway node of LoRa-Cloud-based water pollution sensor hub

2.2 Calibration of pH Sensor

The program code for SEN0161-V2 calibration was written using Arduino IDE to determine the pH voltage for buffer solutions with pH 4 and 7. Variables were declared and an ACD pin (A0) of NodeMCU ESP8266 was assigned to read the analog readings. The digital output value (D) was detected from the SEN0161-V2 module and DAC conversion Equation (1) was used to obtain the analog input voltage (Vi) at NodeMCU ESP8266. The ADC pin of NodeMCU ESP8266 has a 10-bit resolution which is 2^{10} equals to 1024. The voltage range of ADC in NodeMCU ESP8266 (Vr) was from 0V to 3.3V. Lastly, the value of ADC and pH voltage were printed in serial monitor. It was found that the pH voltage for buffer solution with pH 4 was 2.053 V, and pH 7 was 1.528 V. The plot for pH value against pH voltage was depicted in Fig. 2. The detected pH values can be calculated using Equation (2) based on pH 4 and pH 7 buffer solutions using the formula, y=mx+c. Accurate pH values were obtained by performing a two-point calibration. Thus, real-time water quality could be monitored based on the accurate pH values obtained from Equation (2) for sensor node programming.

$$Vi = \frac{DVr}{2^n} \quad (1)$$

$$pHVoltage = \frac{adcValue * 3.3}{1024}$$

$$pHvalue = -5.714 * pHvoltage + 15.731 \quad (2)$$

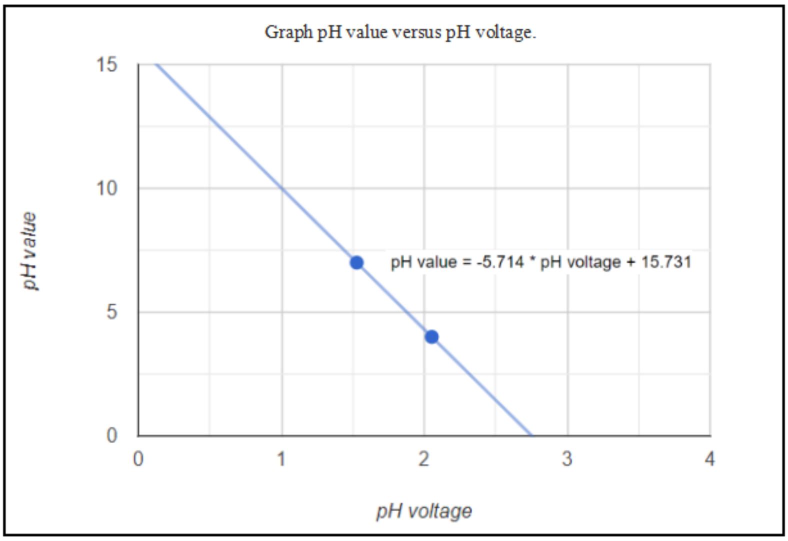

Fig. 2 - Plot of pH value against pH voltage

2.3 Flow Diagram of Programming of Sensor Node and Gateway Node

The NodeMCU ESP8266 microcontroller was programmed using Arduino Intergrated Design Environment (IDE) software. At the sensor node as shown in Fig. 3(a), the program started with initialization of libraries required and declaration of variables. Next, the values of pH, air temperature and humidity were recorded accordingly for an interval of 5 minutes. This LoRa-Cloud-based water pollution sensor hub was basically connected using the MQTT protocol and transmitted sensor data to Ubidots IoT platform. Hence, data in message form must be transmitted in string form. A looping function started with a message in a long string including the AT send command to the gateway node address of 2, data length in bytes, and sensor data in string were transmitted to the gateway node through the LoRa network with condition. Finally, the string message was printed in the serial monitor and on-board LED blinks.

At the gateway node as shown in Fig. 3(b), similar initialization and declaration were performed with the addition of Ubidots setups. The looping function was repeated for an interval of 5 minutes and the received data were in long string with arrangement of address, data length, pH value, humidity, temperature, received signal strength indication (RSSI) and signal-to-noise ratio (SNR). The getValue() function was then used to extract the desired data parameters such as pH, humidity and temperature. It basically functioned to return a single sub-string separated by a predefined character at a given index. After the sub-strings were returned, the desired sub-strings, namely pH, humidity and temperature values were printed in the serial monitor. Ubidots platform only received sensor data in float form. Thus, all the desired sub-strings were converted into floats. Then, the three data parameters were added into the Ubidots.add() functions and sent to a device labeled “reyax_LoRa" in Ubidots to be displayed and updated.

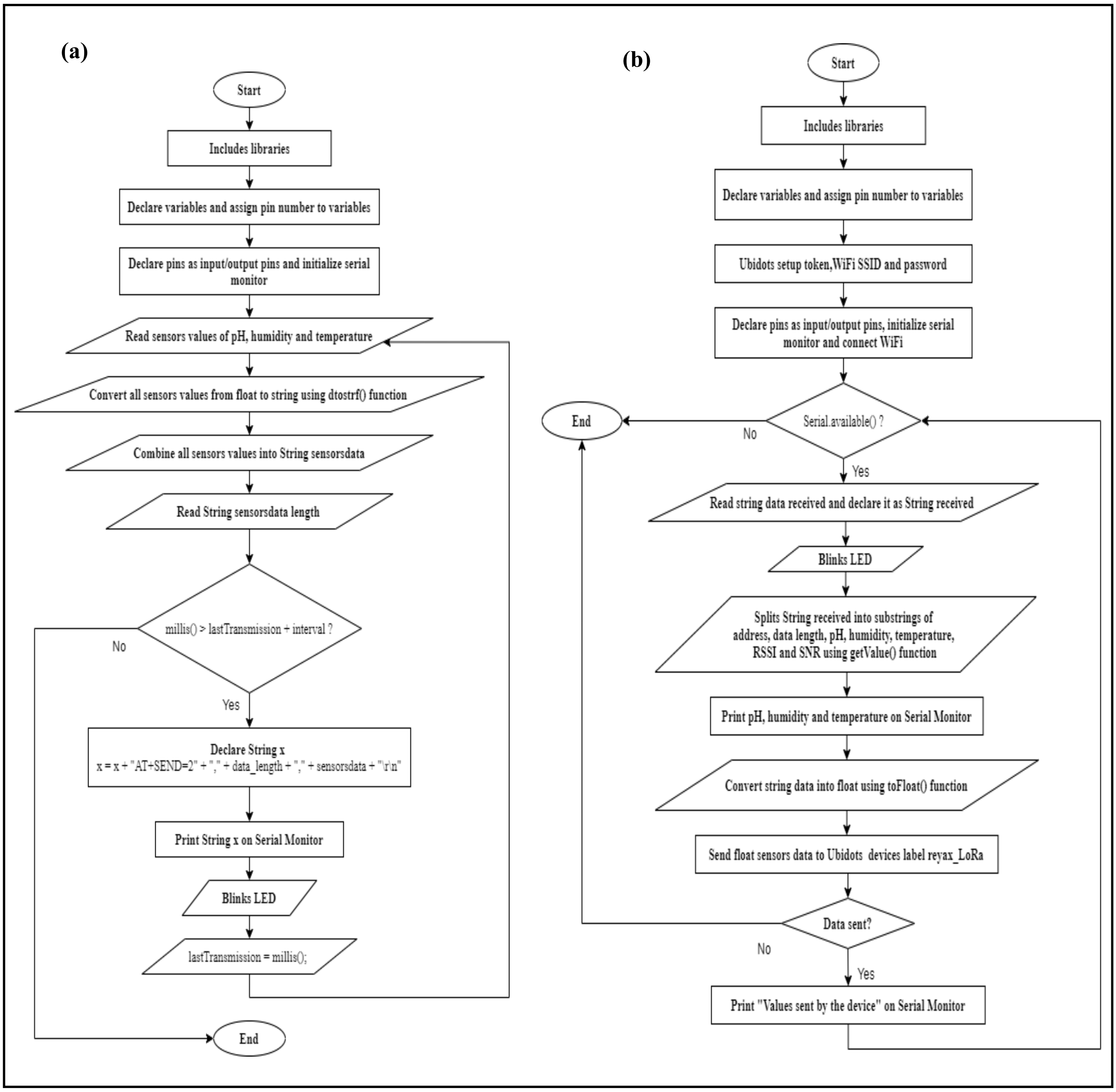

Fig. 3 - Flowchart of program code for (a) sensor node; (b) gateway node

2.4 Development of Final Functional Prototype

The final functional prototype of LoRo-Cloud-based water pollution sensor hub was setup as shown in Fig. 4(a) and 4(b) for sensor node and gateway node, respectively.

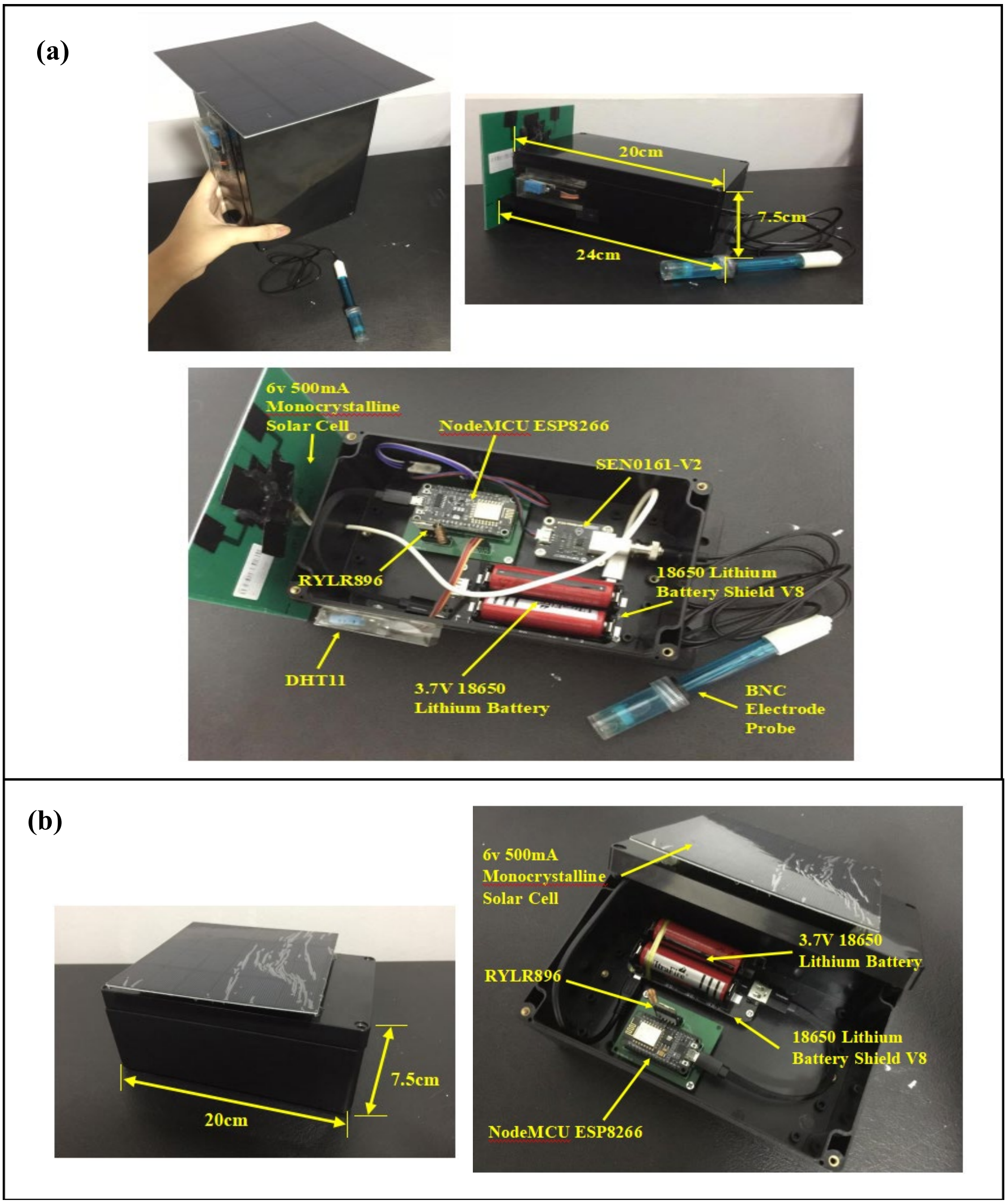

Fig. 4 - Side and top views of the prototype for (a) sensor node; (b) gateway node

3. Results and Discussion

The Lora-Cloud-based water pollution sensor hub prototype device was tested for its functionality and performance by conducting a field test at Taman Metropolitan Batu Park Lake. The prototype device was installed on 22th April 2021 to monitor the real-time lake water quality for 10 hours continuously from 8 a.m to 6 p.m. The sensor node was installed on the lake side where the movement of surface water was stable, while the gateway node was installed more than 30 meters away from the sensor node at the uphill near the car park as shown in Fig. 5. It was installed with only distance of 30 meters away due to the maximum transmission distance for the REYAX transceiver module was limited with antennas of 17.5mm length and geographical limitation. After the installation of the prototype device was completed, the real-time monitoring of the lake water was initiated. The real-time sensor data were monitored through the Ubidots IoT platform using a smartphone as shown in Fig. 6 while conducting the field test. The information shown in the Ubidots dashboards included air temperature, humidity, and pH value in metric number, pH indicator widget, line chart of air temperature and humidity, line chart of pH value, clock, and prototype location map. The sensor data were updated every 5 minutes in Ubidots.

A total of 120 sensor data sets were then exported from Ubidots and downloaded as .csv files with the desired time frame. The exported data included three parameters, namely pH value, air temperature and humidity. Fig. 7 depicts the plot of pH against time taken from the lake, while Fig. 8 displays the plot of air temperature and humidity against time taken from the lake.

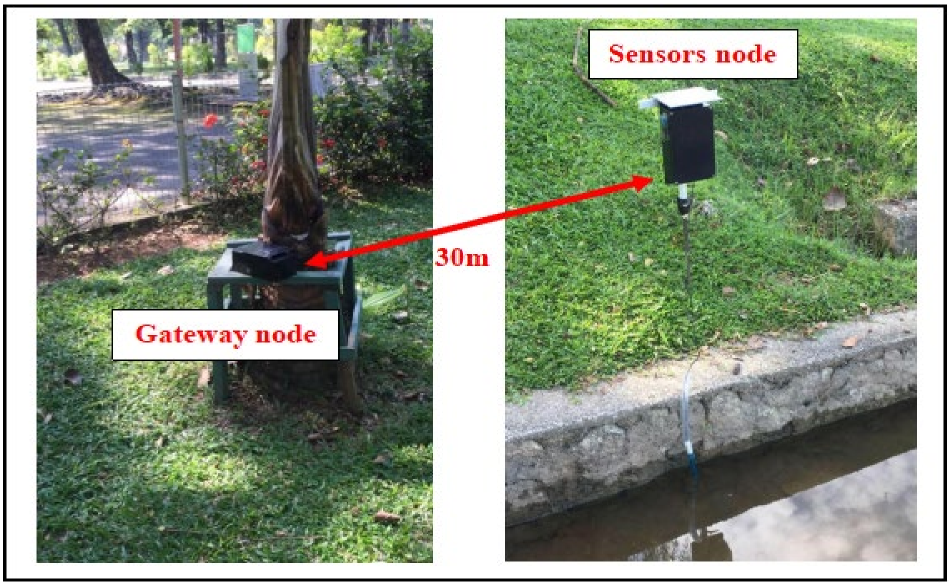

Fig. 5 - Installation of sensor node and gateway node at Taman Metropolitan Batu Park Lake

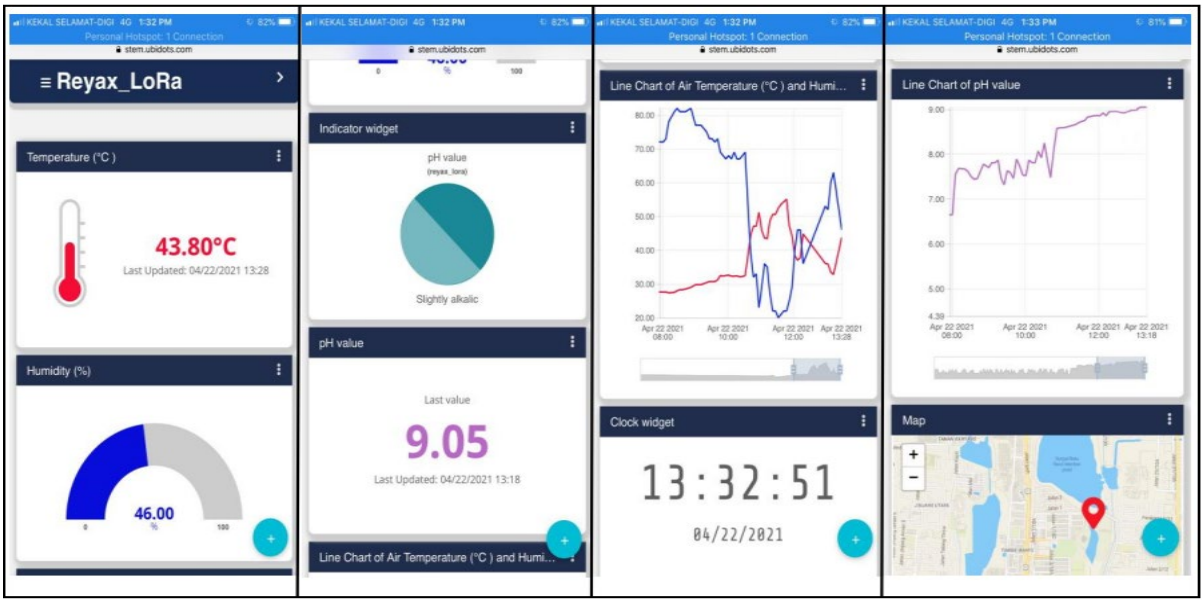

Fig. 6 - Monitoring of real-time sensors data through Ubidots using smartphone

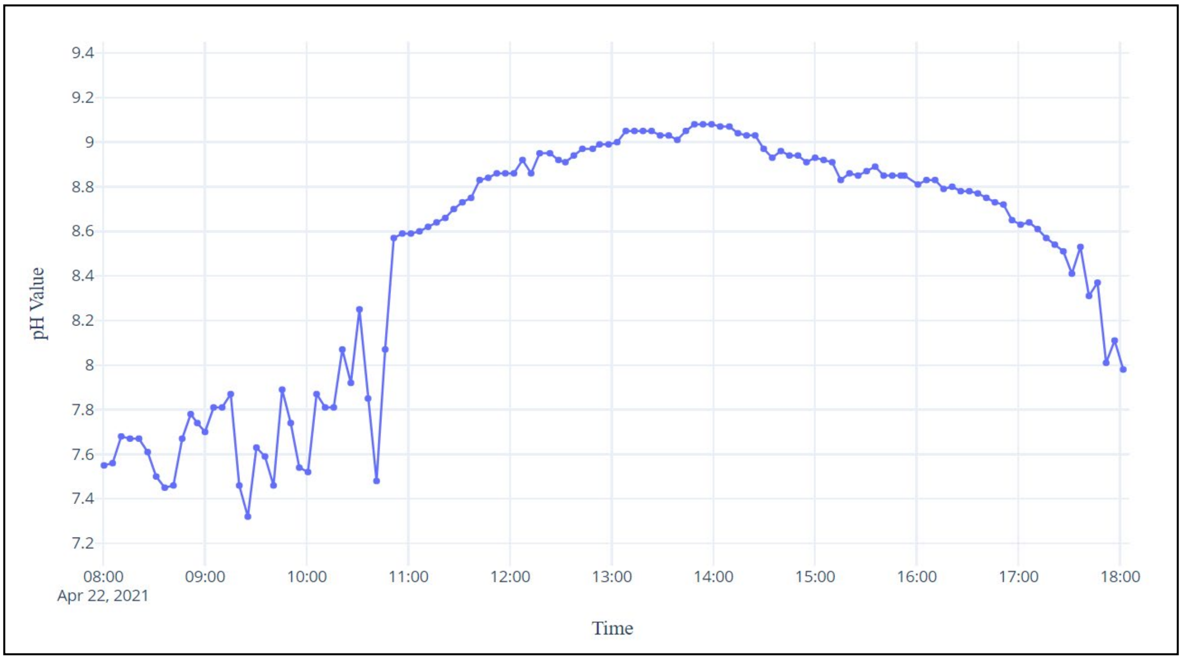

Fig. 7 - Plot of pH against time taken from the Taman Metropolitan Batu Park Lake

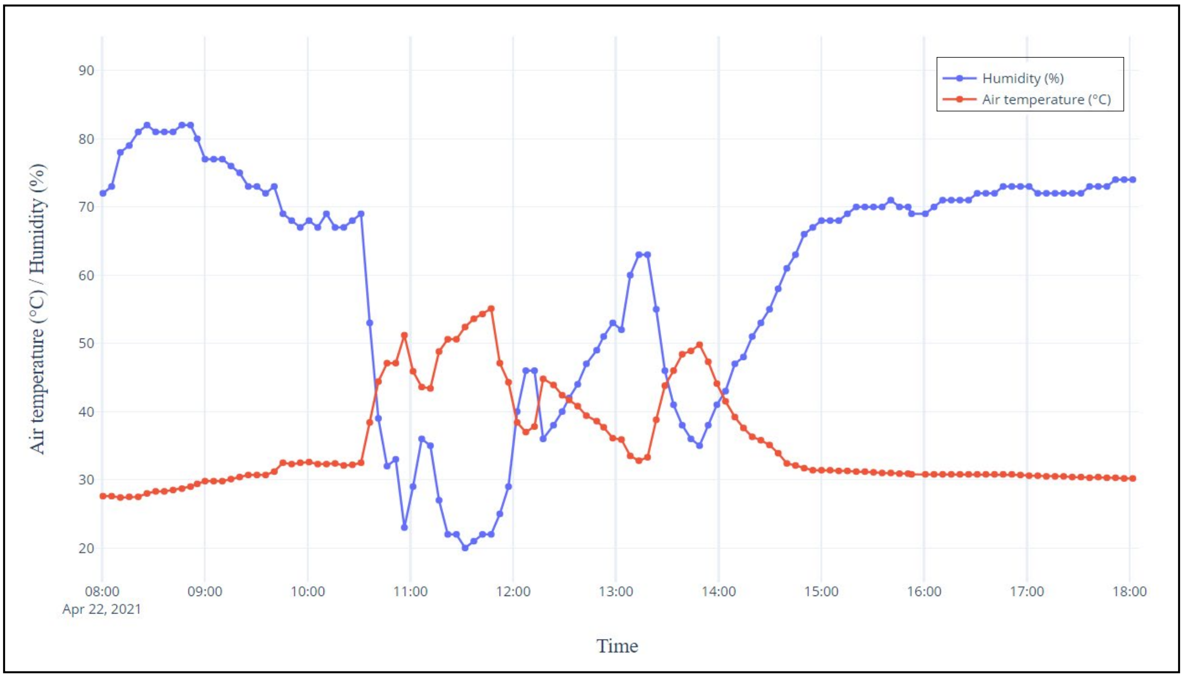

Fig. 8 - Plot of air temperature and humidity against time taken from the Taman Metropolitan Batu Park Lake

In Fig. 7, the pH level range of Taman Metropolitan Batu lake water was between 7.32 (lowest) to 9.08 (highest). The overall pH level was slightly alkaline. The pH of the lake water demonstrated an increasing trend until 2 p.m and then decreased until 6 p.m. These changes may be due to the photosynthesis of aquatic plants and respiration of aquatic animals [11]. The photosynthesis rate was higher than the respiration rate in the presence of sunlight before 2 p.m, and became the opposite after 2 p.m assuming that was lesser photosynthesis occurred as there was lesser exposure to sunlight. Nonetheless, aquatic animals exchanged respiratory gases from dissolved oxygen in the water, thereby excreting carbon dioxide. Consequently, the pH of the lake water would decrease.

In Fig. 8, the air temperature range of the lake was from 27.4°C to 55.1°C. In addition, the humidity range of the lake was from 20% to 82%. The trends obtained in the plot exhibited that the air temperature increased as the humidity decreased and vice versa. As the air temperature increases, a larger amount of water molecules or water vapor can be held by air as its capacity increases [12]. Therefore, the relative humidity decreased.

As can be seen from Figs. 7 and 8, the air temperature at the lake often influenced the pH values of the lake water. When the lake began to be exposed to sunlight at 8 a.m, the air temperature started to slowly increase from 27.6°C to 32.5°C and the pH values of the lake water also started to slowly increase from 7.55 to 8.25 until 10.31 a.m. This could be attributed to the biological aspects of the lake. When exposed to sunlight, the aquatic plants started photosynthesis process and the air temperature also started to increase. During the photosynthesis process, light energy is captured and aquatic plants use carbon dioxide to produce oxygen in the water. Basically, carbon dioxide will lower the pH of aquarium water as it is highly soluble in water and forms weak carbonic acid [13]. However, aquatic plants will remove carbon dioxide from the water in the presence of photosynthesis process, thus increasing the pH level of the water.

Since aquatic plants photosynthesize in the presence of sunlight, it can be assumed that the pH of the lake water will be highest during the peak sun hour. This was evident when the air temperature increased tremendously to 51.2°C which indicated that direct sunlight present and the pH value of lake water also increased to 8.59 at 10.56 a.m. The highest pH value of the lake water was 9.08 at 1.48 p.m. From Fig. 11, the air temperature and humidity were inconsistent as there were fluctuations occurred from 10.30 a.m to 2 p.m. This situation suggested that direct sunlight sometimes was obstructed by the clouds. After 2 p.m, the weather changed with heavy rain. The air temperature dropped gradually to 30.2°C and the humidity increased to 74% at 6.01 p.m. The pH value of the lake water also slowly dropped to 7.98 from the highest pH of 9.08. Through the LoRa-Cloud-based water pollution sensor hub, real-time water quality based on the range of pH level was successfully observed to determine whether the water was polluted or not. If the pH value is out of the pH level range observed as reference or abnormal, this indicates that the water is polluted and water treatment is required.

4. Conclusion

In this paper, we successfully designed and implemented LoRa-Cloud-based water pollution sensor hub with a real-time visualization of Ubidots IoT platform. The sensor node and gateway node of the water pollution sensor hub were developed using REYAX RYLR896 transceiver modules. The system was employed at Taman Metropolitan Batu Park Lake. Data for real-time lake water quality for parameters such as pH value, air temperature and humidity were monitored using pH sensor (SEN0161-V2), and temperature and humidity sensor (DHT11). All the data were collected and visualized in Ubidots dashboard. For future studies, we could improve the prototype by applying sleep mode to the microcontrollers to minimize the power consumption of the prototype devices. In addition, we could also improve this real-time water quality monitoring system by applying other types of sensors such as electrical conductivity (EC) and oxidation-reduction potential (ORP) sensors for the measurement of water quality parameters.

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