A Concept Paper on Smart River Monitoring System for Sustainability in River

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Abstract: River is a major source of water in Malaysia and one of the major threats to its sustainability is pollution. The existing methods for monitoring of water quality in rivers are manual monitoring and continuous monitoring. These methods are costly and less efficient. Hence, we propose a smart river monitoring system (SRMS) that uses unmanned aerial vehicles (UAVs) or drones and low power wide area (LPWA) communication technology. The Internet of Things (IoT) and data analytic are promising techniques which provide real-time monitoring and enhances efficiency. However, due to the span of river that needs to be monitored, conventional communication technology such as Wi-Fi, Zigbee, Bluetooth are not suitable. Hence, there is the need for LPWA communication technology. We discuss the application of LPWA and UAV for sustainability of rivers in Malaysia as a case study. Preliminary results show that the use of UAV will increase the efficiency of measuring the water quality parameters compared to manual monitoring method. Also, real-time monitoring enables us to study the changes in water quality. Finally, we provide future direction in the application of UAV and LPWA for sustainability in river.

Keywords: Data analytic, drones, internet of things (IoT), low power wide area (LPWA) Malaysia, river monitoring, water sensors, water quality index (WQI)

1. Introduction

Pollution is a major threat to sustainability of river in Malaysia and other parts of the world. The pollution of rivers results in high cost of water tariffs, threat to life and the ecosystem, reduction in water quality, and high cost of cleaning up the rivers. It affects the physical, chemical and biological composition of the river. River is a major source of water in Malaysia and the Department of Environment (DoE) of Malaysia classifies rivers into five different classes based on water quality index (DoE-WQI). The sources of river pollution include surface runoff, sullage and effluent discharge from industries and sewage treatment plants (Juahir, H. *et al*, 2011; Mohamed, I., *et al*. 2015).

To ensure the water quality (WQ) of river in Malaysia, several initiatives have been taken by the Malaysian government. Two methods that are commonly employed to ensure WQ are manual water quality monitoring (MWQM) and continuous water quality monitoring (CWQM). These methods are costly and less efficient in identifying the

pollutants, pollution level, and the source of the pollutants. These methods are considered conventional methods and have low resolution both in time and space. To overcome these limitations, a smart river monitoring system is proposed which combines the use of internet of things (IoT) and UAV. The use of IoT and data analytic have been recognized as an efficient way to monitor the WQ (Perumal *et al*, 2015; Pranata *et al*, 2017; Ranjbar & Abdalla *et al*, 2017) as compared to traditional methods where water samples are collected periodically for analysis purposes. However, due to the large span of area that needs to be monitored using UAV and IoT, the existing communication technology such as WiFi, Bluetooth, Zigbee and 3G are inadequate due to high power consumption and short range of communication. In addition, the use of fixed location sensors in river for collection of WQ parameters are affected by corrosion and marine substances. This reduces the accuracy of the measured data. Hence, we propose the smart river monitoring system (SRMS) that takes advantage of LPWA and UAV for remote monitoring. The proposed concept is discussed in detail in Section 3.

The rest of this paper is organized as follows. In Section 2, the process of classification of rivers using the WQI is presented. The challenges related to water pollution and existing methods for monitoring of river is discussed. Section 3 covers the proposed methods. In the proposed method, the application of UAV, LPWA, IoT, data analytic and system algorithm are discussed. In Section 4, the preliminary results are presented. Section 5 concludes the paper and future direction is presented.

2. Water Quality Monitoring

There are two common methods employed by the DoE of Malaysia to monitor the changes in river water quality. They are MWQM and CWQM. The MWQM uses manual stations located within 143 river basins throughout Malaysia while 15 automatic water quality monitoring stations have been installed for CWQM purpose (EQR-2015-Annex-1, 2015). The quality of river in Malaysia is evaluated using the DoE-WQI by considering six parameters, namely pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (AN), suspended solid (SS) and dissolved oxygen (DO). These parameters can be measured in-situ or via laboratory analysis. The water quality data is later compared with the National Water Quality Standards (NWQS) for Malaysia which can be obtained from (EQR-2015-Annex-1, 2015). The process of classification of river using the DoE-WQI is described in Fig. 1 and Table 1 shows the WQI for each class of river. The DoE-WQI formula is expressed in (1) (EQR-2015-Annex-1, 2015).

$$WQI = (0.22 \times SIDO) + (0.19 \times SICOD) + (0.15 \times SIAN) + (0.16 \times SISS) + (0.12 \times SIpH) \quad (1)$$

where $SIDO$ is the sub-index of dissolved oxygen, $SICOD$ is the sub-index of chemical oxygen demand, $SIAN$ is the sub-index of ammoniacal nitrogen, $SISS$ is the sub-index of suspended solid, and $SIpH$ is the sub-index of pH.
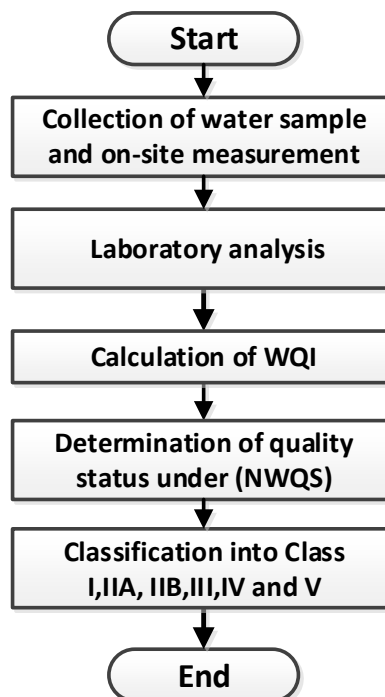

Fig. 1 - Classification of rivers in Malaysia using WQI

Table 1 - River Classification (EQR-2015-Annex-1, 2015).

Classes	Uses	Index (range)	BOD (mg/l)	COD (mg/l)	NH$_3$N (mg/l)	pH	DO (mg/l)	SS (mg/l)
I	Conservation of natural environment. Water Supply I – Practically no treatment necessary. Fishery I – Very sensitive aquatic species	> 92.7	< 1	< 10	< 0.1	> 7.0	> 7	< 25
II-A	Water Supply II – Conventional treatment required. Fishery II – Sensitive aquatic species	76.5 – 92.7	1- 3	10 - 25	0.1 - 0.3	6.0 – 7.0	5-7	25 - 50
II-B	Recreational use with body contact.	76.5 - 92.7	1 - 3	10 - 25	0.1- 0.3	6.0 -7.0	5-7	25 - 50
III	Water Supply III – Extensive treatment required. Fishery III – Common, of economic value and tolerant species; livestock drinking.	51.9 – 76.5	3 - 6	25 - 50	0.3 - 0.9	5.0 - 6.0	3-5	50 - 150
IV	Irrigation	31.0 – 51.9	6 - 12	50 -100	0.9 - 2.7	< 5.0	1 - 3	150 - 300
V	None of the above	<31.0	>12	>100	>2.7	> 5.0	<1	> 300

The emergence of IoT technology has allowed for more modern methods as proposed in (Perumal *et al*, 2015; Pranata *et al*, 2017; Ranjbar & Abdalla *et al*, 2017; Geetha & Gouthami, 2016). The use of IoT is enabling real-time monitoring and it involves use of sensor nodes, gateways, cloud server and portable equipment. The communication between the sensor nodes and cloud serve are limited by use of short-range communication technology Wi-Fi, Zigbee, Bluetooth and 3G which are power consuming and require considerable amount of cost to run. Other methods that are being used for WQ monitoring are Robotic dolphin (Liang *et al*, 2009; Liu, Yu & Yu, 2016; Wu, Liu & Yu, 2017) and UAV (Koparan et al, 2018; Zang et al, 2012). We summarize the characteristics and limitations of these existing methods in the Table 2.

Table 2 - Summary of Existing Methods.

Reference	Methods and Characteristics	Limitations
(EQR-2015-Annex-1, 2015).	MWQM - collection of water samples for laboratory analysis	Non-real-time, requires lot of man power, less efficient, high cost of sampling, delay in determining source of pollution
(EQR-2015-Annex-1, 2015).	CWQM - Fixed water monitoring stations at strategic locations	High cost of deployment, corrosion of sensor probes, not flexible for monitoring at different locations
(Perumal *et al*, 2015; Pranata *et al*, 2017; Ranjbar & Abdalla *et al*, 2017; Geetha & Gouthami, 2016).	IoT sensor devices -use of sensor nodes, gateway and cloud	Not suitable for wide area coverage and difficult to deploy on river
(Liang *et al*, 2009; Liu, Yu & Yu, 2016, 2017)	Robotic dolphin – under water monitoring	Low speed and adaptation in complex underwater environment
(Koparan et al, 2018; Zang et al, 2012)	UAV – use of drones	Short time of flight requires low power consumption.

3. Proposed Method

The proposed method is shown in Fig. 2. The proposed method incorporates the use UAV, LPWA communication technologies (LoRa and NB-IoT), IoT and data analytic. The data can be sent to the cloud server via the base station by using NB-IoT or LoRaWAN. For the NB-IoT communication, the data are sent directly to the base station while for the LoRaWAN communication, the data are first sent to the LoRaWAN gateway which then forwards to the base station. Some of the advantages of the proposed method are unmanned operation, easy deployment, real-time monitoring, and relatively low cost. The proposed method is divided into four main sections which are UAV application, LPWA application, IoT application and big data application.
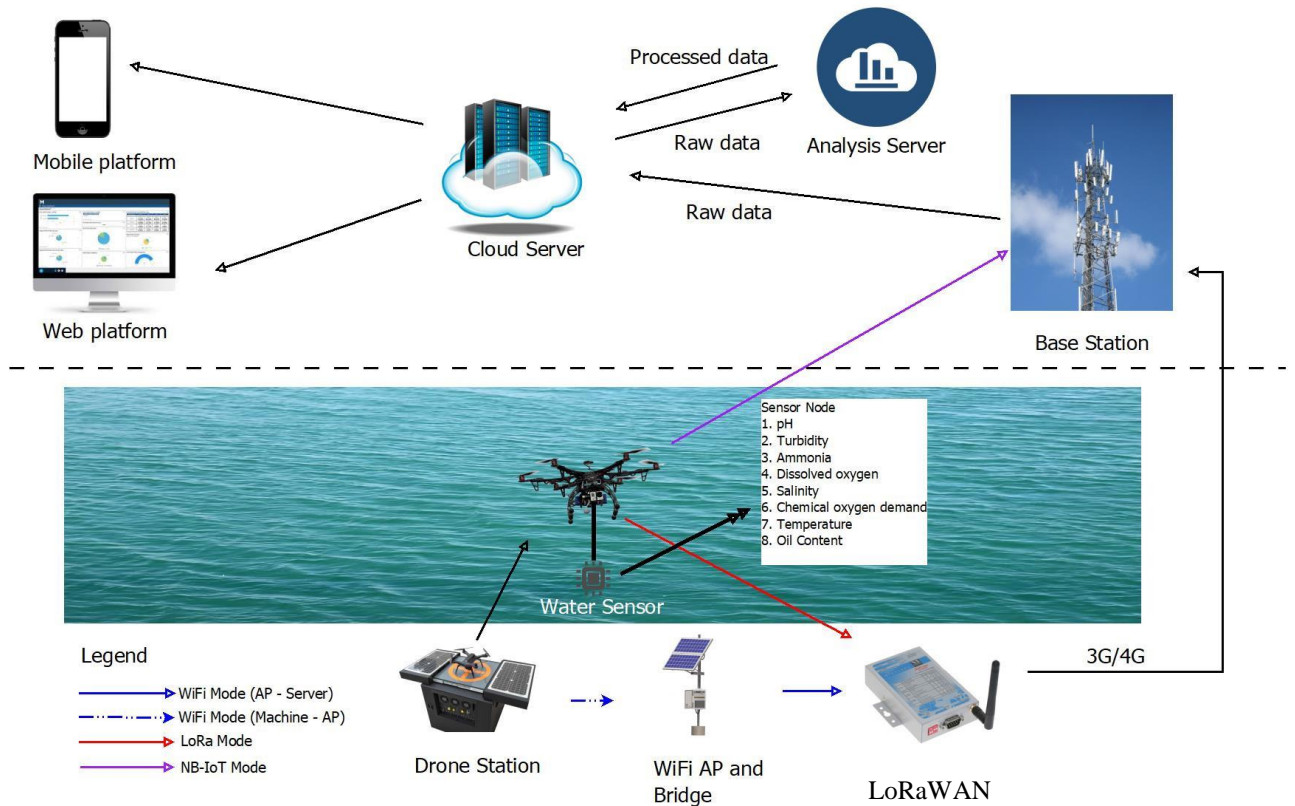

Fig. 2 - Proposed Method – Smart River Monitoring System

3.1 UAV Application

The UAVs or drones are seen as cost-effective solutions for various applications such as wireless communications (Mozaffari *et al*, 2017), disaster management (Maza et al, 2011), crowd surveillance (Motlagh , Baggaa & Taleb, 2017) agriculture (Elijah *et al*, 2018) river monitoring (Koparan *et al*, 2018; Zang *et al*, 2012). However, a major constraint in the use of UAV is flight time duration (Mozaffari *et al*, 2017) and it presents a unique design challenge. Hence, the performance of the SRMS significantly depends on the flight duration required for water sampling in the river. In the SRMS, the drone is used for collection of the WQ parameters via sensor probes that are attached to the drone and for collection of water samples from the river. The application of the UAV for river monitoring can be classified into human controlled, semi- autonomous and autonomous control. The human control requires that the user controls the flight, collection of WQ parameters and sample as well as determine the location of the river to be measured. In the semi-autonomous control, a user needs to be present to monitor the drone but the collection WQ parameters at different locations can be automated. While in the autonomous control, the drone can be deployed remotely for collection of water sample and measurement of WQ parameters. The three different modes will be explored in this work.

3.2 LPWA Application

A smart water sensor device that consist of sensor probes, microcontroller and radio frequency module will be attached to the drone. Due to the span of the rivers, LPWA communication technology will be used for real-time transmission of measured WQ data to the cloud. Some of the emerging LPWA communication standards are Narrow Band IoT (NB-IoT), LoRaWAN, enhanced MTC, Sigfox, weightless, Ingenu (Raza, Kulkarni & Sooriyabandara, 2017). The LPWA offers +20 dB gain over legacy cellular systems by using sub-1 GHz band, narrowband modulation, and

spread spectrum techniques. In addition, LPWA offers ultra-low power operations via simplified topology of node devices example star topology, application-based duty cycle foe transmission of data, and light weight medium access control. The choice of which LPWA standard to be used depends on the application. The LoRa and NB-IoT will be explored in implementation of SRMS. LoRa utilizes unlicensed band with radio frequency of 169 MHz, 433 MHz, 868 MHz and 915 MHz. According to the Malaysian Communications and Multimedia Commission (MCMC), LoRa with frequency of 433MHz/868MHz are allowed to be used as unlicensed band in Malaysia under class assignment of RFID category (17th schedule) (MCMC, 2017). On the other hand, NB-IoT uses licensed band provided by the local mobile operator. By using NB-IoT, the communication range is about few kilometers to 20 kilometers and the battery lifetime can go up to 12.8 years (5-Wh battery and 200 bytes sent once per day) (Chen *et al*, 2017). There are 3 types of deployment mode for NB-IoT which are In-band (within the LTE band), Guard-band (band that separates two LTE band with different operating band) and stand-alone band (new band) [20]. In this project, LoRa and NB-IoT are adopted as the communication technology for the smart river monitoring system due to support for long communication range over vast sampling area on the river.

3.3 Internet of Things

The IoT integrates several technologies that already exist, such as wireless sensor networks (WSN), radio frequency identification, cloud computing, middle-ware systems and end-user applications (Manrique *et al*, 2016). The IoT devices consist of embedded systems which interacts with sensors and actuators and requires wireless connectivity as shown in Fig. 3. For successful deployment of the smart IoT water sensor device, the following characteristics are considered: 1) power efficiency, 2) memory, 3) computational efficiency, 4) portability, 5) durability, 6) coverage 7) reliability and 8) cost. To achieve the connectivity of smart water sensor device over the internet, IoT middleware and connectivity protocols are required. There are several existing IoT cloud platforms that provides IoT middleware and connectivity. These platforms enable large storage of data and processing. Examples of such platform are Favorite, Thingspeak, Amazon web services (IoT), Microsoft azure IoT, Carriots among many others.
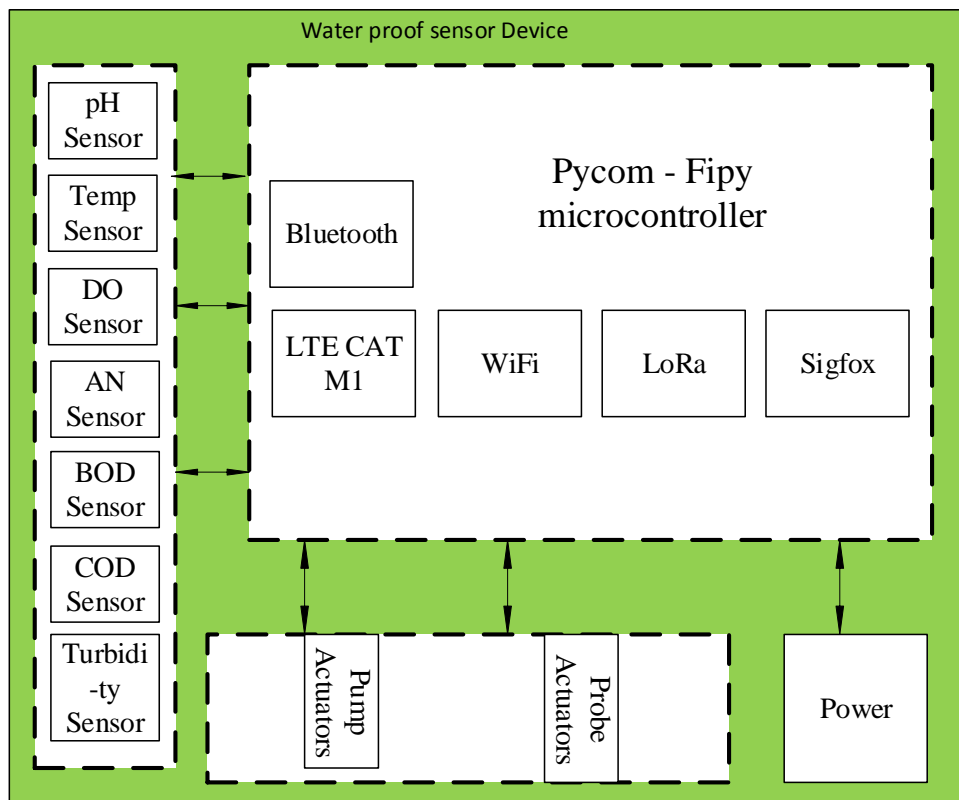

Fig. 3 – Block Diagram of the Smart Sensor IoT Device

3.4 Data Analytic

Data collection plays an important role in assessing the water quality in rivers (Fulazzaky *et al*, 2010; Prasanna *et al*, 2012; Rahmanian *et al*, 2015; Praveena & Aris, 2013; Ali & Qamar, 2013 Zaey, Babunski & Tuneski, 2016; Mamun & Salleh, 2014). The data collected from the study helps to know WQ status and the suitability for different uses. In addition to identifying critical parameters affecting the quality of water in the river, it also helps to verify if the sources and the level of pollution discharged into the river are reasonable. Timely information of such data helps regulatory body

and local authorities to take urgent steps towards managing the river water quality by correctly envisaging priority measures needed. In this project, the data analytic will be used to provide real time notification of state of the river and analyze the pollution pattern over a period. The data analytic will also help in determining the optimal number of times, and methods to monitor the water quality based on location and size of river.

3.5 SRMS Flowchart

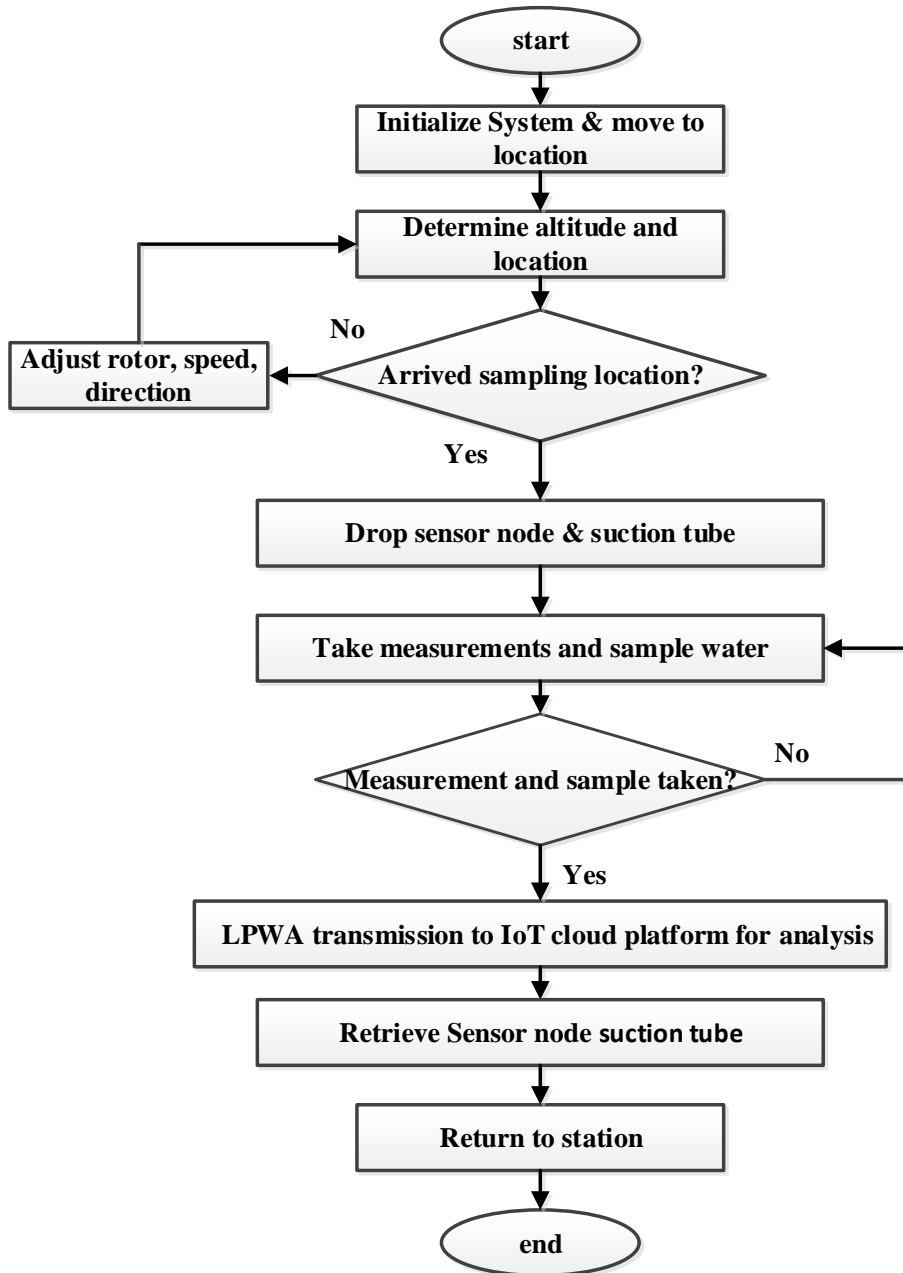The algorithm for the proposed smart river monitoring solution is shown in Fig. 4.

Fig. 4 - Flowchart for Proposed Smart River Monitoring Solution

The Flowchart illustrates the basic principle for collection of WQ samples and sample water using the UAV.

3.6 Setup

The setup for the proposed method is described in this section. It includes the UAV, smart water IoT device, and IoT platform. The IoT device consists of micro-controller board (pycom-fipy board - supports Wi-Fi, sigfox, LoRa, NB-IoT and Cat-M1), temperature sensor (DS18B20), analog pH probe (SKU: SEN0161). The IoT platform used is Thingspeak (Thingspeak). The sensors were calibrated at the Centre for Environmental Sustainability and Water Security (IPASA), UTM (IPASA). Mobile app was developed to monitor the WQ parameters and also to track the movement of the drone.

4. Results and Discussion

The preliminary results of this work are presented in this section. First, we explore the use of UAV in sampling the river in UTM by considering the efficiency in time and the variations in some of the water parameters monitored real time.

4.1 Sampling Time

An experiment was carried out to sample the water parameters at four different locations along the Universiti Teknologi Malaysia Skudai river as shown in Fig. 5. Two approaches were compared which are: manual water sampling which involved measurement of the pH and temperature of the river using the smart sensor device and the use of drone. The time taken, and challenges were compared. An average of ten minutes was used in taking water samples manually using the IoT device at four different sampling locations. The time included time taken to get ready the IoT device, locate a place in the river, insert the IoT device sensors into the water to collect readings manually. Hence, ten minutes was allocated in getting samples from a single location using the drone. The time included time to start the drone, control the drone to different locations on the river for water sampling. Using the drone, five different locations were sampled within the ten minutes period. The outcome of the experiment shows that within the ten minutes of using the drone, data were collected from five different locations where as in the manual sampling data was only collected in a single location in the same river. This shows that the use of drones can offer higher efficiency in terms of time and accessibility to different location in the river. However, the challenges faced with the drone was limitation of flight duration and control of drone. While the challenges faced with manual sampling was difficulty in measurement of WQ parameters due to slippery conditions and attacks by insects.

4.2 Real-time Monitoring

The preliminary result of real-time monitoring of the pH and temperature of the UTM Skudai lake is shown in Fig. 6. This was carried out using the developed IoT device to ascertain the performance of the IoT device and sensor readings. In addition, to study the variations in WQ parameters at fixed location. It can be observed that the pH values are lower in the morning when compared to the evening. Also, temperature values in the morning are lower compared to the evening. Further studies will be carried out to monitor readings and variance over longer period. Other parameters such as the turbidity, BOD, COD, AN, SS and DO will be monitored as part of the on-going work. From the results, real-time data provides the opportunity to study changes in the WQ of rivers and several findings can be deduced.
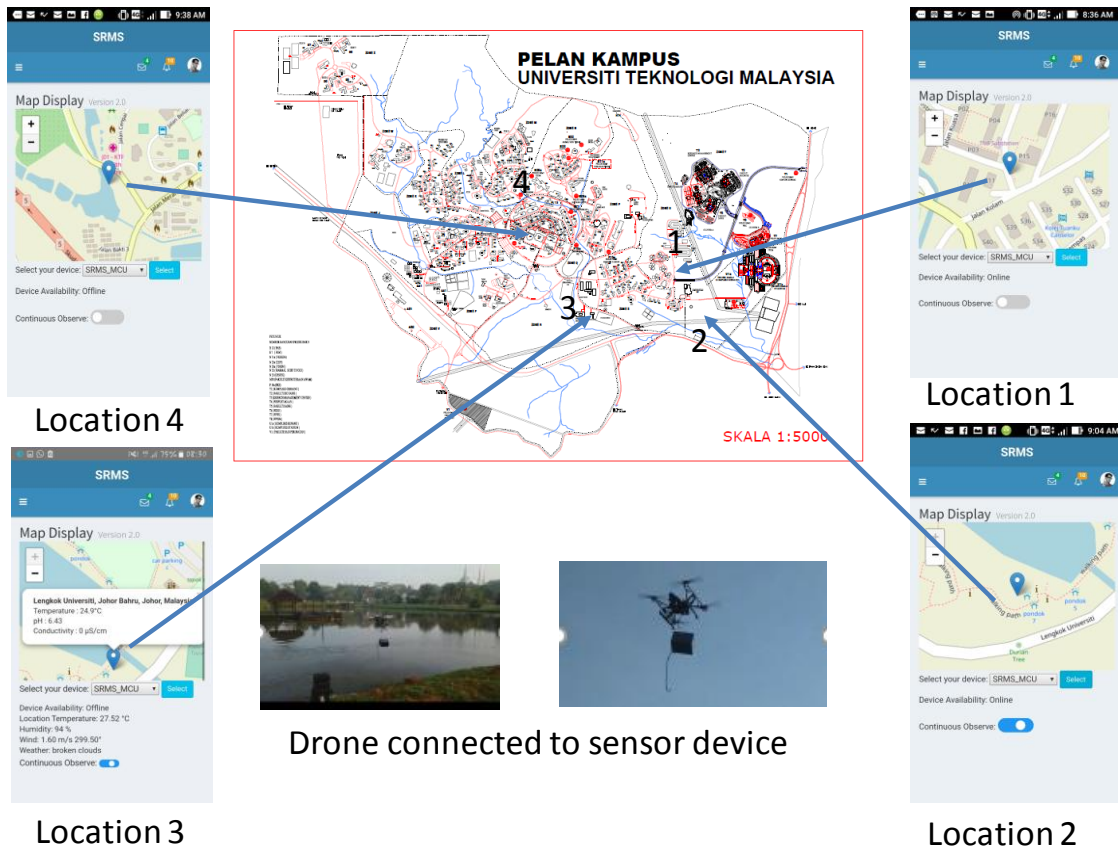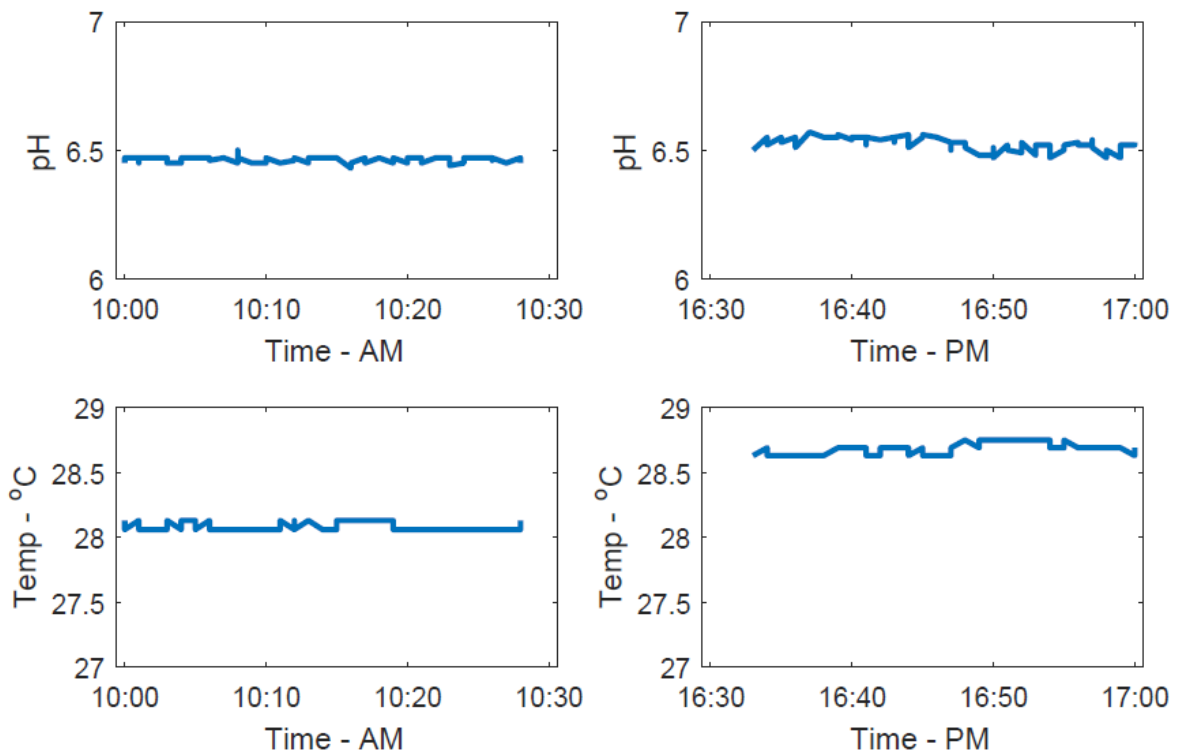
Fig. 5 – UTM Lake and UAV water sampling

Fig. 6 – Temperature and pH values for UTM Skudai lake observed in the morning and evening

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5. Conclusion and Future Direction

In this paper, a smart river monitoring solution for water quality of Malaysian rivers is proposed. The proposed method incorporates the use UAV, IoT, LPWA and data analytic to provide more efficient and real time monitoring solutions. This is expected to solve the problems associated with conventional method such as cost, low resolution both in time and space, the challenges of pollution identification and the lack of real time monitoring. The setup and preliminary results are presented. The preliminary results show increased efficiency in time taken when drone is used compared to when manual sampling of water parameters is carried out. Future work will consider the following: 1) coverage distance of LPWA, 2) manned control and autonomous control of the UAV, 3) power consumption analysis of the smart water sensor device, 4) sampling methods, 5) real-time reporting of in situ measurement, 6) collection of water sample using the UAV, 7) data analysis of collected data and finally 8) remote access to data using web-based app and mobile app.

Future research direction in the use of UAV and LPWA communication technology will focus on optimization of UAV for sampling of WQ in rivers based on flight constraints, power consumption and load and size of the river. The load plays an important part, hence, miniature smart multi-parameter sensors for WQ will attract more research interests (zhou *et al*, 2017).

Acknowledgement

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