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Development of A Real-time IoT Data Logger for API Index Monitoring

Nur Azizah Sabarudin[1], Amirul Syafiq Sadun[1]*, Nor Anija Jalaludin[1], Mohd Arif Rosli[2], Chong Kar Kar[2]

[1]Department of Electrical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

[2]Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: PM2.5 is one of the criteria of the Air Pollution Index (API) which is used in Malaysia to measure ambient air quality. It is critical to keep an eye on PM2.5 levels for air quality monitoring, especially in densely populated area with continuous construction and development. However, the PM2.5 samplers used in research and monitoring such as E-Sampler-9800 from MetOne are usually in manual mode, where data is stored into the equipment data logger and manually extracted from the data logger to a personal computer through cable. This makes it challenging for the person in charge of monitoring and reporting real-time air pollutant data when the access to the E-Sampler site is limited, such as in the event of pandemic, haze, and toxic pollution. However, the issue can be solved with utilization of Internet of Things (IoT) and its components into the monitoring system. This project therefore proposes the construction of IoT Data logger system capable of uploading real-time data from the E-Sampler to cloud and utilise Blynk IoT platform that connect to the same cloud to enable the wireless data extraction from the deployed measurement tool as well displaying the data in graphical form for monitoring purpose through mobile phone. This project resulted in having successfully produced a prototype of IoT data logger system for E-Sampler that uses IoT device to upload eight parameters' data from E-Sampler data logger to Blynk cloud server as well as having made a data monitoring and data extraction system that uses Blynk application to fetch data from Blynk cloud server to be displayed in graphs for monitoring on mobile phone and to be extracted to CSV files via export function in Blynk application user interface for wireless data extraction.

Keywords: Internet of Things, IoT, IoT Data Logger System, Real-Time Data Monitoring, Blynk pPatform, IoT Device

Corresponding author: amirul@uthm.edu.my

1. Introduction

The presence of globalized development has contributed to the rise of air pollution in all over the world. In order to satisfy human needs, aggressive economic activities and excessive exploitation are shifting the environment towards degradation. Pagoh, one of the towns in Muar District is no exception to this issue. Due to the construction of Higher Education Hub in Bandar Universiti Pagoh, Pagoh has since been rapidly growing towards becoming one of the most commercialized towns in Muar. Since then, many factories, office buildings, residential buildings and infrastructures are being constructed around the town to develop the area for urbanization and industrialization. These rapid development activities have affected the wellbeing of human and environment in Pagoh. Pollutants continuously escape from the construction sites and factories area where they spread over to UTHM Pagoh campus and its surrounding area. This constantly degrades ambient air quality, causing health damages such as irritation to the eye, nose, throat and lung, coughing and shortness of breath in the community within UTHM Pagoh compound.

According to Wolf et al, air pollution induced 6.4 million deaths worldwide in 2015 [1]. In comparison, tobacco induced 7 million deaths in the same year, 1.2 million for HIV, 1.1 million for tuberculosis, and 0.7 million for malaria [2]. By 2060, air pollutants in the environment are expected to cause between 6 and 9 million fatalities per year due to a lack of efficient air pollution control [3]. In reference to the World Health Organization, ischemic heart failure and strokes accounted for about 58 percent of early deaths related to air pollution in 2016, while chronic obstructive pulmonary disease and acute lower respiratory infections accounted for 18 percent of fatalities, and lung cancer accounted for the remaining 6 percent [4]. In addition, Grandjean and Landrigan [5] found that ambient air pollution is a significant risk factor for neurodevelopmental issues in children and neurodegenerative diseases in adults [6]. In short, air pollution is a major threat to human health and the environment, and it is fair to say that it is soon becoming one of the most lethal killers of this century.

For that reason, air quality must be monitored and kept under control for a better prospect of the health for UTHM Pagoh community. Monitoring gives overview of the concentration level of at least one if not all main pollutants namely two particulate matters (PM_{10} and PM2.5), ozone (O_3), carbon monoxide (CO), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) which can then be analyzed and interpreted to determine the air pollution level. This data then can be relayed and presented to relevant parties for further action. Air quality monitoring tool such as E-Sampler from MetOne can be deployed to do such measurement where it uses nephelometer to measure airborne particulate matter (PM), sensors to measure parameters like humidity and temperature, and data logger to record that information for the length of the monitoring span. This type of tool is usually deployed at a location and often left unattended to measure and record information needed, and the data inside the tool data logger will be retrieved manually by operator at intervals by connecting the tool to a computer that has tool software installed. Figure 1 shows the conventional method.

Figure 1: Conventional method

From several papers published in recent years that developed system for data extraction from field instrument data logger, only a handful are using IoT technologies to wirelessly collect data such as in [7] where they claimed to use microcontroller NodeMCU and Blynk cloud to wirelessly obtain data from data logger. However, they did not actually extract data from data logger and only acquire the data from the DHT11 temperature sensor which is not a field instrument with data logger. In papers such as [8],[9] and [10], they used an approach where they made their own IoT data logger but both papers are just similar to [7] in which they did not actually extract data from data logger and only acquire the data directly from the sensors. [8] constructed "ALog data logging hardware and software" that utilised Arduino platform and comprehensive programming library for data logging system while [9] constructed "field datalogger-modem stations", an Arduino-based datalogger with cellular modem and FTP communication that comprised of Adafruits data-logging shield and Adafruit cellular modem shield, and [10] developed "OPEnS Hub" which retrieve data from field sensors and log the data into Google Sheet.

There is hardly any published paper discussing data retrieval from data logger of field instrument, but authors managed to find [11], where this paper used sensors connected to Campbell Scientific CR1000 datalogger as their field instrument and used CRBasic editor programming to extract the data from the data logger automatically. This is different from the previous papers as this project actually extracted data from data logger and not directly from sensor. However, it seems like the method in this paper will only work if the data logger used is Campbell Scientific brand as CRBasic editor is only compatible for Campbell Scientific dataloggers and would not work with other brands of data logger. In short, unarguably, these papers are all valid solutions for automating the data extraction process however none of these can extract data from data logger of field instruments such as E-Sampler. This issue afflicts UTHM Pagoh campus, of which this institution has encountered the challenge where there is a lack of appropriate and advance instrument and tool to monitor the real-time ambient air quality whereby the existing API monitoring tool at UTHM Pagoh still uses the conventional methods for data collection of which the operators need to collect data periodically by connecting the E-Sampler tool to a computer. This leaves room for errors and complicates the data collection process especially when the access to the E-Sampler site is limited during event of pandemic, haze season or toxic pollutions. To solve this issue, the tool can be improved with utilization of IoT and its components.

Therefore, this brings to the main objectives of this project which are to develop a new prototype of IoT Data Logger which acquire data from API measurement device (E-Sampler from MetOne) and upload it to cloud, then to propose a real time application for mobile phones that download E-Sampler data from cloud and act as IoT monitoring medium for API data and lastly to provide a graphical presentation of particulate matter concentration, sample flow rate, ambient temperature, ambient barometric pressure, external ambient relative humidity, internal filter sample relative humidity, wind speed and wind direction data in the real time mobile application. However, the project scope and limitation need to be address as well. The scopes of this project are that the study is conducted in UTHM Pagoh area, and this project uses the existing E-Sampler-9800 tool from MetOne at Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia as the field instrument. Next, the API monitored in this project is limited to PM2.5 and not focusing on other five indexes. Lastly, this project is only concerned with the technical aspect of obtaining data from E-Sampler through IoT means as well as the monitoring of said data, and neither concerned with the exact value of data obtained nor API calculation aspect.

2. Methodology

To develop the IoT data logger, the IoT device is first constructed and then it is connected to E-Sampler data logger so that the real-time data from the E-Sampler can be uploaded to cloud server. To enable real-time monitoring on mobile phone, an application is created on Blynk mobile application so that the data of E-Sampler uploaded on cloud can be viewed as history graph in real time on phone and can also be exported from cloud to email address in form of CSV file with export button in Blynk. In order to achieve the objectives of this project, all the steps in developing and implementing the system must be planned well and executed correctly.

2.1 Components and system design

E-Sampler dual ambient tool is the center of data collection. The data obtained from the sensors of E-Sampler will be forwarded to the IoT device and uploaded to the cloud host i.e. Blynk server host. The data then will be collected and stored at Blynk cloud server. After that, the user can access the data via the Blynk mobile application. The flow of the data in IoT data logger system is shown in Figure 2, and the full system's architecture diagram is as shown in Figure 3.

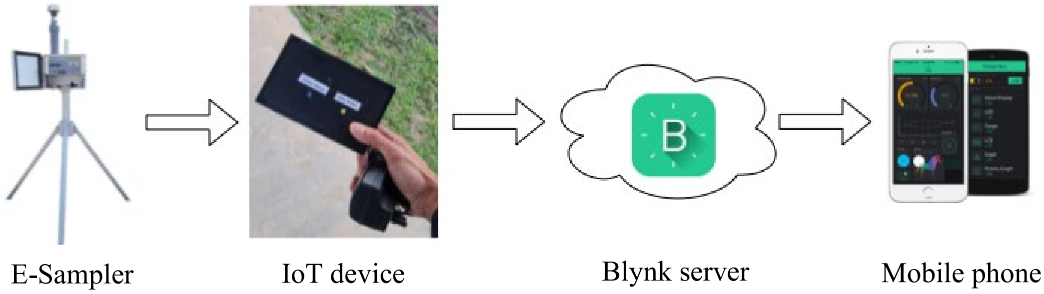

Figure 2: Flow of data in IoT data logger system

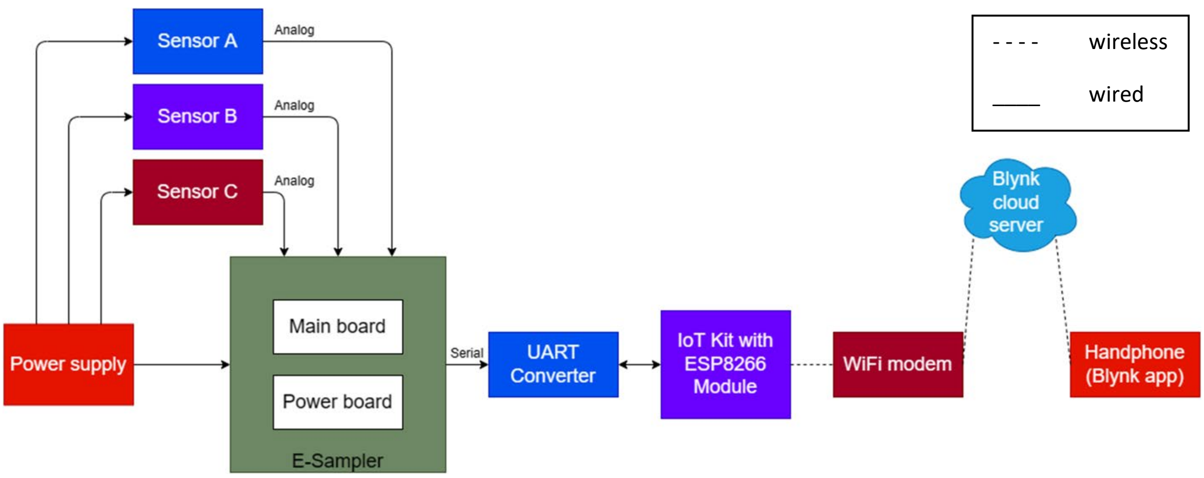

Figure 3: System architecture

2.2 Working principle

The IoT device mainly consists of IoT Kit, Arduino Mega 2560 microcontroller, ESP8266 Wi-Fi Serial Transceiver Module and UART to RS232 Converter. In this project, this device helps the hardware to access internet and transmit data from E-Sampler to cloud database which is Blynk server. Once the data is hosted in Blynk server, it can be accessed by mobile phone installed with Blynk application for monitoring and data retrieval. Figure 4 shows the overall IoT monitoring system including IoT device connection to E-Sampler. The idea of integrating IoT device to monitoring system is to provide the simplest and easiest way for student, lecturers or staffs to collect data from the E-Sampler. Once integrated to E-Sampler data logger, anyone can access the data that are recorded by the E-Sampler tool and its sensors through a mobile application (Blynk). The IoT device interacts with Blynk server to upload the data, and the Blynk cloud server will store and host the data. Blynk mobile application then interacts with the Blynk cloud to get the data and display the data through widget available in it such as history graph. The data can also be saved for further analysis by exporting it in CSV format and emailing it to user's email address with export function in Blynk mobile application.

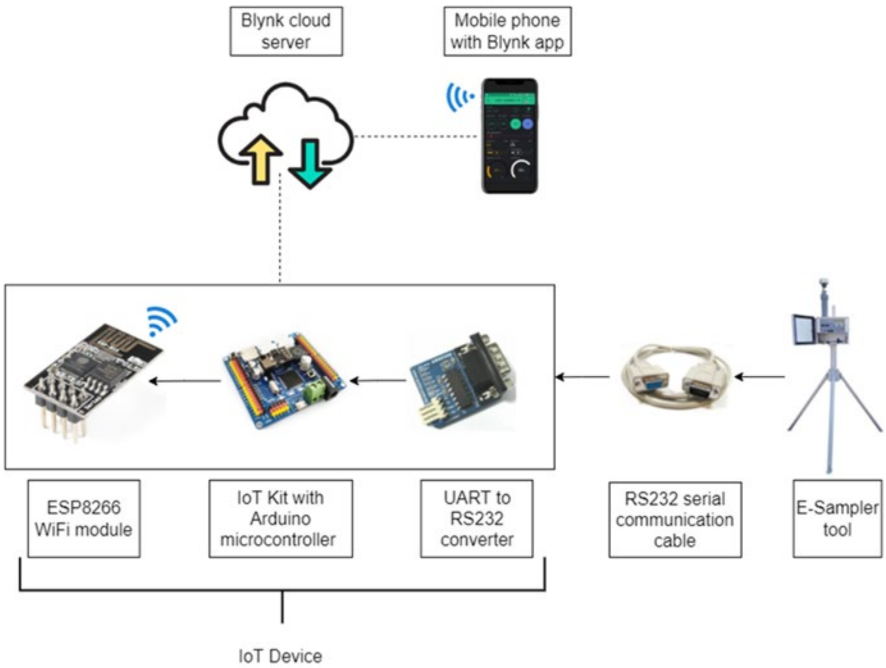

Figure 4: IoT monitoring system

2.3 Operational programming flowchart

Figure 5 shows the operational programming flowchart for this project. The system starts when IoT device is connected to the E-Sampler and is switched on. Once switched on and connected to internet, the IoT device will check if there is any sensors data in E-Sampler data logger. Once data is logged in into the E-Sampler data logger, IoT device will read from the data logger and then decode it. After decoding, the device will send the data to Blynk cloud server, where the Blynk server will host the data and act as cloud data storage. On the other side, the Blynk mobile application will fetch data from the Blynk cloud server and then plot the data into history graphs. Then the system loop. When the export function in Blynk mobile application is initiated by the user, Blynk will convert the data from Blynk cloud into CSV files and send them all to user's email address. The system will continuously run until E-Sampler and IoT device are turned off.

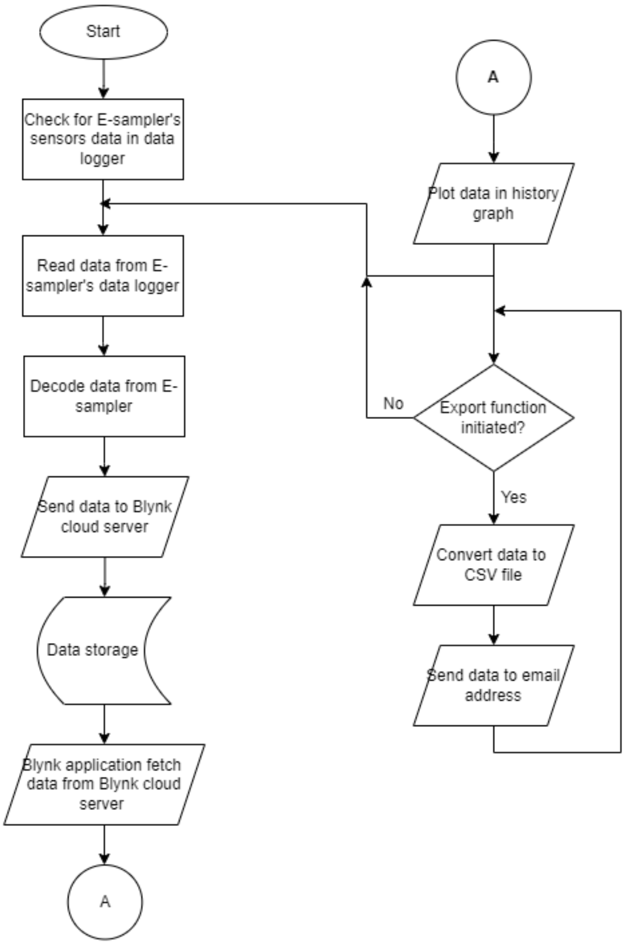

Figure 5: Operational programming flowchart

2.4 Type of data

In this project, the IoT data logger upload the data from E-Sampler to the cloud to be accessed by user through Blynk mobile application. Those data include one main data of air pollutant measured by E-Sampler namely concentration of Particulate Matter sized 2.5 micron (PM2.5), and data of seven accompanying parameters that have influence upon the measurement of particulate such as sample flow rate, ambient temperature, ambient barometric pressure, external ambient relative humidity, internal filter sample relative humidity, wind speed and wind direction data in the real time mobile application. The summary of the types of data are as in Table 1.

Table 1: Types of data

Data	Parameters	Parameter description
1	CONC	Real-time concentration of PM2.5 Unit: microgram per cubic meter ($\mu g/m^3$) Colour in graph: green
	FLOW	Real-time sample flow rate Unit: liters per minute (l/m) Colour in graph: purple
	AT	Ambient temperature Unit: degree celsius (°C) Colour in graph: blue
	BP	Ambient barometric pressure Unit: pascals (pa) Colour in graph: orange

2	RHx	External ambient relative humidity Unit: percentage (%) Colour in graph: maroon
	RHi	Internal filter sample relative humidity Unit: percentage (%) Colour in graph: black
	WS	Wind speed Unit: meters per second (m/s) Colour in graph: green
	WD	Wind direction Unit: degree (°) Colour in graph: purple

2.5 Functionality

There are several functions that this project must achieve, so as to make the data extraction of IoT data logger method as reliable as the manual method of data extraction from data logger and to improve the monitoring process. The first functionality achievement of IoT data logger should be that the 8 data from E-Sampler can be uploaded to the cloud and accessible to user via Blynk application that displays those data in form of history chart. The second functionality achievement is that those data can be wirelessly extracted and exported via Blynk mobile application instead of manual extraction through cable wire to personal computer. The last functionality achievement should be that the IoT method enable real-time monitoring of the parameters data from E-Sampler by displaying the data in graphical presentation i.e. in form of history chart on Blynk mobile application, without having to manually extract the data first using Comet software for the monitoring to be done.

2.6 Tests

The tests need to be conducted to prove that IoT data logger and its components are functioning and running smoothly where it is able to upload the data to cloud and able to view and export the data by mobile phone application. In this project, there are 3 tests done which is indoor test, corridor test and outdoor test. The indoor test is conducted to ensure all components in the system are functional and can interoperate with each other without issue. This test is also done to determine if IoT data logger is able to transmit the data to the cloud database, before the system can be tested at outdoor location. The test is performed inside the lab to test the functionality of all the components that are involved in the implementation of IoT method without the natural elements. The indoor test is conducted during troubleshooting phase and considered successful once all the functions mentioned in 2.6 are achieved, and the system works as intended. The corridor test comes after indoor test is completed. It is performed outside the lab to test if IoT method could survive in the outside setting and achieve the same result as in indoor test. The E-Sampler and IoT device are placed at the corridor just outside the lab to expose them indirectly to the natural element such as rain splatter, morning dew, heat, wind and humidity. This test is done to observe if the indirect exposure to the elements would affect the ability of the IoT components to function properly. The test would be considered successful if the IoT device is still online, the data is still transferred from E-Sampler to Blynk cloud, and the value of data extracted via IoT method is similar to the value of data extracted by manual method despite being partially exposed to the elements. The outdoor test is conducted after corridor test. It is performed to test if IoT method could survive the natural elements just like in corridor test except in harsher surrounding. The E-Sampler and IoT device are placed in an outdoor setting located near the road to expose them directly to the natural element such as rain, morning dew, sun, ambient wind and ambient humidity as well as air pollutants such as exhaust emission and dust from construction site. This test is done to observe if the direct exposure to the elements would affect the ability of the IoT method such as connectivity to cloud and data latency. The test would be considered successful if the IoT device is still online, the data is still transferred from E-Sampler to Blynk cloud through IoT device, and the value of data extracted by IoT method is like the value of data extracted by manual method despite being fully exposed to the elements.

2.7 Description of graph analysis

The analysis needs to be conducted to prove that data from IoT data logger is usable to monitor PM2.5 and other E-Sampler parameters. The analysis is done onto the 8 plotted graphs of which each contains different data exported from Blynk application. The graph provides data value, data pattern and data trend of API. It can also verify the reliability of the IoT method. From the graph, we can determine the pattern similarity of data between the two methods: IoT method vs manual method. If the pattern is similar, then we can assume that the IoT method is reliable as the values of data extracted from E-Sampler by IoT method do not have disparity or only have minimal difference when compared to data from manual extraction method. People can also monitor the trend of the API (PM2.5) in the studied area by looking at the graph, where they could use their educated judgement to interpret whether the trend of air pollutant is rising, receding, or not changing. In short, the analysis will be able to give insight on air pollutant data, data pattern and data trend as well as prove the reliability of the IoT data extraction method as compared to manual data extraction method.

3. Results and Discussion

The tests had been conducted to ensure all components in the IoT monitoring framework are functional and can interoperate with each other without issue. These tests were also done to determine if IoT data logger is able to transmit the data to the cloud server. These tests succeeded in achieving functionalities as mentioned in 2.6. The tests results are in subsections below.

3.1 IoT device functionality

Figures 6 and 7 show the hardware prototype of IoT data logger. The two LEDs on the IoT device are turned on and blinking, indicating that IoT device is in online state (blue LED) and is able to upload the data (orange LED) from E-Sampler to cloud as shown in Figure 8. This confirms that the IoT device is functional. When combined E-Sampler data logger and IoT device are combined and working together, the IoT data logger is constructed, therefore achieving one of this project objectives.

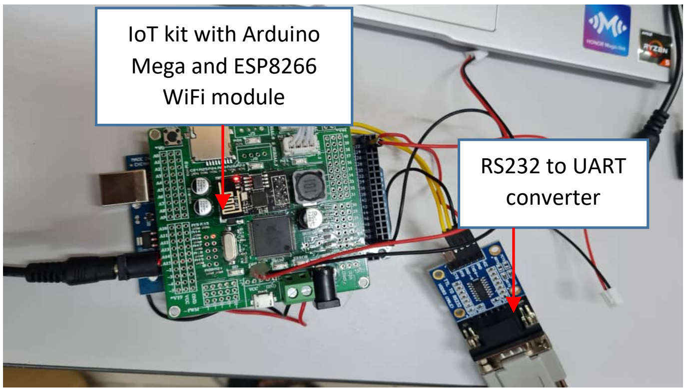

Figure 6: The components inside the IoT device

Figure 7: The IoT device prototype

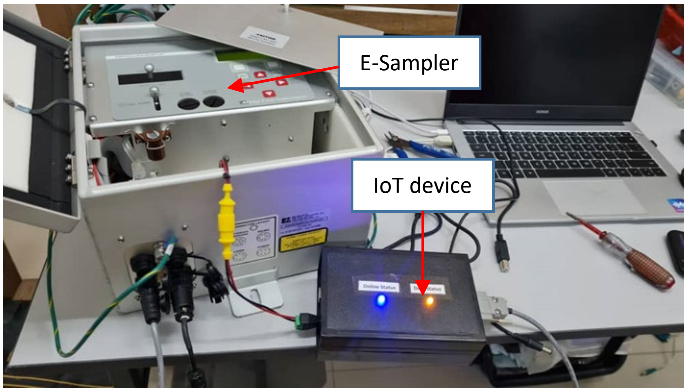

Figure 8: Blinking LEDs confirm the online status and data status of IoT device

3.2 Displaying E-Sampler Data on Blynk Mobile Application

Figures 9 and 10 show the graphs of the data on Blynk mobile application that were extracted from E-Sampler by IoT method. The graphical presentation used is history chart which is available as Blynk widget. They show that the IoT device is successful in sending data from E-Sampler to Blynk cloud, which then enable the data to be displayed as graph on Blynk mobile app since it is connected to Blynk cloud. With these graphs, the value of parameters can be monitored. Figure 11 shows the black line that indicate the parameter values on specific time when drag across the graph timeline. The details of parameters in the graphs are described in Table 2 mentioned in 2.5 subsection. As mentioned before, this project is only concerned with the technical aspect of obtaining data from E-Sampler through IoT means as well as the monitoring of said data, and not concerned with the value of data parameters obtained. Thus, the values in these graphs are not relevant to be discussed.

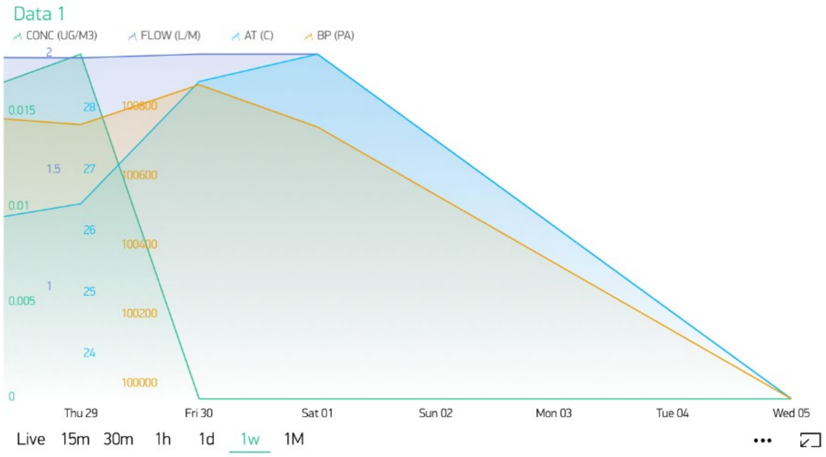

Figure 9: First graph of data

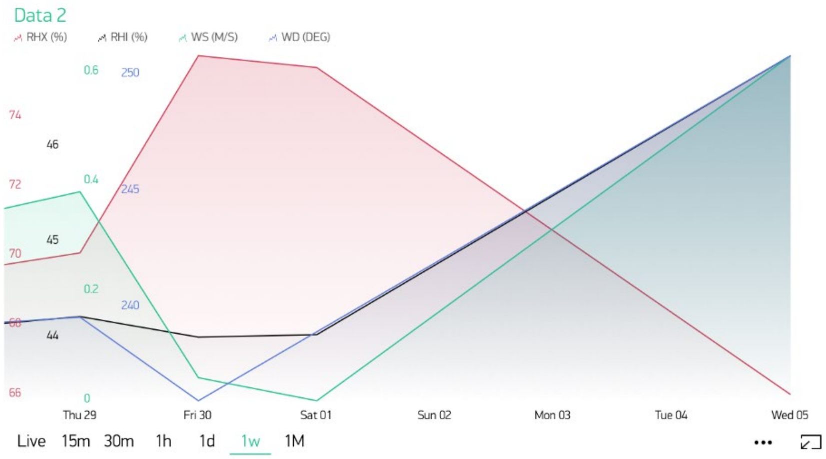

Figure 10: Second graph of data

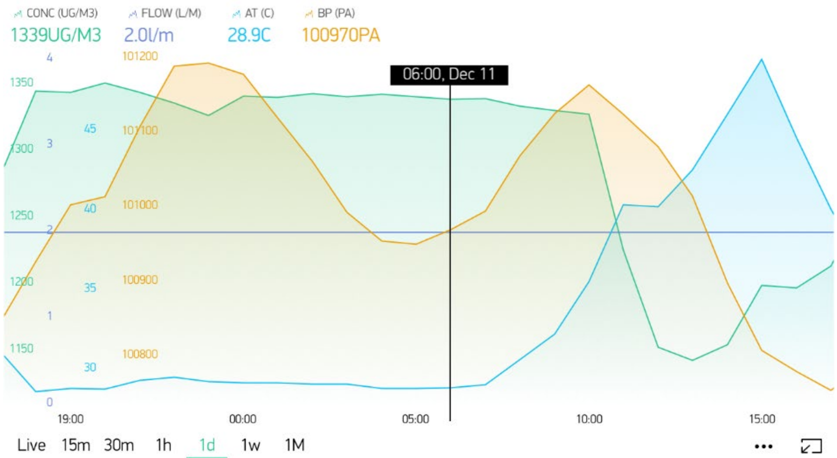

Figure 11: Indicator line

3.3 Exporting Function in Blynk Mobile Application

The export function enabled data extracted from E-Sampler to be transferred from Blynk cloud to other devices such as mobile phone and computer through email. The data is sent to user's email address in CSV format, so that it can be opened readily in Excel compatible format for further analysis. Figure 12 shows the process flow of the Export Function. The first image shows the Export Function being initiated in Blynk application where Blynk app will convert the raw data to CSV files while second image shows that the Blynk app is sending the CSV file containing the converted raw data to user's email address. The third image shows the user's email inbox after receiving the CSV files containing the E-Sampler data that were sent by Blynk app and fourth image shows the screenshot of PM2.5 concentration data in one of the CSV files that was opened in Excel. The naming format for the file is shown in Table 2. All of this shows that IoT method succeeded in achieving the export function for extracting the data from E-Sampler wirelessly as mentioned in 2.6.

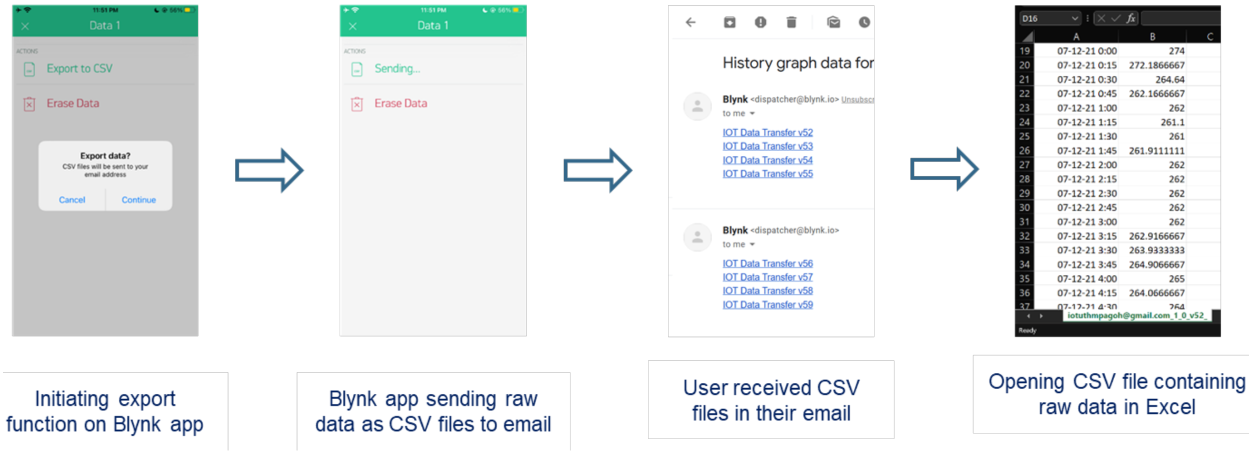

Figure 12: Export Function in Blynk Mobile Application

Table 1: Naming format of files

Format	Data
IOT Data Transfer v52	Real-time concentration of PM2.5
IOT Data Transfer v53	Real-time sample flow rate
IOT Data Transfer v54	Ambient temperature
IOT Data Transfer v55	Ambient barometric pressure
IOT Data Transfer v56	External ambient relative humidity
IOT Data Transfer v57	Internal filter sample relative humidity
IOT Data Transfer v58	Wind speed
IOT Data Transfer v59	Wind direction

3.4 Comparison Between Data from Manual Method and IoT Method

Since data from E-Sampler data logger has been successfully extracted using IoT method, the next step is to compare those data to the data that were manually extracted as to verify the IoT method reliability. The data that are compared were the data from outdoor test which run from 7/12/2021 to 13/12/2021. Each graph compared IoT method data versus manual method data, where X-axis shows time and Y-axis shows unit. Figure 13 to Figure 20 show the double line graph with data of IoT method plotted at the back as blue line and data of manual method plotted at the front as red line. Here onwards, assume the data from manual method as the reference data and data from IoT method as test data.

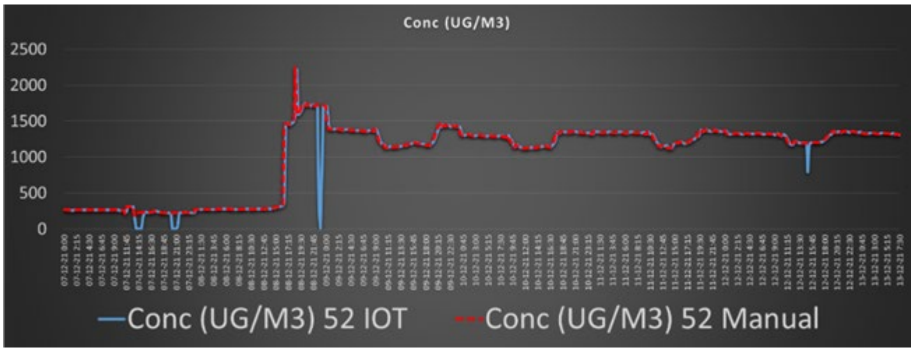

Figure 13: PM2.5 concentration

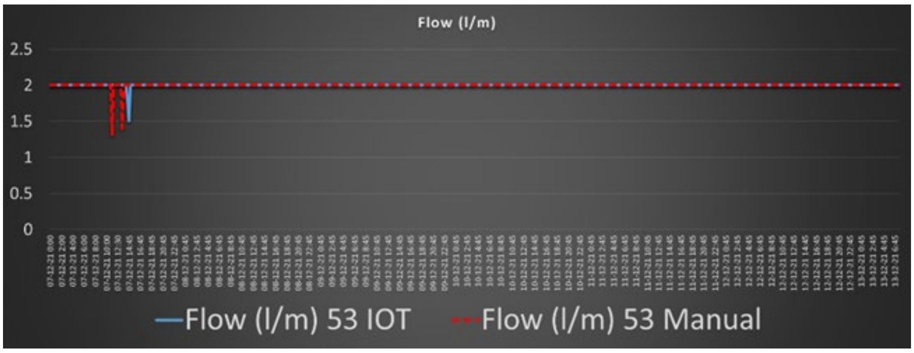

Figure 14: Sample flow rate

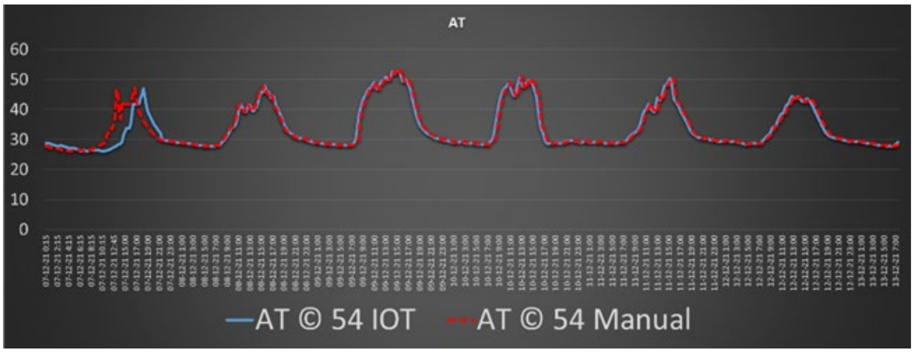

Figure 15: Ambient temperature

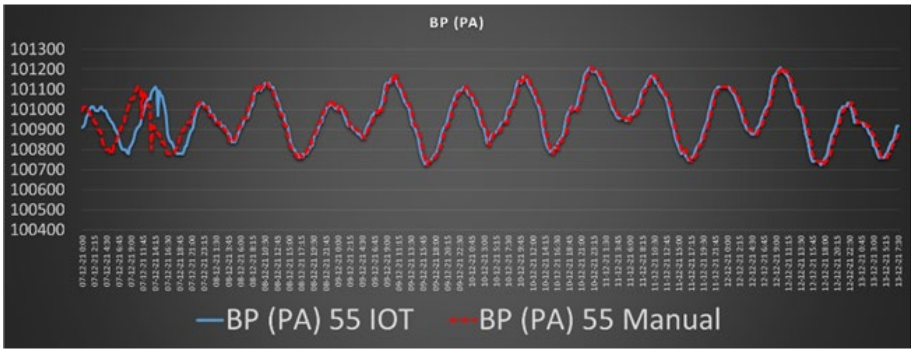

Figure 16: Ambient barometric pressure

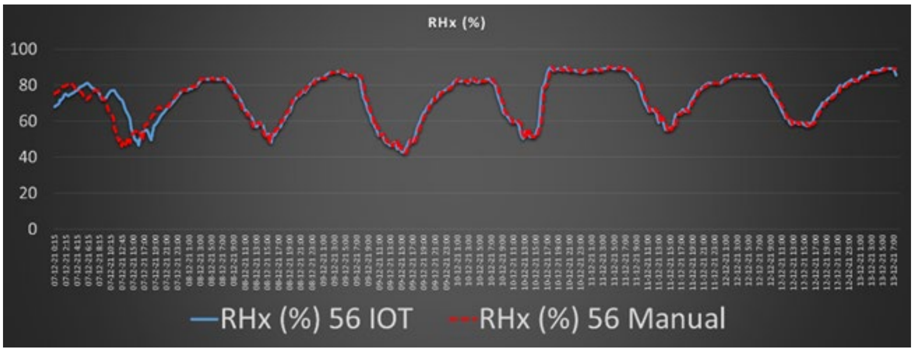

Figure 17: External ambient relative humidity

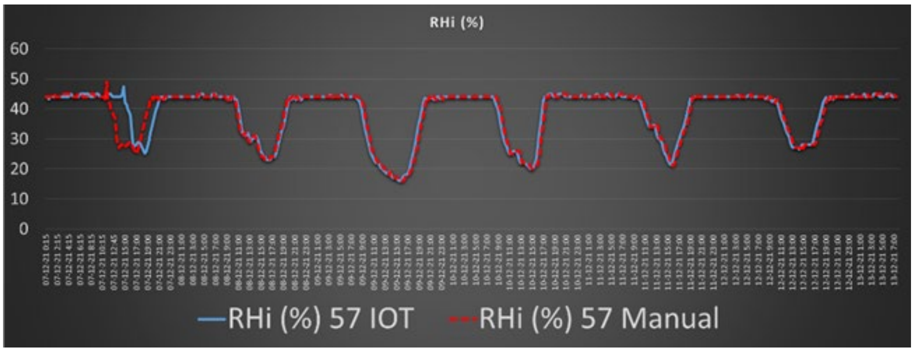

Figure 18: Internal filter sample relative humidity

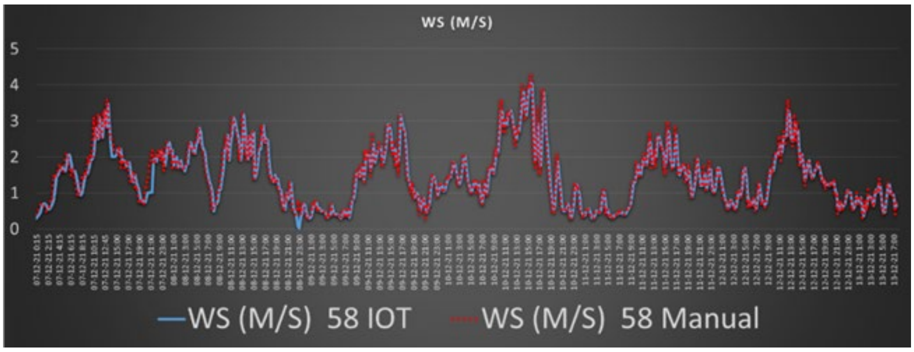

Figure 19: Wind speed

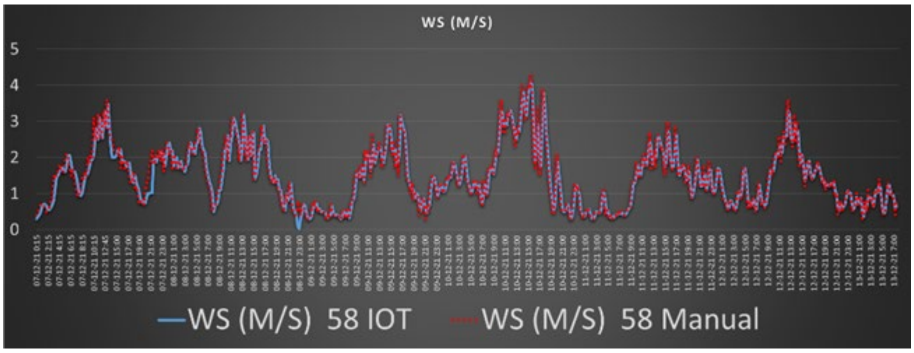

Figure 20: Wind direction

3.5 Discussion

As mentioned before, this project is only concerned with the technical aspect of obtaining data from E-Sampler through IoT means as well as the monitoring of said data, and not concerned with the value of data parameters obtained. However, these data can be useful to see the pattern of the lines in each graph, to gauge whether the two lines match or not when overlaid together. If the two lines match with each other, this means that IoT method is reliable to be used as data from IoT method are similar to the data from manual method. It can be seen in graphs above that the patterns of data for PM2.5 concentration, sample flow rate, ambient temperature, ambient barometric pressure, external ambient relative humidity, internal filter sample relative humidity, wind speed and wind direction from both methods look similar, though there are a few offsets on IoT method suggesting the data were not properly registered on Blynk cloud. The possible explanation for this is there was issue with the communication aspect between the E-Sampler and IoT device such as mismatched baud rate between two devices or the issue with data latency while uploading because the IoT device was lagging due to bad internet connection. It can be said that IoT method is sufficiently reliable most of the time and could be improved in future studies.

4. Conclusion

The objectives of this research are to develop a new prototype of IoT Data Logger which acquire data from API measurement device (E-Sampler from MetOne) and upload it to cloud, to propose a real time application for mobile phones that download E-Sampler data from cloud and act as IoT monitoring medium for API data, as well as to provide a graphical presentation of particulate matter concentration, sample flow rate, ambient temperature, ambient barometric pressure, external ambient relative humidity, internal filter sample relative humidity, wind speed and wind direction data in the real time mobile application. All the functionalities that are required for this IoT method to be sufficiently reliable like the manual method have been achieved. The first functionality achievement of IoT data logger is that the 8 data from E-Sampler can be uploaded to the cloud and are accessible to user via Blynk application that displays those data in form of history chart. The second functionality achievement is that those data can be wirelessly extracted and exported via Blynk mobile application instead of manual extraction through cable wire to personal computer. The last functionality achievement is that the IoT method enabled the real-time monitoring of those 8 parameters data from E-Sampler by displaying the data in graphical presentation i.e. in form of history chart on Blynk mobile application, without having to manually extract the data first using Comet software for the monitoring to be done.

4.1 Recommendation

There are a few recommendations for the improvement of this project in the future. Firstly, there should be further development of this IoT monitoring system since it is still in preliminary phase such as improvement of coding and addition of API analysis process into the prototype system. Secondly, future researchers should test the E-Sampler integrated with this IoT data logger and monitoring system at a much more remote location so that it resembles the real-life application. Thirdly, implement the IoT system to a much better environmental sampler that can measure all 6 air pollution indexes instead of just PM2.5, if budget permits. Next, the future study should choose telco sim with strong and stable internet connection for WiFi modem so that IoT device connectivity to the internet would not be affected by distance to the modem or weather condition such as rain. Lastly, authors would like to recommend further researchers to integrate social media to the system for information dispersion to the public once API data is obtained and analysed.

Acknowledgement

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