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Application of Internet of Things (IoT) Data Logger: A Comparison of Different Techniques for Assessing Ambient Air Pollution Levels

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Abstract: Air pollution has an impact on the daily lives of humans and the standard of living. It presents a danger to the environment and quality of life. There is an essential need to monitor air quality because of growing industrial activity in recent years. This study is to implement an IoT-based data logger (IoTDL) for the E-sampler dual ambient monitor that collects raw data from Air Pollution Index (API) data measurement device. The MA-01 IoT Magic Kit-ESP8266 was developed to build the air pollution monitoring system. Its major purpose is to access the internet through the Blynk application which is one of the IoT mobile applications that enables a wireless connection between the equipment and the Blynk application. The air pollution monitoring system was created to monitor and evaluate air quality. This study is also looking to verify the reliability of the IoTDL method in the real-time mobile application for the particulate concentration of particulate matter smaller than 2.5 μm ($PM_{2.5}$), sample air flow rate, ambient temperature, ambient barometric pressure, external ambient relative humidity, internal filter sample relative humidity, wind speed, and wind direction in comparison on the conventional framework for the E-sampler. The comparison is made between the IoTDL method and the conventional framework for the E-sampler. The difference between both techniques is focusing on the reliability of the data obtained from the IoTDL method compared to the conventional framework for the E-sampler. Based on the collated graphs and the table, they show that the data obtained from the IoTDL method compared to the conventional framework are almost the same. Therefore, the data obtained from the IoTDL method is reliable. In summary, the results illustrate that the techniques correspond well.

Keywords: Air Pollution, Air Monitoring System, Internet of Things

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1. Introduction

One of the most important components of the human environment is air. Humans need a contaminant-free environment to live in. This is extremely important for human survival and well-being. The accumulation of one or more chemicals in the environment such as gases in quantities that are harmful to humans, livestock, and plants is known as air pollution [1]. Pollutants in the air are calculated in parts per million (ppm) or microgram per cubic meter ($\mu g/m^3$) [2]. Air exposure has a variety of effects including trouble breathing, coughing, and the worsening of asthma and emphysema [3]. Several researchers around the world have constructed models to track a variety of emission gases, including CO, nitrogen oxides (NOx), carbon dioxide (CO_2), sulphur dioxide (SO_2), and others [4].

An environmental monitoring system is used to conduct environmental impact assessments and other conditions where human actions which have adverse impacts on the environment and require the use of sensors with regard to expense, effectiveness, and opportunity restriction [5]. The system is crucial in determining the intensity of safety and health issues for the community and environment. It allows us to keep track of their well-being and alert them to any possible problems by monitoring. The environment monitoring system may provide data about how environments are changing over time by measuring physical, chemical, and biological components. Repeated observations for several factors at one or multiple locations through predetermined routes in time and space over a longer duration are referred to as monitoring [6].

The IoT has revolutionised the whole world by providing a platform for not only monitoring but also controlling important statistical information in our environment with the aid of a multitude of devices. The data obtained is wirelessly transferred to the cloud, and then collects, preserves, converts, and analyses the data into something functional [7]. Mobile and online software can be used to view the collected data. The use of an IoTDL allows for online real-time tracking and management of equipment status and environmental conditions. This can ensure that the equipment operates in a secure zone in an environmentally friendly condition and energy-saving mode. As a result, the IoTDL guarantees equipment reliability, personal protection, and appropriate environmental conditions [8].

2. Materials and Methods

2.1 Set-up

All the hardware components of the E-sampler such as the IoT Magic Kit board, the ESP8266 Wi-Fi serial transceiver module flashed with AT firmware, a Secure Digital (SD) card, and a power supply have to be well prepared as shown in Figure 1 and set them up by following the instruction of installation. The empty SD card is inserted into the IoT Magic Kit board and plugged in the ESP8266 Wi-Fi serial transceiver module that has been loaded with AT firmware.

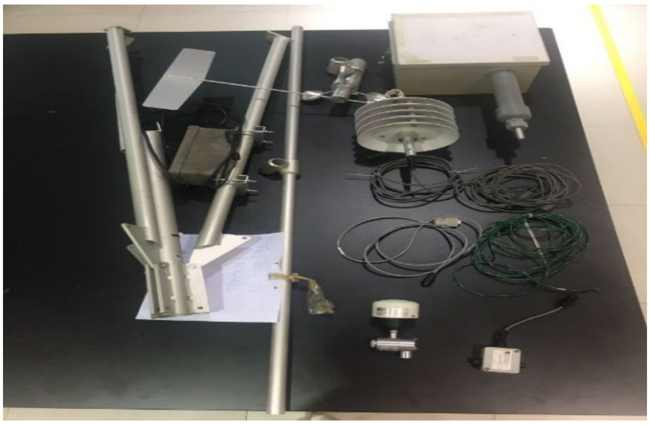


Figure 1: Hardware components of the E-sampler

The power supply should then be connected as shown in Figure 2 and the extension used is passed through the window from the nearby laboratory.

Figure 2: Connected power supply

The Wi-Fi modem is also plugged-in at the nearby laboratory as shown in Figure 3 to get a better connection of the internet for transferring raw data to the Blynk application via the IoTDL.

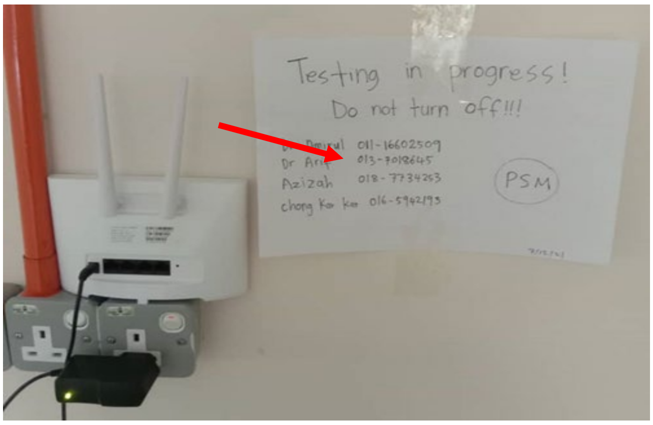


Figure 3: Plugged-in of Wi-Fi modem

When set-up on-site, make sure the E-sampler is in a horizontal line as shown in Figure 4 (a). The E-sampler is also fully wrapped with plastic wrap as shown in Figure 4 (b) to ensure that all the connection of wire is water-resistant.

Figure 4: (a) E-sampler in a horizontal line

Figure 4 (b): Wrapped the E-sampler to water-resistant

2.2 Indoor and outdoor testing

The indoor testing is conducted inside the building of Block B, UTHM Pagoh Campus for about 1 week. The purpose of this testing is to ensure all components in the E-sampler are well functioning and can interoperate with the IoTDL without error. The parameters obtained from the E-Sampler via the Blynk application are monitored to ensure the IoTDL is able to transmit the raw data to the cloud database before the ambient air monitoring system can be carried out for the on-site testing. The E-sampler equipment device and its setup for indoor testing are shown in Figure 5.

Figure 5: E-sampler (indoor testing)

The on-site testing is conducted outside the building of Block B, UTHM Pagoh Campus for about 1 week. The purpose of this testing is to monitor the condition of ambient air in an open area. The location selected is based on the guideline from the United States Environmental Protection Agency (USEPA). The parameters obtained from the E-Sampler via the Blynk application are used to determine the Air Pollution Index (API) for the data analysis. The E-sampler equipment device and its setup for indoor testing are shown in Figure 6.

Figure 6: E-sampler (on-site testing)

2.3 IoT-based data logger (IoTDL) and conventional framework

The data collected is transferred to a microcontroller device (MA-01 IoT Magic Kit–ESP8266) and then to a web server. After that, the data is transmitted and sent to the Blynk application. The parameters such as external ambient relative humidity (RHx), internal filter sample relative humidity (RHi), wind speed (WS), wind direction (WD), the particulate concentration of particulate matter smaller than 2.5 µm ($PM_{2.5}$) (Conc), sample air flow rate (Flow), ambient temperature (AT), and ambient barometric pressure (BP), that can be accessed in the Blynk application are shown in Figure 7 (a) and (b).

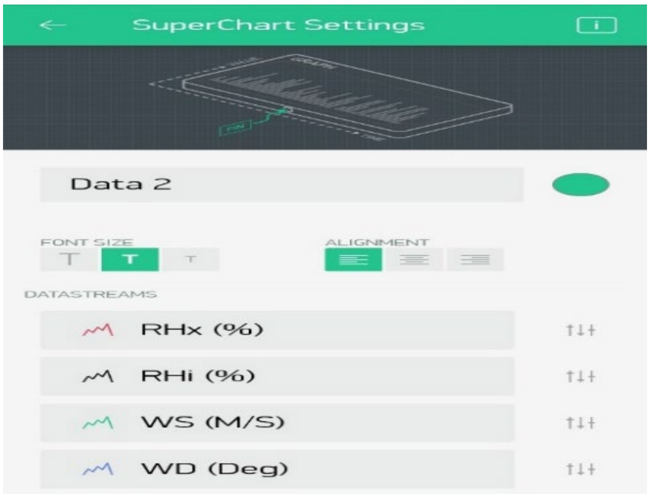


Figure 7: (a): External ambient relative humidity (RHx), internal filter sample relative humidity (RHi), wind speed (WS), and wind direction (WD)

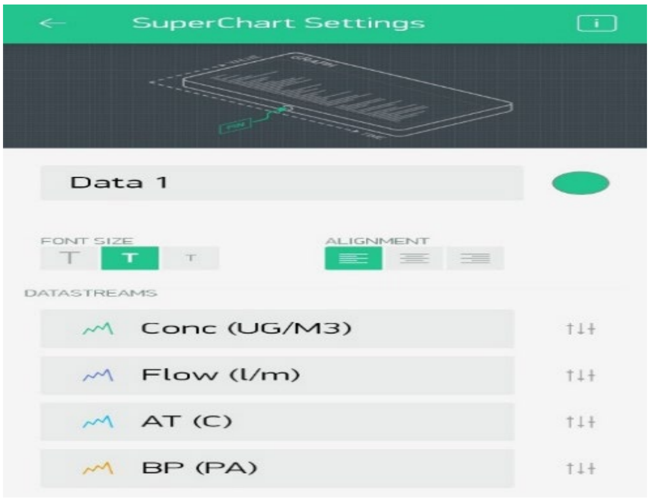


Figure 7 (b): Particulate concentration of particulate matter smaller than 2.5 µm ($PM_{2.5}$) (Conc), sample air flow rate (Flow), ambient temperature (AT), and ambient barometric pressure (BP)

The raw data is then compiled and exported out as the Microsoft Excel file via the email in Figure 8. The data received is stated as IOT Data Transfer v52, v53, v54, v55, v56, v57, v58, and v59 which are external ambient relative humidity (V52), internal filter sample relative humidity (V53), wind speed (V54), wind direction (V55), particulate concentration of particulate matter smaller than 2.5 µm ($PM_{2.5}$) (V56), sample air flow rate (V57), ambient temperature (V58), and ambient barometric pressure (V59). The operation of an E-sampler dual ambient monitor with IoTDL is shown in Figure 9.

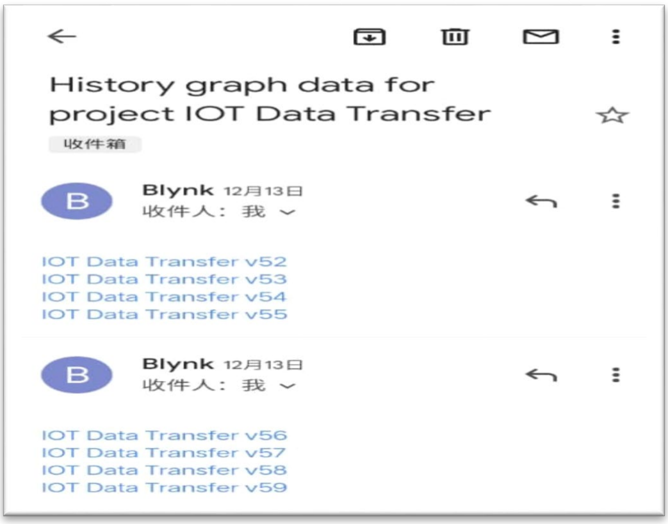


Figure 8: Raw data sent by email

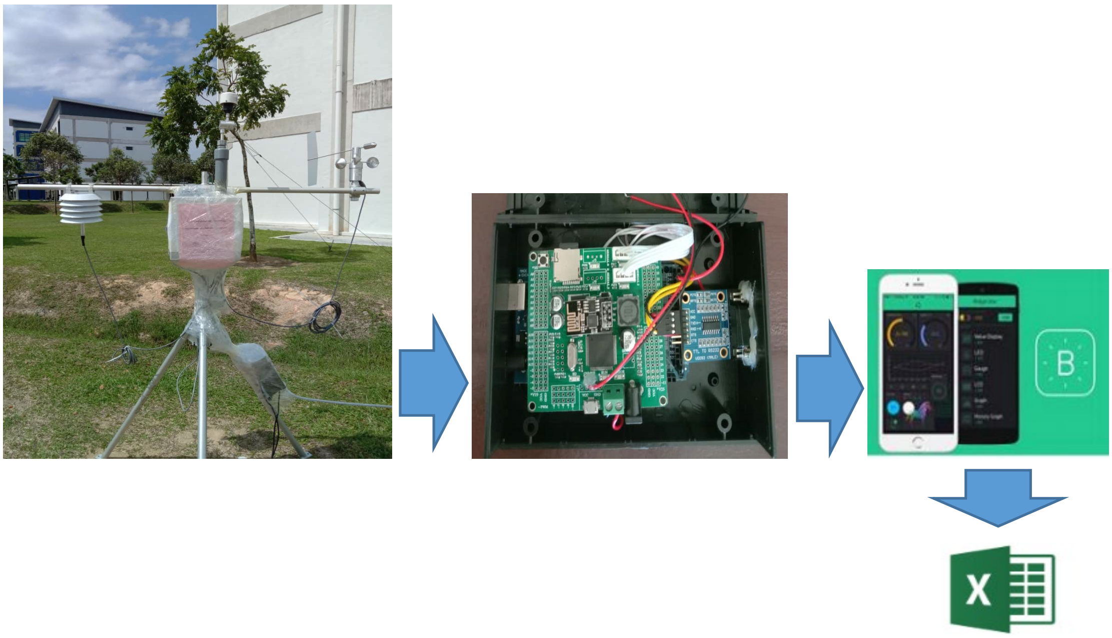
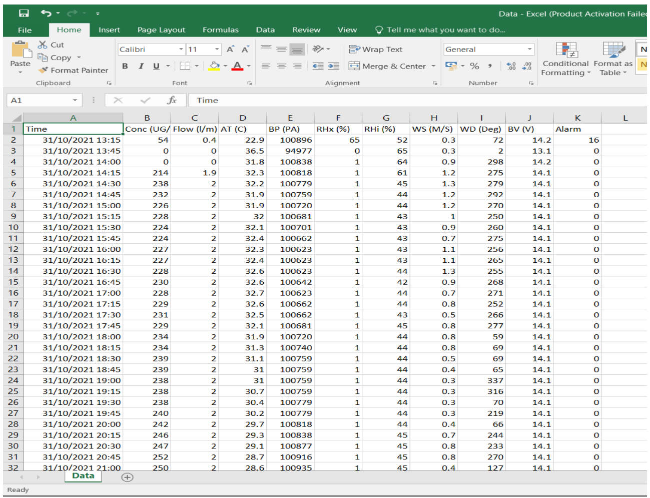


Figure 9: Operation of the E-sampler dual ambient monitor with IoTDL

The E-sampler has to uninstall after the testing on-site is completed and brought to the laboratory for data collection. The raw data collected is transferred to a computer software named Comet by using a video graphics array (VGA) connector. This process is under the help of the supervisor due to the unfamiliar usage of the software in Figure 10.

Figure 10: Operation of the E-sampler dual ambient monitor with IoTDL

After that, the data is generated and downloaded as the Microsoft Excel file on the computer in Figure 11. The operation of an E-sampler dual ambient monitor with the conventional framework is shown in Figure 12.



	A	B	C	D	E	F	G	H	I	J	K
1	Time	Conc (UG/	Flow (l/m)	AT (C)	BP (PA)	RHx (%)	RHi (%)	WS (M/S)	WD (Deg)	BV (V)	Alarm
2	31/10/2021 13:15	54	0.4	22.9	100896	65	52	0.3	72	14.2	16
3	31/10/2021 13:45	0	0	36.5	94977	0	65	0.3	2	13.1	0
4	31/10/2021 14:00	0	0	31.8	100838	1	64	0.9	298	14.2	0
5	31/10/2021 14:15	214	1.9	32.3	100818	1	61	1.2	275	14.1	0
6	31/10/2021 14:30	238	2	32.2	100779	1	45	1.3	279	14.1	0
7	31/10/2021 14:45	232	2	31.9	100759	1	44	1.2	292	14.1	0
8	31/10/2021 15:00	226	2	31.9	100720	1	44	1.2	270	14.1	0
9	31/10/2021 15:15	228	2	32	100681	1	43	1	250	14.1	0
10	31/10/2021 15:30	224	2	32.1	100701	1	43	0.9	260	14.1	0
11	31/10/2021 15:45	224	2	32.4	100662	1	43	0.7	275	14.1	0
12	31/10/2021 16:00	227	2	32.3	100623	1	43	1.1	256	14.1	0
13	31/10/2021 16:15	227	2	32.4	100623	1	43	1.1	265	14.1	0
14	31/10/2021 16:30	228	2	32.6	100623	1	44	1.3	255	14.1	0
15	31/10/2021 16:45	230	2	32.6	100642	1	42	0.9	268	14.1	0
16	31/10/2021 17:00	228	2	32.7	100623	1	44	0.7	271	14.1	0
17	31/10/2021 17:15	229	2	32.6	100662	1	44	0.8	252	14.1	0
18	31/10/2021 17:30	231	2	32.5	100662	1	43	0.5	266	14.1	0
19	31/10/2021 17:45	229	2	32.1	100681	1	45	0.8	277	14.1	0
20	31/10/2021 18:00	234	2	31.9	100720	1	44	0.8	59	14.1	0
21	31/10/2021 18:15	234	2	31.3	100740	1	44	0.8	69	14.1	0
22	31/10/2021 18:30	239	2	31.1	100759	1	44	0.5	69	14.1	0
23	31/10/2021 18:45	239	2	31	100759	1	44	0.4	65	14.1	0
24	31/10/2021 19:00	238	2	31	100759	1	44	0.3	337	14.1	0
25	31/10/2021 19:15	238	2	30.7	100759	1	44	0.3	316	14.1	0
26	31/10/2021 19:30	238	2	30.4	100779	1	44	0.3	70	14.1	0
27	31/10/2021 19:45	240	2	30.2	100779	1	44	0.3	219	14.1	0
28	31/10/2021 20:00	242	2	29.7	100818	1	44	0.4	66	14.1	0
29	31/10/2021 20:15	246	2	29.3	100838	1	45	0.7	244	14.1	0
30	31/10/2021 20:30	247	2	29.1	100877	1	45	0.8	233	14.1	0
31	31/10/2021 20:45	252	2	28.7	100916	1	45	0.8	270	14.1	0
32	31/10/2021 21:00	250	2	28.6	100935	1	45	0.4	127	14.1	0

Figure 11: Raw data obtained in Microsoft Excel

Figure 12: Operation of an E-sampler dual ambient monitor with the conventional framework

2.4 Comparison between the IoT-based data logger (IoTDL) method and the conventional framework for the E-sampler

One of the ways to conduct the comparison is by collating the generated graph based on the raw data obtained from both techniques. All the parameters such as particulate concentration for particulate matter smaller than 2.5 µm ($PM_{2.5}$), sample air flow rate, ambient temperature, ambient barometric pressure, external ambient relative humidity, internal filter sample relative humidity, wind speed, and wind direction are generated graphs respectively. In this study, the difference between both techniques in terms average of the raw data is also calculated to show the comparison in percentage. The difference between both techniques is focusing on the reliability of the data obtained from the IoTDL method compared to the conventional framework for the E-sampler. If these graphs and a relevant percentage between both techniques are slightly different, thus the data obtained is reliable.

3. Results and Discussion

3.1 Implementation of the IoT-based data logger (IoTDL) for the E-sampler

The real-time monitoring system and the IoTDL are successfully interfaced with the ambient air quality through the connection of the E-sampler dual ambient monitor and the Blynk application with a Wi-Fi connection. The E-sampler is installed and run at Block B, UTHM Pagoh Campus for collecting the raw data such as particulate concentration for particulate matter smaller than 2.5 µm ($PM_{2.5}$), sample air flow rate, ambient temperature, ambient barometric pressure, external ambient relative humidity, internal filter sample relative humidity, wind speed, and wind direction. After the ambient air is monitored, the raw data is collected and sent to the Blynk application through IoT Magic Kit for access, and last transferred to Microsoft Excel for analysis. The data that has been analysed is carried forwards to compare the reliability of the IoTDL method in real-time application compared to the conventional framework for the E-sampler.

3.2 Comparison of the IoT-based data logger (IoTDL) method and the conventional framework for the E-sampler

Graphs are generated according to the parameters based on the raw data obtained from the E-sampler dual ambient monitor. All the parameters such as particulate concentration for particulate matter smaller than 2.5 µm ($PM_{2.5}$), sample air flow rate, ambient temperature, ambient barometric pressure, external ambient relative humidity, internal filter sample relative humidity, wind speed, and wind direction of the IoTDL method and the conventional framework for the E-sampler have generated graphs respectively. The duration for the on-site testing is about 1 week which was 7 December to 13 December. The raw data obtained from both techniques can refer to Appendix C. Figure 13 (a), (b), and (c) show the particulate concentration for particulate matter smaller than 2.5 µm ($PM_{2.5}$) of IoTDL method and conventional framework. Based on the collated graphs, it shows that the data obtained from the IoTDL method has a similar trend to the real data obtained from the conventional framework for the E-sampler. The differences in the parameter between both techniques are very little.

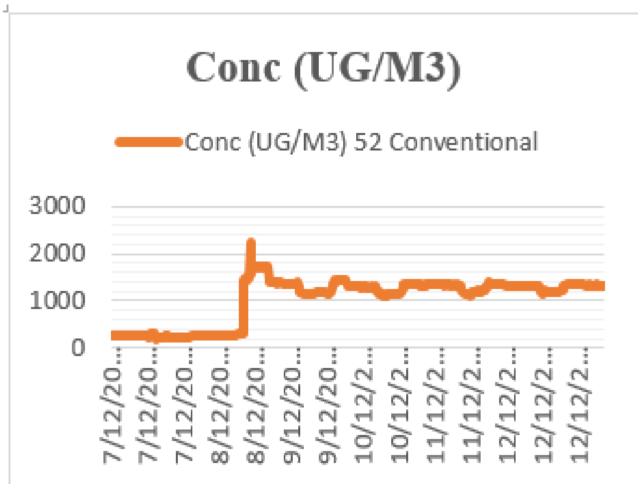


Figure 13: (a): Particulate concentration for particulate matter smaller than 2.5 µm ($PM_{2.5}$) of conventional framework

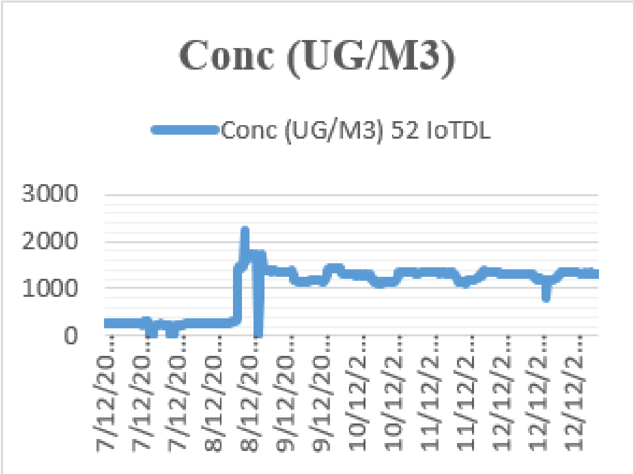


Figure 13 (b): Particulate concentration for particulate matter smaller than 2.5 µm ($PM_{2.5}$) of IoTDL method

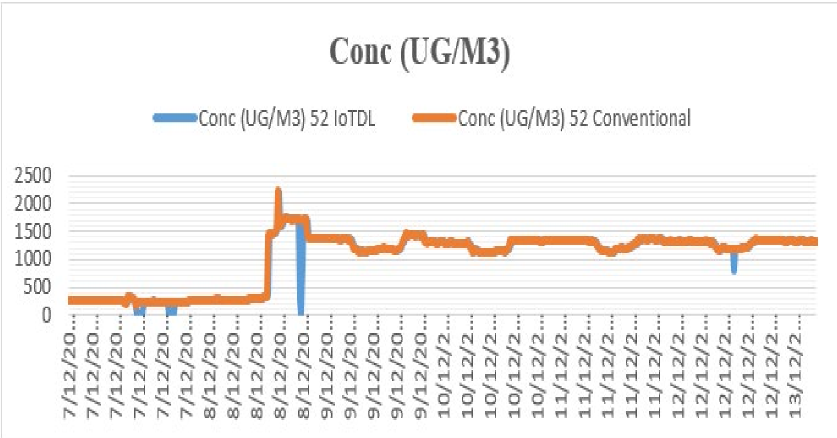
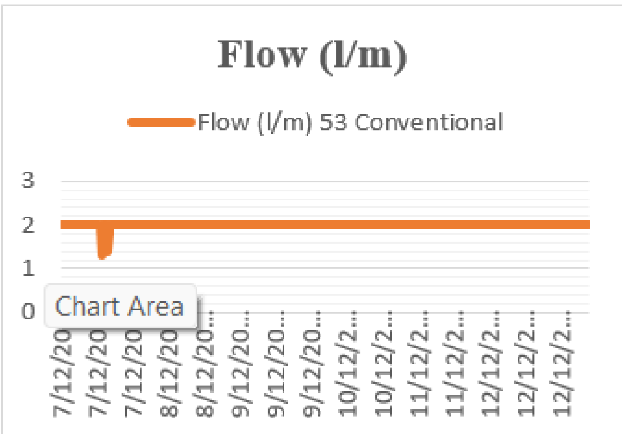


Figure 13 (c): Collation of Particulate concentration for particulate matter smaller than 2.5 µm ($PM_{2.5}$) of IoTDL method and conventional framework

Figure 14 (a), (b), and (c) show the sample air flow rate of the IoTDL method and conventional framework. Based on the collated graphs, it shows that the data obtained from the IoTDL method has a similar trend to the real data obtained from the conventional framework for the E-sampler. The differences in the parameter between both techniques are very little.



(a): Sample air flow rate of conventional framework

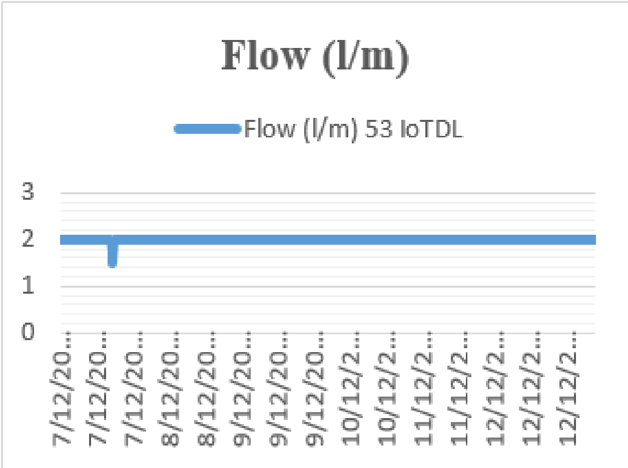


Figure 14: (b): Sample air flow rate of IoTDL method

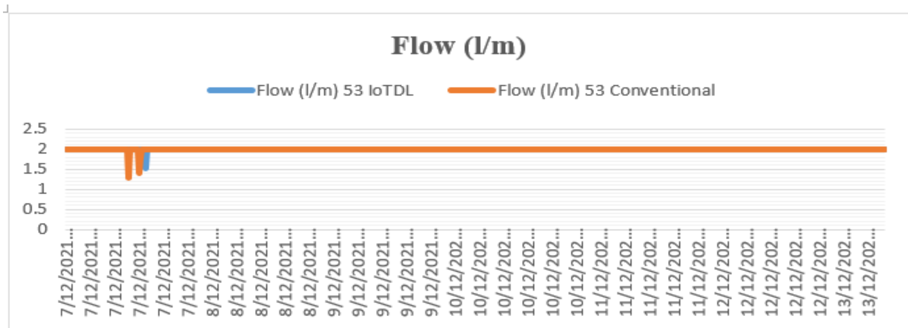


Figure 14: (c): Collation of sample air flow rate of IoTDL method and conventional framework

Figure 15 (a), (b), and (c) show the ambient temperature of the IoTDL method and conventional framework. Based on the collated graphs, it shows that the data obtained from the IoTDL method has a similar trend to the real data obtained from the conventional framework for the E-sampler. The differences in the parameter between both techniques are very little.

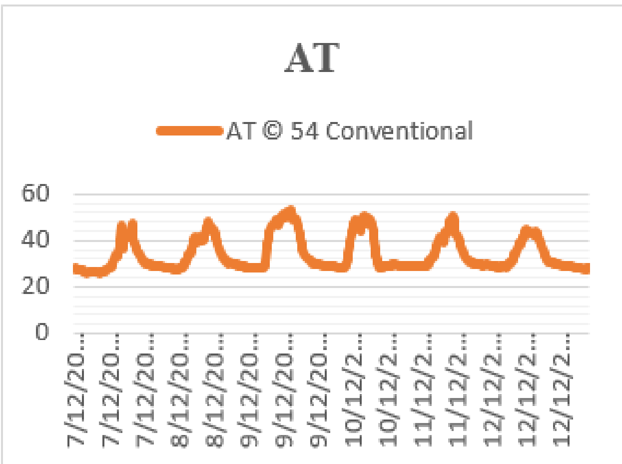


Figure 15 (a): Ambient temperature of conventional framework

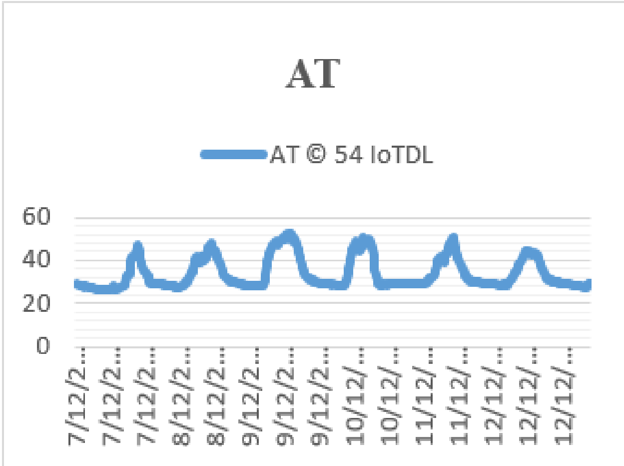


Figure 15: (b): Ambient temperature of IoTDL method

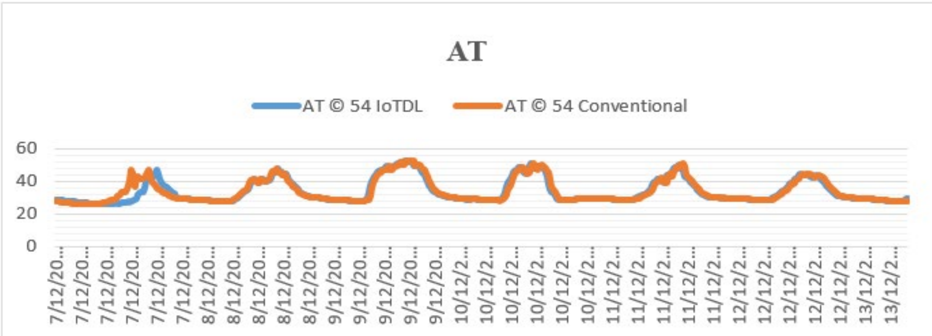


Figure 15: (c): Collation of ambient temperature of IoTDL method and conventional framework

Figure 16 (a), (b), and (c) show the ambient barometric pressure of the IoTDL method and conventional framework. Based on the collated graphs, it shows that the data obtained from the IoTDL method has a similar trend to the real data obtained from the conventional framework for the E-sampler. The differences in the parameter between both techniques are very little.

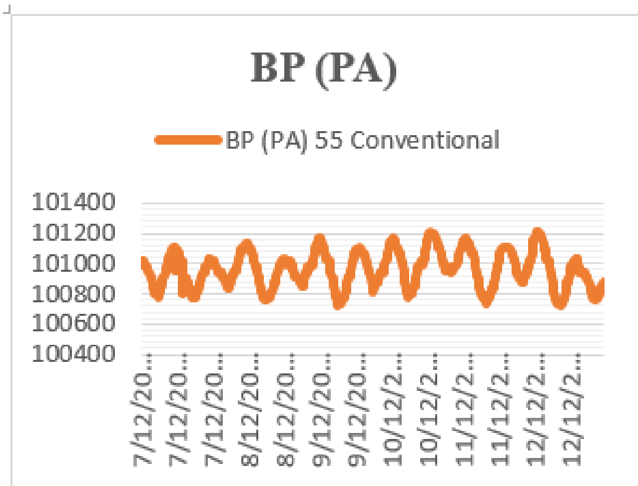


Figure 16: (a): Ambient barometric pressure of conventional framework

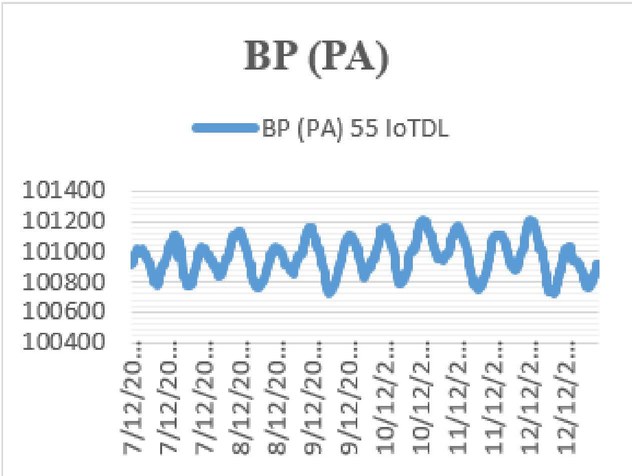


Figure 16: (b): Ambient barometric pressure of IoTDL method

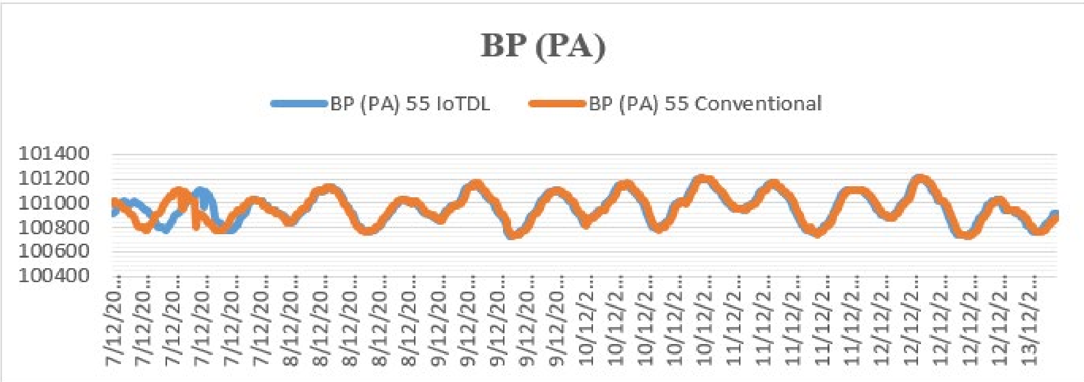


Figure 16: (c): Collation of ambient barometric pressure of IoTDL method and conventional framework

Figure 17 (a), (b), and (c) show the external ambient relative humidity of the IoTDL method and conventional framework. Based on the collated graphs, it shows that the data obtained from the IoTDL method has a similar trend to the real data obtained from the conventional framework for the E-sampler. The differences in the parameter between both techniques are very little.

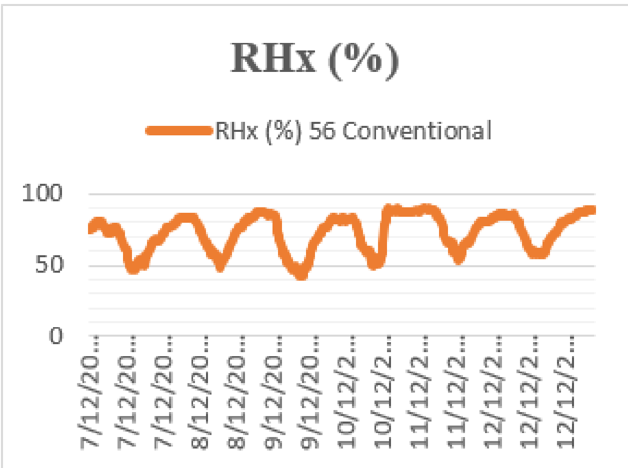


Figure 17: (a): External ambient relative humidity of conventional framework

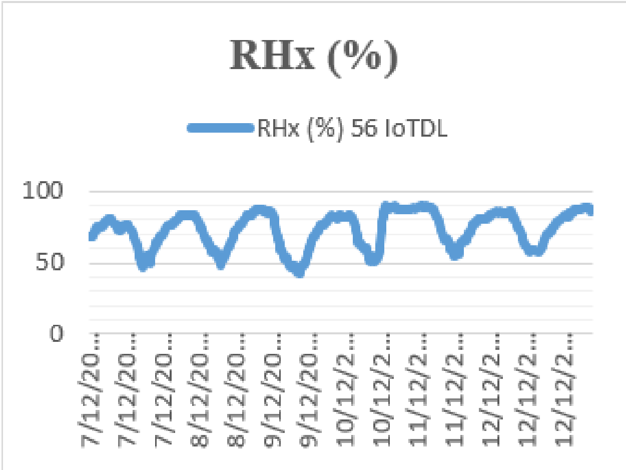


Figure 17: (b): External ambient relative humidity of IoTDL method

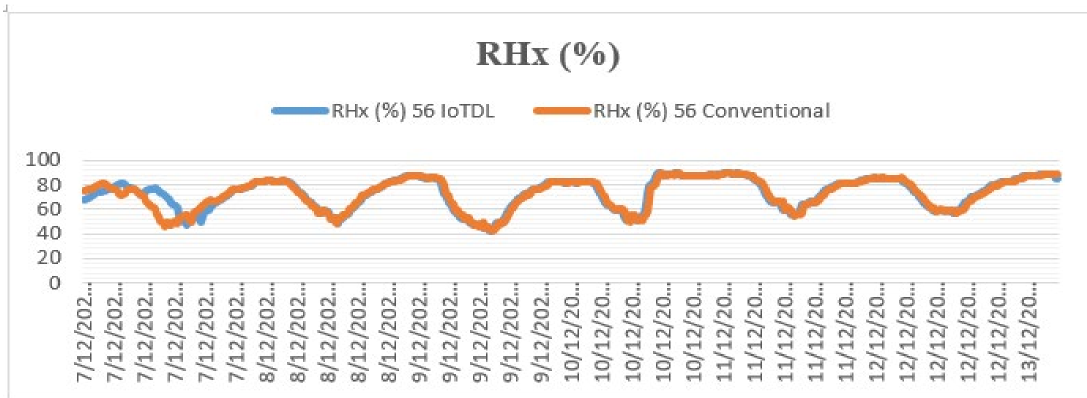


Figure 17: (c): Collation of external ambient relative humidity of IoTDL method and conventional framework

Figure 18 (a), (b), and (c) show the internal filter sample relative humidity of the IoTDL method and conventional framework. Based on the collated graphs, it shows that the data obtained from the IoTDL method has a similar trend to the real data obtained from the conventional framework for the E-sampler. The differences in the parameter between both techniques are very little.

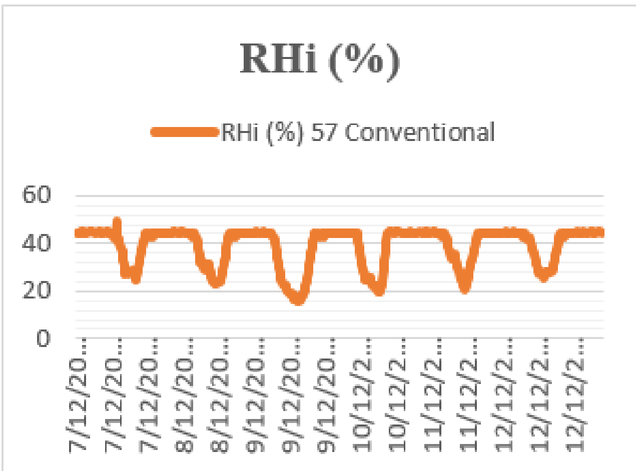


Figure 18: (a): Internal filter sample relative humidity of conventional framework

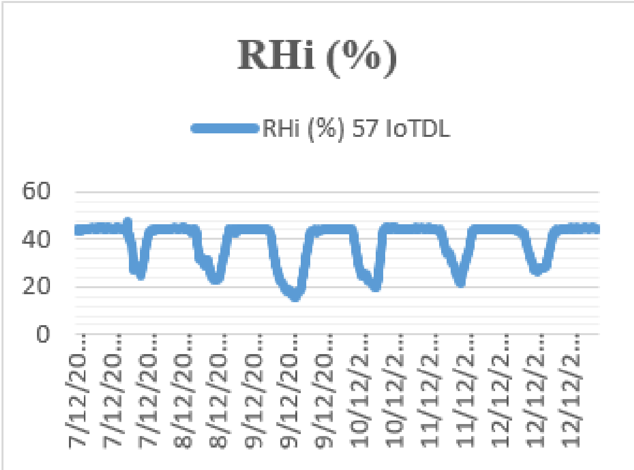


Figure 18 (b): Internal filter sample relative humidity of IoTDL method

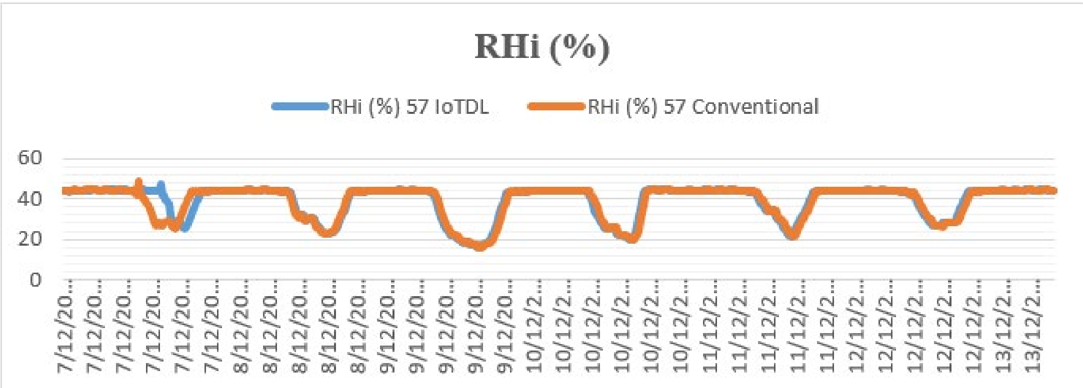


Figure 18: (c): Collation of internal filter sample relative humidity of IoTDL method and conventional framework

Figure 19 (a), (b), and (c) show the wind speed of the IoTDL method and conventional framework. Based on the collated graphs, it shows that the data obtained from the IoTDL method has a similar trend to the real data obtained from the conventional framework for the E-sampler. The differences in the parameter between both techniques are very little.

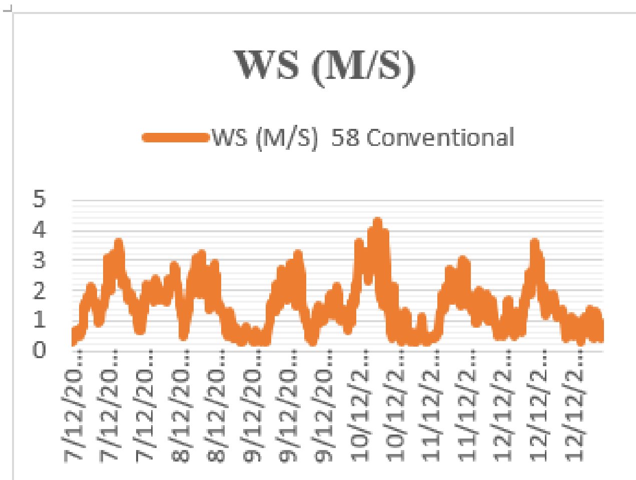


Figure 19: (a): Wind speed of the conventional framework

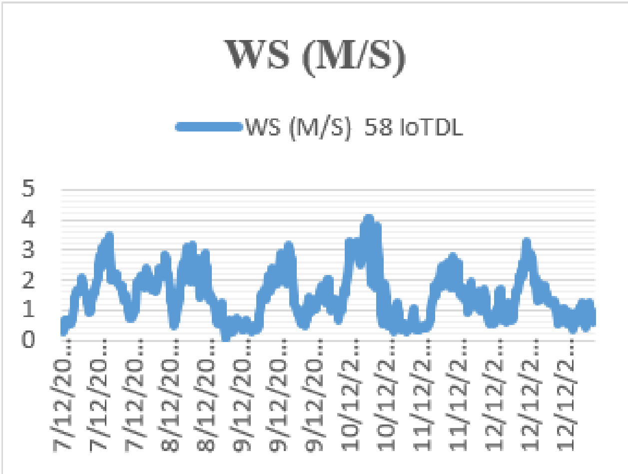


Figure 19: (b): Wind speed of IoTDL method

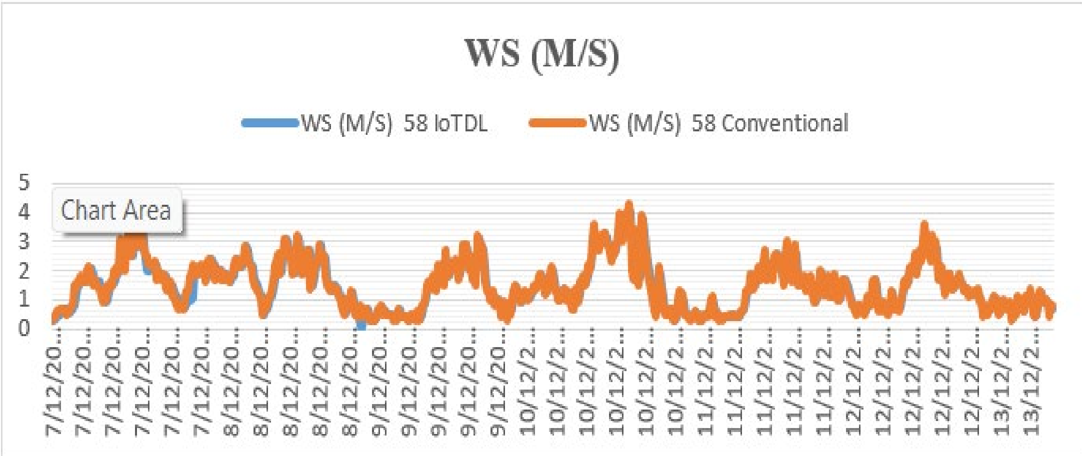


Figure 19: (c): Collation of wind speed of IoTDL method and conventional framework

Figure 20 (a), (b), and (c) show the wind direction of the IoTDL method and conventional framework. Based on the collated graphs, it shows that the data obtained from the IoTDL method has a similar trend to the real data obtained from the conventional framework for the E-sampler. The differences in the parameter between both techniques are very little.

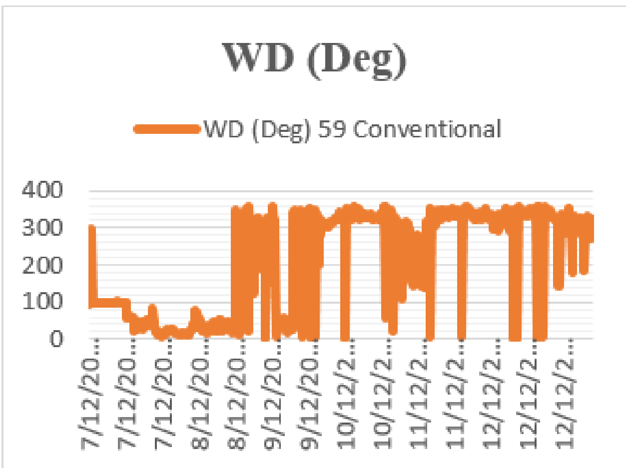


Figure 20: (a): Wind direction of conventional framework

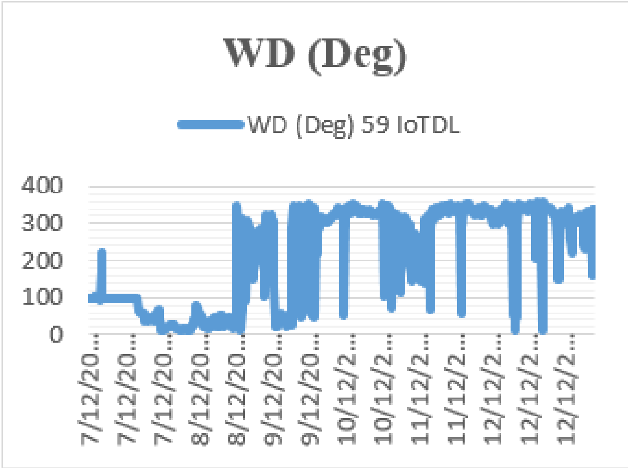


Figure 20: (b): Wind direction of IoTDL method

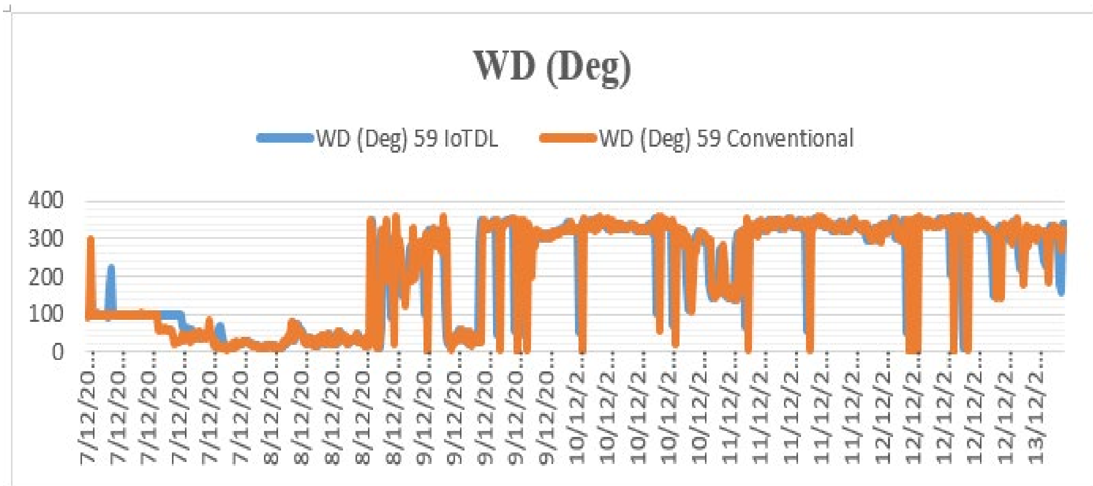


Figure 20: (c): Collation of wind direction of IoTDL method and conventional framework

Furthermore, the differences between the IoTDL method and the conventional framework for the E-sampler of the average per hour of the raw data are shown in Table 1. The differences of all the parameters between both techniques are less than 2.00 % which were 1.24.00 % for the particulate concentration of particulate matter smaller than 2.5 µm ($PM_{2.5}$), 0.07 % for sample air flow rate, 0.58 % for ambient temperature, 0.00 % for ambient barometric pressure, 0.49% for external ambient relative humidity, 0.47 % for internal filter sample relative humidity, 0.91 % for wind speed, and 0.64 % for wind direction. This shows that the data obtained from the IoTDL method is very close to the real data obtained from the conventional framework for the E-sampler.

Table 1: Example of presenting data using a table

Parameters (Average/hour)	Conventional	IoTDL	Difference	Difference (%)
Conc (UG/M3)	1033.3651	1020.5445	12.8207	1.2407
Flow (l/m)	1.9975	1.9988	-0.0013	0.0655
AT ©	34.04688	33.8494	0.1975	0.5800
BP (PA)	100960.8158	100961.2473	-0.4315	0.0004
RHx (%)	73.0576	73.4173	-0.3598	0.4924

RHi (%)	38.7566	38.9392	-0.1827	0.4712
WS (m/s)	1.4976	1.4840	0.0136	0.9051
WD (Deg)	215.0806	216.4623	-1.3817	0.6424

In this study, the raw data of the conventional framework is taken every 15 minutes however the raw data of the IoTDL method is taken every minute. Therefore, the average points of both techniques per hour are slightly different and this is one of the reasons caused difference between both techniques. The difference between both techniques is focusing on the reliability of the data obtained from the IoTDL method compared to the conventional framework for the E-sampler. Based on the collated graphs and the table above, they show that the data obtained from the IoTDL method compared to the conventional framework are almost the same. Therefore, the data obtained from the IoTDL method is reliable.

4. Conclusion

The E-sampler dual ambient monitoring system is successfully implemented with the IoTDL. The E-sampler is installed and run at Block B, UTHM Pagoh Campus for collecting the raw data such as particulate concentration for particulate matter smaller than 2.5 µm ($PM_{2.5}$), sample air flow rate, ambient temperature, ambient barometric pressure, external ambient relative humidity, internal filter sample relative humidity, wind speed, and wind direction. The raw data is collected and sent to the Blynk application through IoT Magic Kit for access, and last transferred to Microsoft Excel for analysis.

The difference between both techniques is focusing on the reliability of the data obtained from the IoTDL method compared to the conventional framework for the E-sampler. The data obtained from both techniques are almost the same based on the collated graphs and the percentage difference. As a result, the data obtained from the IoTDL method is reliable. Therefore, users can access and view the real-time ambient air quality at anytime and anywhere.

The first recommendation is to select the site location away from the arterial roadway. The raw data obtained was extremely high due to the vehicles' exhaust may dominate the concentration measurement. API values are not being calculated in this study because the API values became false when applied in the equation of API. The second recommendation is to carry out the ambient air monitoring throughout the whole UTHM Pagoh Campus. In this study, the ambient air monitoring was only run at Block B, UTHM Pagoh Campus due to some limitations such as lack of the API measurement device and unstable Wi-Fi connection. The third recommendation is to introduce the Blynk application to all the staff and students of UTHM. The Blynk application was only used for this study and not being used by other students that not doing related topics on their research.

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