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Original Article

A Remote Long-Range Localized Air Pollution Monitoring System

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Abstract *- Air pollution is a global issue that affects us every day, which brings about the need to monitor air quality regularly. However, fixed air monitoring systems in Malaysia are only situated in several areas, and the public is unaware of air quality conditions in terms of pollutants at specific locations. In efforts to tackle localised air pollution, this paper proposes to construct a low-cost remote air quality monitoring system and develop a web application to act as an interface for users. The proposed system comprises a sensor system and a ground terminal, which are connected using Long Range (LoRa) technology. Both units function to measure air quality parameters such as carbon monoxide (CO), sulphur dioxide (SO2), ozone (O3), particulate matter (PM) particles, etc., and upload the collected data onto the Internet of Things (IoT) platform. The functionality of the prototype was verified by testing it in different environments. The sensor's data was also verified to be accurate through data comparisons, where the majority of percentage differences fell below 10%. Performance analysis was then performed through statistical measures such as standard deviation, mean, etc., to categorise the data in each tested area. The low-cost nature of this proposed system would benefit everyone, especially underdeveloped countries that are always under threat of poor air quality.*

Keywords *- Air quality monitoring, Air pollution, Long-range communication, Internet of Things, Web application.*

1. Introduction

Environmental impact is one of the major concerns in most developing countries, such as Malaysia. In the recent 2020 AQI (Air Quality Index) country ranking, Malaysia was ranked as the 58th country among 106 countries in terms of worst air quality [1]. The country's most polluted city is located in Klang, Selangor, one of Malaysia's most industrialised cities and is populated with many companies and workers [2]. Hence, the air quality must be monitored regularly and analysed to raise awareness among people about it since poor air quality leads to dangerous health effects for humans, such as respiratory problems, cardiovascular problems, etc. [3]. Besides that, poor air quality also causes acid rain and global warming, which affect the environment, such as damaging lakes, increasing droughts [4], etc. With an air quality monitoring system, various Sustainable Development Goals (SDGs) could be achieved, including Good Health and Well-Being (SDG 3), Affordable and Clean Energy (SDG 7) and Sustainable Cities and Communities (SDG 11) [5,6].

Numerous air quality monitoring systems have been established in current years. In [7,8], a sensor prototype consisting of an MQ-135 gas sensor (which detects general air quality), an Arduino Uno, and an ESP8266 (for wireless fidelity (Wi-Fi) connectivity) was used to analyse the surrounding air pollution. The collected data was communicated to the user via a liquid crystal display (LCD) and a buzzer. The results were classified based on the MQ-135 ppm readings. In [8], the system was slightly improved by adding additional sensors such as MQ-6 liquefied petroleum gas (LPG) sensor, LM35 temperature sensor, etc., and a Global System for Mobile Network (GSM) communication module for interactivity with users. Similar work has been done [9] by replacing the Arduino with a NodeMCU and a SIM900. In [10], the MQ-7 carbon monoxide (CO) gas sensor was used additionally, and the ESP-01 was used for Wi-Fi connectivity. The researcher calibrated the results to match the guidelines per the United Nations (UN) data and used the ThingSpeak IoT platform to store the sensor data for presentation. In [11], the MQ-2 smoke-detecting gas sensor, along with the LM35 temperature sensor, was used to detect poor quality, which affects both the environment and human health significantly. The researcher classified the results based on the different areas, i.e., village, city, industrial, and open burning areas and established a Blynk application as an interface with the user. In [12], a sensor system controlled by an ESP-32 was built. It consisted of a DHT-22 temperature and humidity sensor, an MQ-131 ozone sensor, a MICS-6814 (which detects CO, ammonia (NH3), and nitrogen dioxide (NO2)), and a PMSA PM gas sensor. The sensor system was developed in an attempt to increase the number of monitoring stations across Brazil. The sensors' data were communicated to users via the ESP-32 Bluetooth feature. On the other hand, noise pollution was also included in an air monitoring system for a specific environment [13]. It used air sensors to detect harmful and hazardous substances like NH3, benzene, and smoke.

Recently, the Internet of Things (IoT) has become a popular technology due to widespread of Internet Protocol (IP) usage, ubiquitous connectivity, developments in data analytics, computing economics, and the expansion of cloud computing [14]. In short, the IoT connects all the physical devices in the world to the Internet. IoT also offers several advantages to users, such as ease of access, convenience, reduced costs, fewer human errors, etc. [15]. IoT-based monitoring systems have been developed successfully for various applications such as medical, agriculture, disaster, domestic, etc. [17-19,28].

Table 1. Comparison of existing work with proposed work

Authors	Pros and Cons
P. Pal et al. [7]	- easy to install and low cost - use only one sensor with limited measurement, no Wi-Fi or IoT functionality, and terrestrial range monitoring (on land)
H. N. Shah et al. [8]	- additional LPG gas, temperature and humidity measurements and smartphone connections - terrestrial range monitoring and limited Wi-Fi coverage area
I. A. Suhaidi et al. [11]	- simple system with the Blynk IoT application platform - terrestrial range monitoring, limited Wi-Fi coverage area, and limited Blynk functionality
H. P. L. D. Medeiros et al. [12]	- measure a variety of air pollutants with useful analysis done based on IQAr, with good accuracy - require Wi-Fi and Bluetooth coverage areas (not for long range), and absence of mobile monitoring stations
Proposed work	- measure all necessary air pollutants required to calculate the air quality accurately based on API - use Wi-Fi and LoRa technologies to cover a wide range of areas for air monitoring and interconnect all mobile stations with IoT platform, able to monitor the air quality in space

One of the huge challenges IoT devices and networks face is the ability to send and receive data through the Internet constantly. Long Range (LoRa) technology, which is a wireless low-power radio frequency technology, is a common solution and technology used by IoT networks worldwide [20]. LoRa has effectively become the backbone of the IoT because of its wide coverage area.

Therefore, a smart air quality monitoring system uses IoT, and LoRa can be built with several hardware components and software. Through a mobile and IoT-based air quality monitoring system, accurate air quality information can be made available and accessible to users such as the public, environmental authorities, etc., anywhere and anytime at a low cost. The aim of this paper is to develop an accurate, remote, low-cost, and efficient air quality monitoring system. The proposed system consists of two core parts: the sensor system and the ground terminal. The sensor system consists of various gas sensors to measure air quality parameters such as carbon monoxide (CO), carbon dioxide (CO2), ammonia compounds (NHx), sulphur dioxide (SO2), ozone (O3), particulate matter (PM)2.5, and PM10 particles and send the data to the ground terminal via LoRa transmission—the ground terminal acts to receive the collected data and upload it onto the IoT platform.

The web application can access the data in real time by communicating with the IoT platform. The prototype's functionality and the measured data's accuracy will be tested in different areas and environments by comparing the results with different data sets collected. Manual data analysis through statistical measures such as standard deviation, mean, etc., will then be performed to categorise the data in each area where the remote sensor system is tested. The current pollutant readings and Air Pollution Index (API) can be viewed on a web application developed based on the open-source framework streamlit [21]. The novelty of the proposed work has been clearly addressed and compared with existing works in Table 1. As stated, the research gap in the air monitoring system is the coverage of the area and the ability to monitor air quality in the air space remotely. The drawbacks of the existing work will be solved and improved in this research using Wi-Fi, LoRa and IoT technologies.

The following section in this paper will describe the system architecture of this prototype in detail in terms of its hardware and software perspectives. Besides that, the results obtained from the system and web application will be presented and discussed.

2. System Architecture

2.1. System Overview

Figure 1 represents a high-level view of the overall system architecture. The sensor system is a remote system that should communicate with the ground terminal via the LoRa communication protocol. The sensor system comprises various sensors integrated into a microcontroller to sense several parameters, which are CO, SO2, O3, PM2.5, PM10, etc. The ground terminal will redirect the received data to the selected IoT platform using Wi-Fi. The web application and IoT platform will communicate with each other, i.e., read data via Wi-Fi. The user can view the readings in the web application, which can retrieve the data from the database via API.

2.2. Hardware Description

Figure 2 and Figure 3 depict the schematic diagrams of the sensor system and ground terminal, respectively. The items used have been tested and calibrated if there is a necessity to use appropriate resistors. The role that each item plays in the respective parts of the system has been summarised in Table 2.

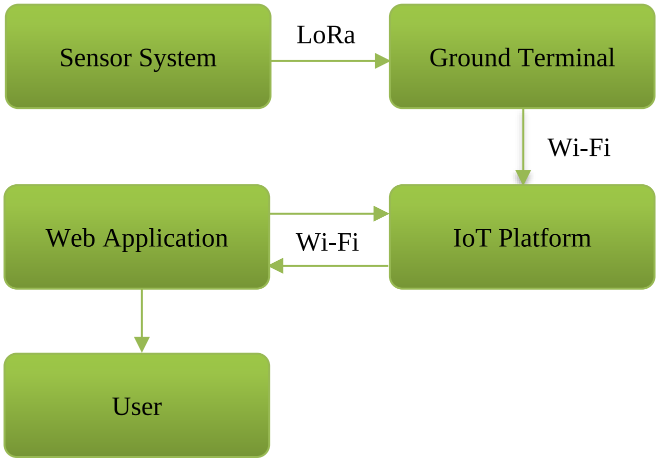


Fig. 1 Overall architecture

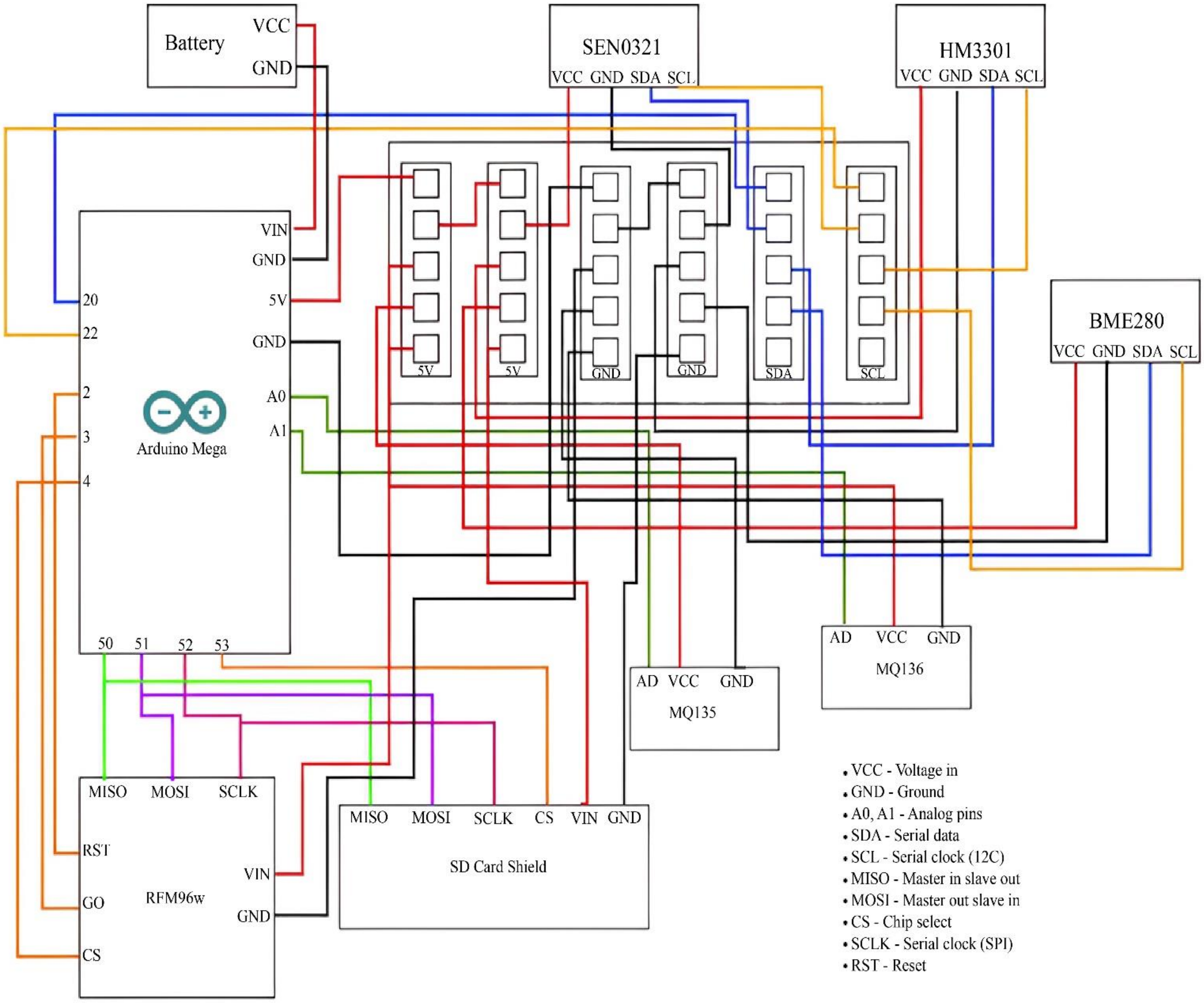


Fig. 2 Sensor system schematic diagram

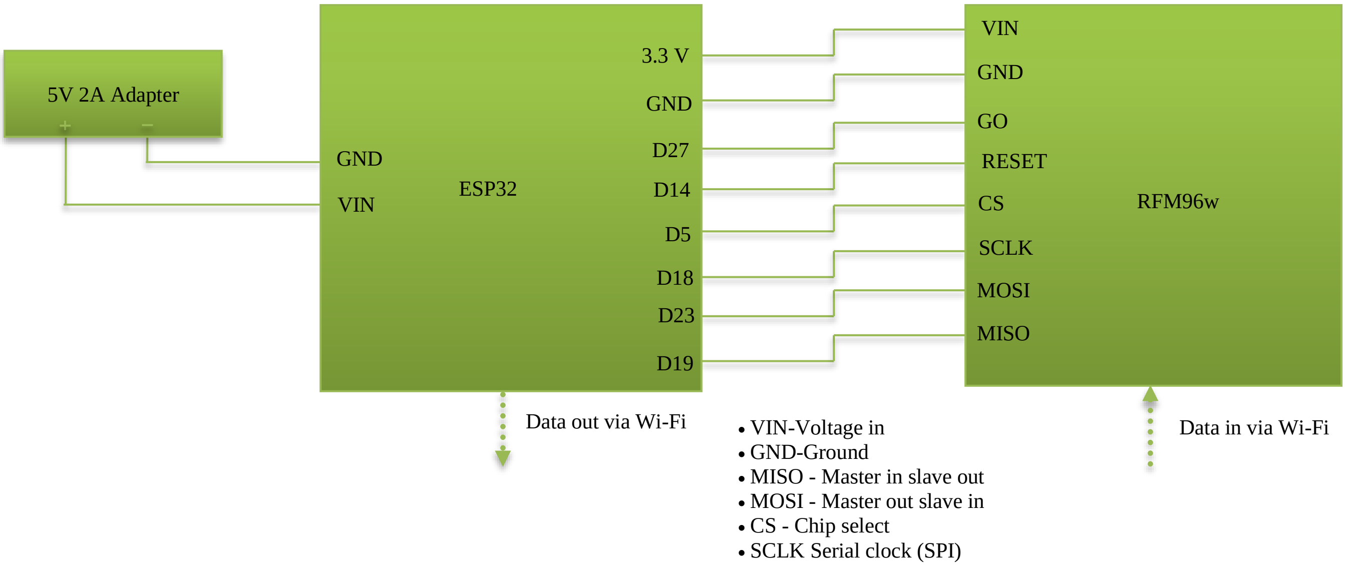


Fig. 3 Ground terminal schematic diagram

Table 2. Components and their roles

Components	Role
Arduino Mega 2560	A microcontroller is used to control the overall operation of the sensor system.
ESP32	A microcontroller with Wi-Fi capability is used to process the data received from the LoRa transceiver and upload it to the selected IoT platform.
RFM96w	- For the sensor system, it acts to send all the data as a LoRa message - For the ground terminal acts to receive the data from the other LoRa transceiver
MQ-135	Senses CO, CO2, and NHx gasses
MQ-136	Senses SO2 gas
SEN0321	Senses O3 gas
HM3301	Senses particulate matter, PM2.5 and PM10
BME280	Measures temperature, humidity and atmospheric pressure
MicroSD Card Shield	Interfaces the external card to the Arduino Mega

The connections are made on a breadboard, and a 11.1 V, 1100 mAh battery can provide sufficient voltage and current. For MQ-135 and MQ-136, the analog inputs are used to obtain their voltage and determine their respective pollutants concentrations. For HM3301, SEN0321, and BME280, the I2C interface is used, where all three components share the Serial Data (SDA) and Serial Clock (SCLK) pins. There is no conflict between the three components as they have different I2C addresses. The Serial Peripheral Interface (SPI) pins of the microcontroller are used to connect the SD cards shield appropriately, where the microcontroller has its own designated SPI pins: 50-Master In Slave Out (MISO), 51-Master Out Slave In (MOSI), and 52-Serial Clock (SCLK). The chip select pin for the SD card is selected as pin 53. The Serial Peripheral Interface (SPI) pins are used between the LoRa transceiver and microcontroller, where the SPI pins, MOSI, MISO, and SCK of the microcontroller are allocated to the LoRa transceiver. The chip select pin can be any General Purpose Input Output (GPIO) pin randomly chosen for the ESP-32, D18, and Arduino Mega.

2.3. Software Description

The program's flowcharts programmed into the microcontrollers of the sensor system and ground terminal are depicted in Figure 4 and Figure 5 correspondingly. In the sensor system, after necessary variable definitions and library imports are made, the sensors and LoRa transceiver will be initialised to confirm that all the components have been connected and detected successfully by the microcontroller. Upon successful initialization, the sensor operation will begin, where the sensors will start to sense the parameters they are sensing. After all the readings have been obtained, the readings will be embedded into a message separated with unique delimiters, i.e., “?”, “/”, etc., to be sent to the ground terminal as a LoRa packet. The message copy will also be stored on the SD card for backup purposes in the event of unexpected events. The ground terminal program will need to connect to Wi-Fi, Firebase Firestore (a selected IoT platform) [22], and LoRa. Once the ground terminal connects successfully, it will wait to receive packets from the other LoRa transceiver. Upon receiving the packet, the microcontroller will analyse the packet and retrieve the data from it based on the preset delimiters. The data retrieved will be uploaded to the IoT platform. This process will continue until the maximum number of packets to be received is reached.

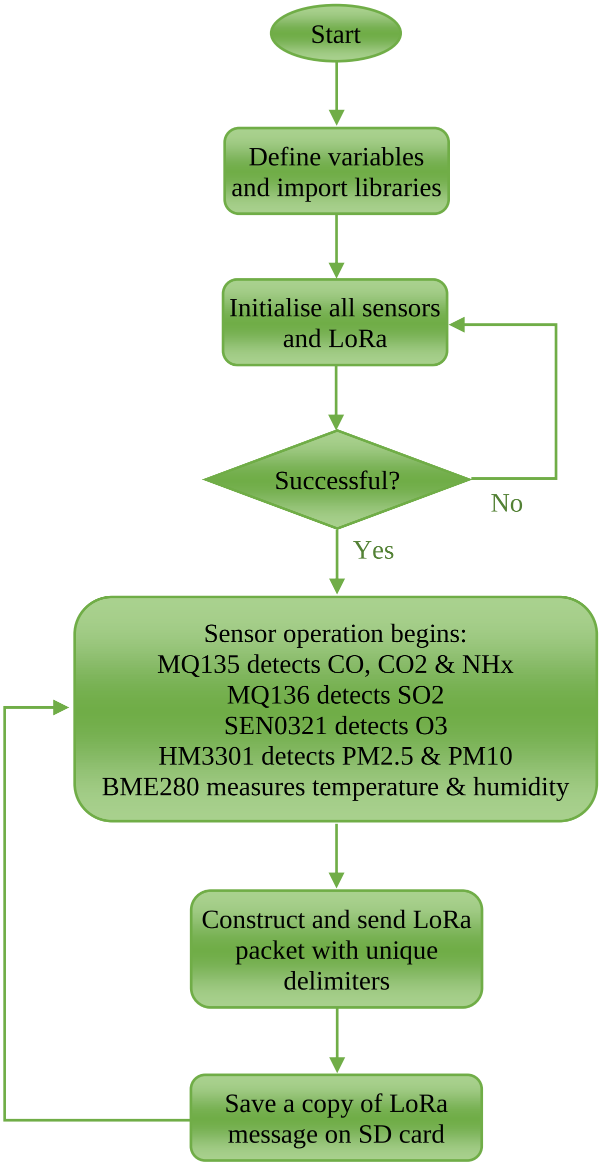


Fig. 4 Sensor system flowchart

The remote sensor system can be brought to any location, regardless of whether there is an existing Wi-Fi connection. However, the ground terminal must be connected to Wi-Fi. The sensor system and ground terminal will operate as described earlier in real-time. When there are updates in the IoT database, the web application will retrieve the values, calculate the API, and display all the values. The API has been calculated using the formulas set by the Malaysia Department of Environment (DOE) [23].

3. Results and Discussion

3.1. Experimental Testing

A series of experiments have been conducted in different environments to ensure that all the sensors used output accurate and reliable measurements.

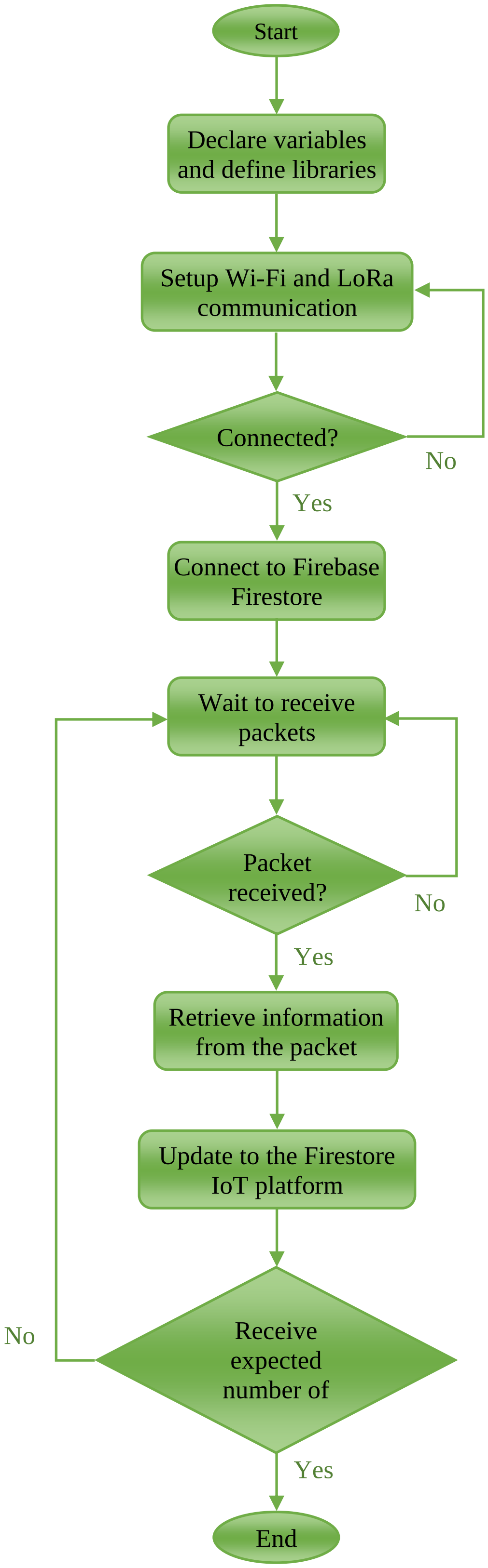


Fig. 5 Ground terminal flowchart

The first environment is the normal environment, where the sensor system has been placed under normal circumstances in a residential area. The second environment, on the other hand, is a polluted environment in which the sensor system has been positioned near a car exhaust pipe, and the car's accelerator is pressed at regular intervals to release polluted gas from the exhaust. The results are collected simultaneously. The data collected from the two sensors have been compared, and the differences have been tabulated using the equation below:

$$\%Difference = \frac{v_1 - v_2}{\left(\frac{v_1 + v_2}{2}\right)} \times 100\% \qquad (1)$$

where v_1 and v_2 refer to the different concentration values obtained from the two different sensors.

3.1.1. Temperature, Pressure and Humidity Sensors

Table 3 and Table 4 show the results of a comparison between all temperature, pressure, and humidity measurements in different environments. Only a few data points from the huge dataset have been selected and compared with Equation 1. For the temperature, humidity, and atmospheric pressure, the readings are compared between BME280 (which measures all three components), BMP180 (which measures only atmospheric pressure), and DHT22 (which measures temperature and pressure). Most differences fall within the 10% range, which is deemed acceptable, except for the humidity in a polluted environment. This may be due to the instability of air quality polluted by the gas from car exhaust pipes. Nonetheless, the abnormal measurements only exist for a short period of time.

3.1.2. Gas Sensors

Table 5 and Table 6 show the results of comparing all gas sensors in both normal and polluted environments. Most of the differences again fall within the 10% range, which is deemed satisfactory. The sensors behave similarly in a normal environment where air quality is more stable. In a polluted environment, the percentage differences are higher due to unstable air quality, as different sensors may have different response rates. However, once the air quality becomes stable again, for example, five minutes after the pedal has been pressed, the air quality becomes quite similar once again.

For PM gases, the readings from the SEN0177 PM sensor are used to compare with the HM3301 PM sensor's readings. For O3 gas, the readings produced by the SEN0321 gas sensor are compared with the readings from the MQ-131 sensor. Two similar MQ-135 gas sensors are compared to measure the CO, CO2, and NHx levels, whereas two similar MQ-136 gas sensors are used to compare the differences in measuring the SO2 levels between each other.

Table 3. Measurement differences of temperature, pressure, and humidity in the normal environment

Measured Quantity	**Maximum Difference (%)**						
	Data 1	Data 2	Data 3	Data 4	Data 5	Data 6	Data 7
Temperature	4.24	4.41	4.63	4.59	4.43	4.23	4.2
Pressure	0.341	0.321	0.33	0.321	0.325	0.314	0.315
Humidity	4.46	4.62	5.67	4.93	5.52	4.09	5.3

Table 4. Measurement differences of temperature, pressure, and humidity in a polluted environment (exhaust air)

Measured Quantity	**Maximum Difference (%)**						
	Data 1	Data 2	Data 3	Data 4	Data 5	Data 6	Data 7
Temperature	4.71	7.2	7.97	6.45	6.98	7.29	4.2
Pressure	0.463	0.451	0.448	0.456	0.40	0.461	5.32
Humidity	9.87	6.61	2.42	9.15	13.62	2.89	12.78

Table 5. Measurement differences of gas sensors in the normal environment

Gas Substance	**Maximum Difference (%)**						
	Data 1	Data 2	Data 3	Data 4	Data 5	Data 6	Data 7
CO	1.55	0.76	0.54	5.29	4.41	1.51	4.29
CO2	0.007	0.005	0.002	0.025	0.02	0.007	0.02
NHx	0.93	0.70	0.24	3.43	2.79	0.77	2.60
PM2.5	6.45	0	5.71	5.71	5.71	5.71	5.71
PM10	5.41	0	10	10	5.13	5.13	5.13
SO2	2.47	2.30	2.30	0	2.35	4.65	9.10
O3	2.79	2.79	6.48	2.79	6.48	6.48	2.79

Table 6. Measurement differences of gas sensors in a polluted environment (exhaust air)

Gas Substance	Maximum Difference (%)						
	Data 1	Data 2	Data 3	Data 4	Data 5	Data 6	Data 7
CO	0.51	0.72	4.34	6.83	8.80	2.89	4.29
CO2	0.002	0.007	0.29	0.54	7.21	0.09	0.007
NHx	0.23	0.72	2.74	4.29	5.55	1.79	0.15
PM2.5	2.60	6.67	7.41	3.92	7.69	5.56	3.92
PM10	6.32	8.70	6.45	9.84	9.84	4.76	6.90
SO2	7.19	6.35	9.17	3.60	3.41	7.56	5.88

3.2. Pollutants Measurement

3.2.1. Pollutants Indicator

The pollutants are classified into three distinct categories, as shown in Table 7, based on the sources [24-26]. The values set match the experimental values obtained from several tests done on the sensors. For SO2, the values have been adjusted slightly so that the “good” range has been categorised below 0.5 ppm. According to the SO2 classification chart described previously, the good and average ranges fall below 0.2 ppm. However, according to the United States Environmental Protection Agency (USEPA), the three-hour SO2 standard level was set at 0.5 ppm. The readings obtained from the sensor match more towards the 3-hour SO2 standard level; hence, only for the “good” range, the value has been modified to 0.5 ppm.

3.2.2. Statistical Measurement

The air quality monitoring system has been successfully constructed, as shown in Figure 6 and Figure 7. The system has been tested in three distinct types of areas, which are residential, commercial, and industrial, located around Klang Valley, Malaysia. To observe the changes between the air quality measurements in the three different areas, the pollutant concentrations have been analysed in terms of their range of values, mean, standard deviation, and mode [27]. The range of the pollutant represents the maximum and minimum concentrations that each pollutant may have, which can give a hint if there are possibilities of unhealthy values present. The pollutant’s mean helps us summarise the behaviour of the pollutant with a single concentration value. With a single value, it allows us to classify the pollutant readings easily. The standard deviation shows how random the concentration of each pollutant was. A random standard deviation (value closer to 1) indicates that the pollutant concentration in the environment is constantly changing. The mode represents the concentration value that appears most frequently in the dataset, which allows us to observe how much the mean value varies from the most frequently occurring value. Table 8, Table 9, Table 10, and Table 11 represent the calculated mean, range, standard deviation, and mode for each pollutant, respectively.

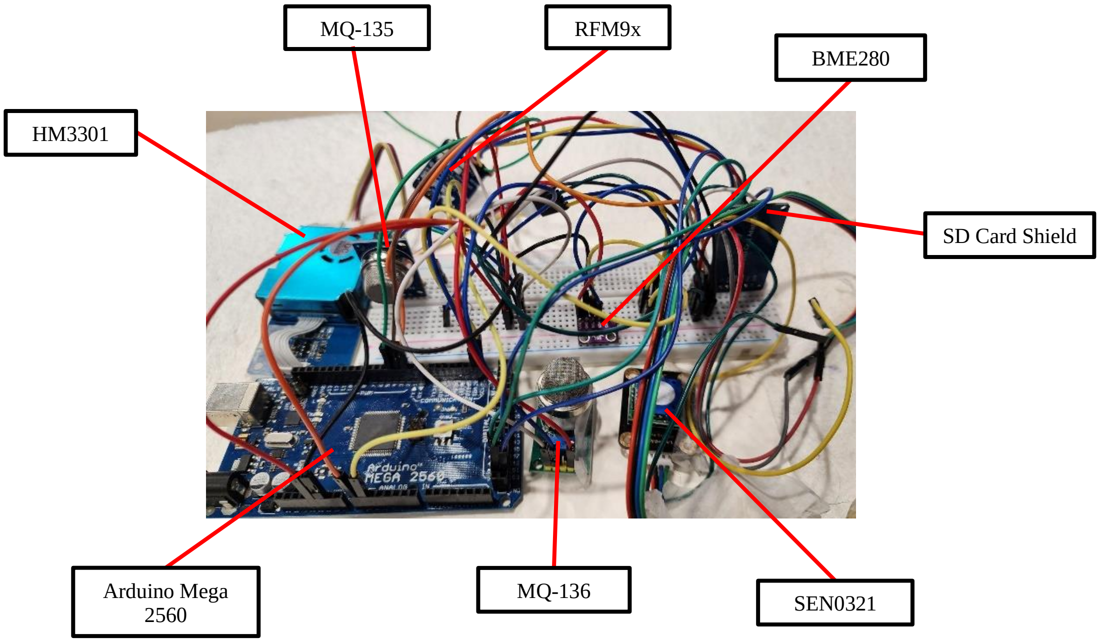


Fig. 6 Sensor system

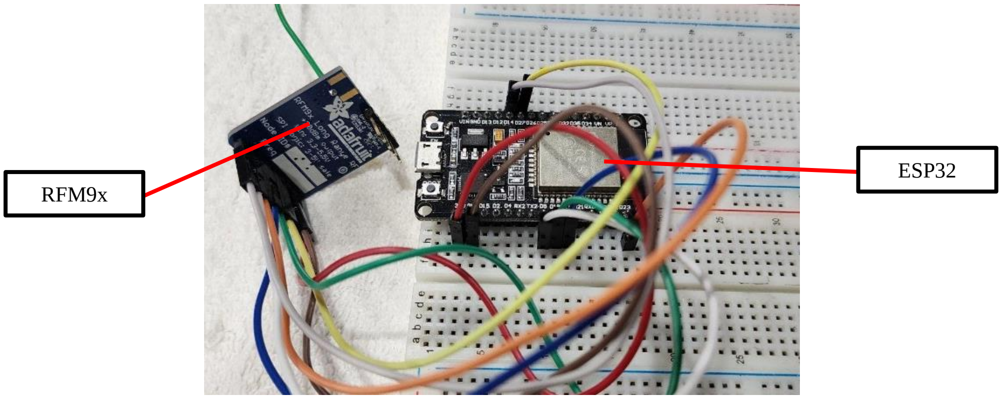


Fig. 7 Ground terminal

3.2.3. Statistical Analysis

PM2.5 and PM10 Gas

The dust levels in the specific residential area are considered average as they fall between 12 µg/m^3 and 35.4 µg/m^3, whereas the dust levels in the commercial and industrial areas are considered good as they fall below 12 µg/m^3. The dust levels in the residential area are expected to be average as it is a newly constructed building where dust remaining from construction work may exist.

Table 7. Pollutants classification chart

Pollutants	**Categories**		
	Good	Average	Bad
CO (ppm)	<= 3	<= 10	> 10
SO2 (ppm)	<= 0.5	<= 1	> 1
O3 (ppb)	<= 54	<= 85	>= 86
PM2.5 (ug/m^3)	<= 12	<= 35.4	>= 35.5
PM10 (ug/m^3)	<= 12	<= 35.4	>= 35.5

Table 8. Mean of pollutant values

Pollutants	**Area**					
	Residential	**>= Mean (%)**	**Commercial**	**>= Mean (%)**	**Industrial**	**>= Mean (%)**
		< Mean (%)		**< Mean (%)**		**< Mean (%)**
PM2.5 (µg/m^3)	15.036	39.496	3.710	54.446	9.888	67.742
		60.504		45.554		32.258
PM10 (µg/m^3)	16.129	44.258	3.710	54.446	9.888	67.742
		55.742		45.554		32.258
SO2 (ppm)	0.185	41.737	0.227	46.648	0.911	42.473
		58.263		53.352		57.527
O3 (ppb)	19.948	90.616	19.969	97.264	78.816	24.731
		9.384		2.736		75.269
CO (ppm)	0.251	31.373	0.968	29.685	1.834	39.113
		68.627		70.315		60.887

Table 9. Range of pollutant values

Pollutants	Area		
	Residential	Commercial	Industrial
PM2.5 (µg/m^3)	13 - 20	3 - 10	7 - 13
PM10 (µg/m^3)	13 - 20	3 - 10	7 - 13
SO2 (ppm)	0.08 - 0.39	0.17 - 0.35	0.33 - 2.7
O3 (ppb)	0 - 58	17 - 20	0 - 494
CO (ppm)	0 - 3.93	0.63 - 3.61	0.66 - 4.47

Table 10. Standard deviation of pollutant values

Pollutants	Area		
	Residential	Commercial	Industrial
PM2.5 (µg/m^3)	1.623	0.920	1.277
PM10 (µg/m^3)	2.703	0.920	1.277
SO2 (ppm)	0.066	0.033	0.402
O3 (ppb)	7.167	0.204	116.475
CO (ppm)	0.499	0.365	0.953

Table 11. Mode of pollutant values

Pollutants	Area		
	Residential	Commercial	Industrial
PM2.5 (µg/m3)	14	4	11
PM10 (µg/m^3)	14	4	11
SO2 (ppm)	0.13	0.19	0.54
O3 (ppb)	20	20	20
CO (ppm)	0	0.76	0.8

SO2 Gas

The levels of the pollutant SO2 in both residential and commercial areas are also acceptable since the maximum value is below 0.5 ppm. However, the SO2 levels can be categorised as hazardous in industrial areas. This is because the mean value is 0.911 ppm and the mode is 0.54 ppm, both of which fall into the average category, but there have been 273 occurrences where the concentration exceeded 1 ppm (hazardous level), accounting for approximately 37% of the data.

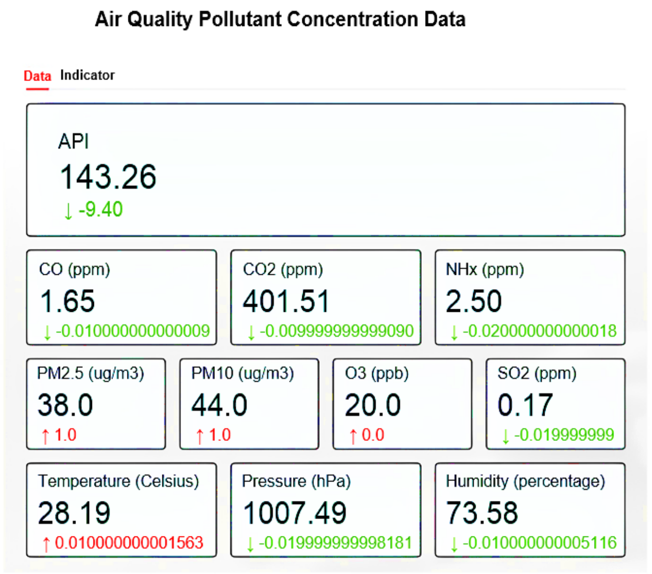
O3 Gas

The levels of the pollutant O3 in both residential and commercial areas are considered good since the mean value is approximately 19.9 ppb. The standard deviation from the mean value for commercial areas is minimal. On the other hand, the residential area's standard deviation is higher, possibly due to anomalous results that can be traced. It is deemed anomalous as the mean value is 19.948 ppb and the mode is exactly 20 ppb, which occurs 598 times out of 731 times, where most of the data fall within the acceptable range. In the industrial area, the ozone levels are considered harmful because the mean value is around 78.816 ppb. Although the mode for the area is 20 ppb, almost 25% of the data are above the mean value, indicating that the collected data has some harmful ozone concentrations. The maximum value reached is 494 ppb. The values for ozone in the industrial area have major fluctuations around the mean value, which shows that the ozone concentrations in the area have not been stable.

CO Gas

The levels of the pollutant CO in the residential area are extremely low since the mean concentration is 0.251 ppm, and 68.627% of the values fall below this mean value. Besides that, the standard deviation is also low, at 0.499. In the commercial area, the CO levels are slightly higher than in the residential area at 0.968 ppm mean value; however, they still fall below the safe range of below 3 ppm. There are only 6 instances out of 714 and 4 instances out of 731 where the CO levels in residential and commercial areas exceed 3 ppm, respectively. This is due to the sensor's initial behaviour at the beginning of the operation, when it has yet to stabilise. However, in the industrial area, the CO levels are not as good as in the other two areas. The mean CO value in the industrial area is reported as high as 1.834 ppm, where approximately 39% of the values are above the mean. There are 120 instances out of 744 where the CO levels exceed 3 ppm, indicating that the CO levels are less than ideal, with more than 10% of the data indicating unhealthy CO levels.

The statistical analysis reported here shows that the developed system can provide reliable and accurate air quality measurements in all three areas, which are residential, commercial, and industrial. This is because the prototype can collect data in space using a LoRa module to transmit the data back to the ground terminal, which other existing works have not been accomplished so far.



Air Quality Pollutant Concentration Data

Data Indicator

API
143.26
↓ -9.40

CO (ppm)
1.65
↓ -0.010000000000009

CO2 (ppm)
401.51
↓ -0.009999999999090

NHx (ppm)
2.50
↓ -0.020000000000018

PM2.5 (ug/m3)
38.0
↑ 1.0

PM10 (ug/m3)
44.0
↑ 1.0

O3 (ppb)
20.0
↑ 0.0

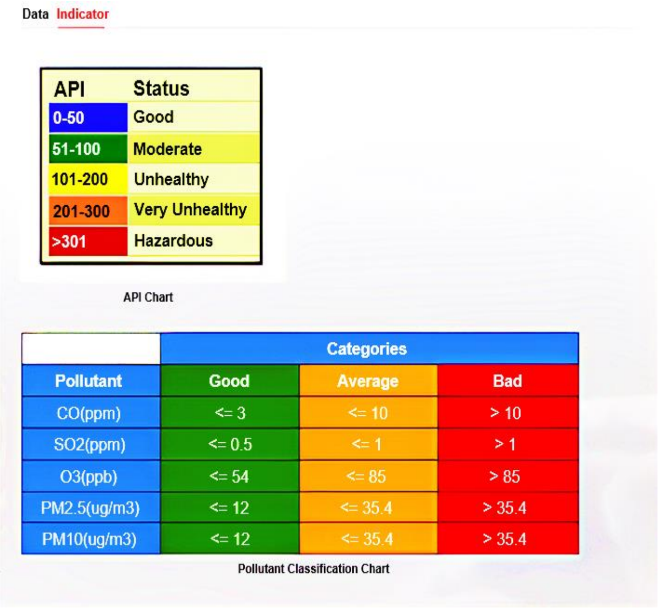
SO2 (ppm)
0.17
↓ -0.019999999

Temperature (Celsius)
28.19
↑ 0.010000000001563

Pressure (hPa)
1007.49
↓ -0.019999999998181

Humidity (percentage)
73.58
↓ -0.010000000005116

Fig. 8 Data tab



Data Indicator

API	Status
0-50	Good
51-100	Moderate
101-200	Unhealthy
201-300	Very Unhealthy
>301	Hazardous

API Chart

	Categories		
Pollutant	Good	Average	Bad
CO(ppm)	<= 3	<= 10	> 10
SO2(ppm)	<= 0.5	<= 1	> 1
O3(ppb)	<= 54	<= 85	> 85
PM2.5(ug/m3)	<= 12	<= 35.4	> 35.4
PM10(ug/m3)	<= 12	<= 35.4	> 35.4

Pollutant Classification Chart

Fig. 9 Indicator tab

3.3. Web Application Results

The web application has also been successfully developed, as shown in Figure 8 and Figure 9. There are two tabs available on the web application for the user. The first tab, “Data”, appears as in Figure 8, where the user can view the current pollutant concentration readings and the meteorological parameters, i.e., temperature, humidity, and atmospheric pressure. The user can also know how much the value has changed from the previous value by looking at the indicator value right below the reading. A green label is used when the value reduces, indicating a good change, whereas a red label is used to denote an increase, indicating a bad change in the pollutant concentration or API. From Figure 8, the API reading at that point in time is 143.26. The API reading is calculated based on that particular time’s concentration for CO (1.65 ppm), PM2.5 (38 µg/m^3), PM10 (44 µg/m^3), O3 (20 ppb) and SO2 (0.17 ppm).

Meanwhile, an indicator chart will be shown in the application to guide users about the significance of each current pollutant concentration and API reading. The API Chart is the level to which Malaysia adheres, and the pollutants classification chart is developed based on air quality-related sources found online. The “Indicator” tab is shown in Figure 9. According to the API reading in Figure 8, the API value is rather unhealthy (yellow reading), which is expected due to PM levels falling under the average category, which influences the API reading to be higher.

4. Conclusion

Due to the current alarming pollution rate, authorities have recommended that more air quality monitoring systems be built. However, fixed monitoring stations are costly; hence, this paper aims to describe how to construct a remote IoT-assisted air quality monitoring and analysis system whose data will be available to users anytime and anywhere via the developed web application. The sensors used in this research have been tested and verified to provide acceptable values. Besides that, the system has also been tested in three distinct areas, and the ability of the air quality monitoring system to adapt to different environments has also been tested. The analysis of the results in terms of mean, standard deviation, etc., shows that the system can adapt successfully to changes in the environment. The web application developed can present users with all the required information, such as APIs, sensed parameter values, and indicator charts that act as a reference for users. All these features can enhance the functionality, reliability, and practicability of the existing works, as mentioned in the literature review.

Nevertheless, the project can be improved by adding an additional sensor for NO2 gas. The NO2 gas is an important pollutant to be measured, affecting the API. All the gas sensors can be better calibrated in the presence of test gases, which would improve the accuracy of the air quality monitoring system. A Printed Circuit Board (PCB) can be designed to reduce space and improve the visual aspects of the prototype.

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