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IoT-Based Real-Time Air Quality Surveillance System using Arduino Uno

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Abstract: Recently, air pollution has become a critical environmental concern globally as a result of rapid population growth, increasing vehicle emissions, industrialization, and urbanization. They are all factors that can negatively impact human health and the respiratory system. Consequently, this study presents a low-cost, Internet of Things (IoT)-based air quality monitoring system designed to provide real-time local and remote assessments of air pollution levels. The proposed system integrates an Arduino Uno microcontroller, an MQ135 gas sensor, and a NodeMCU ESP8266 Wi-Fi module for data collection, processing, and wireless transmission. The MQ135 sensor is used to monitor changes associated with different kinds of gaseous pollutants such as carbon dioxide, smoke, alcohol vapors, benzene, and ammonia. The MQ135 sensor data are processed by the Arduino Uno and displayed on an LCD screen as indicative air quality values. In addition, the air quality level is assessed according to predefined pollution thresholds. When the measured pollutant concentration exceeds a predefined safe limit, the system triggers an alert to indicate unsafe air pollution conditions. Besides that, the collected data is sent to the ThingSpeak cloud platform, where it is stored, analyzed, and displayed graphically as time-sequence graphs via a web interface. This allows users to remotely monitor air quality in real time using a computer or mobile device with an internet connection. Overall, the proposed system offers a simple, cost-effective, and accessible IoT-based solution for continuous air quality monitoring and early detection of potentially hazardous pollution.

Keywords: IoT, Air quality level, Arduino Uno, Gas sensor.

1. Introduction

1.1 Overview

Pollution is one of the most serious environmental problems of today's society as it affects the environment, the quality of life and human health [1]. The traditional air quality monitoring stations have high costs of installation, operation, maintenance and laboratory analysis [2][3]. These restrictions point to the need for smart and cost-effective monitoring systems and also the ability to collect and send real-time environmental data continuously for the assessment of air quality and monitoring of environmental pollution [4]. The Internet of Things (IoT) is a web of real-world objects that can sense and/or communicate with each other through the internet, thereby extending the Internet's reach to these physical things [5]. By combining sensors, wireless communication technology and cloud platforms, IoT technology can be leveraged to create an effective and easy-to-use environmental pollution monitoring system. In this context, the low-cost micro-controller, like the Arduino Uno, can be used to combine with environmental sensors to capture and process the air quality data. The MQ135 gas sensor is highly sensitive to a variety of gaseous contaminants such as ammonia, benzene, alcohol fumes and smoke and is widely used in air quality measurement applications [6]. Considering the above capabilities, the design and implementation of a low-cost, IoT based air quality monitoring system using Arduino Uno microcontroller, MQ135 gas sensor and NodeMCU ESP8266 Wi-Fi module is proposed in this study. The Arduino Uno collects the real-time data from the sensor, and an I2C LCD displays the air quality data locally. In addition, if the measured value is found to be above a certain limit, an alarm is sounded, alerting the user to high sensor readings. The wireless data transfer module ESP8266 allows the data to be transferred to the cloud-based platform ThingSpeak for storage and viewing the measurements graphically so that users can remotely monitor how air quality varies over time [7]. Therefore, the main goal of the proposed system is to enable low-cost and easy to use continuous air quality monitoring by incorporating local monitoring, threshold-based alert and cloud-based air quality data visualization. The purpose of the system is to enable the monitoring of changes in air quality indicators and open access to recorded environmental data remotely.

1.2 Related work

The development of Internet of Things (IoT) based Air Quality Monitoring Systems with the different sensing technologies, microcontroller and communication platforms have been studied. The systems are designed to offer affordable solutions in continuous environment monitoring, real-time data collection and access to air quality information from remote locations. In [8] the authors designed an inexpensive monitoring system for the measurement of particulate matter (PM2.5 and PM10), temperature and humidity in real-time using an ESP8266 NodeMCU module. The system was designed to send the data over the internet using Wi-Fi to a remote server and include a GPS module for tracking the location. A one-month field experiment showed the system's ability to detect high pollution zones, and high pollution times. The research team in [9] designed an IoT system for air pollution monitoring which can measure various air pollutants and environment parameters. A 3D printed protective housing was designed to resist tropical environmental conditions and added to the system. In [10] researchers have designed an air pollution monitoring system using the internet of things technology and machine learning techniques to deliver air pollution information and health advice in real time. A Decision Tree classifier was used to make personalized recommendations and real-time data was synchronized using the Firebase platform. A low-cost air quality monitoring station was made in [11] by building it based on MQ7, MQ135 and DHT11 sensors with the use of the ThingSpeak cloud platform. The study also explored the use of blockchain technology to enhance the transparency and trustworthiness of environmental data.The researchers in [12] have developed an IoT-based indoor air quality monitoring system based on calibrated low-cost sensors for measuring carbon dioxide (CO_2), particulate matter (PM2.5 and PM10), temperature and humidity. The system was installed in 84 households and enabled real-time measurements and notifications via a cell phone application.

The results of these studies indicate the importance of using IoT technologies for monitoring air quality and that is by using low-cost sensors, wireless communication, cloud-based platforms and automatic warnings. But the reviewed systems have varying sensing capabilities, experimental conditions, calibration methods and performance evaluation procedures. Table 1 shows a comparison of the main contributions, technologies and evaluation approaches of the existing air quality monitoring systems based on the use of IoT.

Table 1: shows the comparative analysis of the existing air quality monitoring systems based on IoT.

Main contribution	Quantitative Evidence/Assessment	physical components (Sensors /platforms)	Ref.
Mobile air pollution monitoring and critical point identification.	The study was field-based and lasted for only one month, and samples were taken every 5 seconds, compared to the PurpleAir system.	ESP8266 NodeMCU, PM10 and PM2.5 sensors, DHT22 sensor, GT-U7 GPS module	[8]
Multi-pollutant monitoring system equipped with a protective enclosure designed for tropical environments.	Prototype of an environmental monitoring system.	IoT-based multi-sensor monitoring stations equipped with sensors for measuring ambient temperature, relative humidity, and pollutant concentrations.	[9]
Health advisories and pollution-aware route recommendations.	ML-based prediction and advisory functions; numerical accuracy not verified.	IoT-based multi-sensor monitoring station.	[10]
Low-cost monitoring and greater transparency of data.	Test a prototype and assess the blockchain.	MQ7, MQ135, DHT11, ThingSpeak, Blockchain.	[11]
Indoor Air Quality Monitoring and user alert.	84 home field study; Reference comparison; 52 homes were reduced by a mean of 10.3% CO_2.	Calibrated CO_2 and PM sensors, mobile application.	[12]
Monitoring and awareness of air quality.	Prototype implementation; no quantitative accuracy verified.	Arduino, Gas Sensors, ThingSpeak, Android.	[13]
Local gas display and sound alarms.	Prototype demonstration, quantitative accuracy not verified.	Arduino Uno, MQ135, MQ6, Wi-Fi, LCD.	[14]
Local and remote monitoring and alarming using thresholds.	Only a model was demonstrated, quantitative accuracy was not checked.	Arduino Uno, MQ135, MQ6, ESP8266.	[15]
Air quality remote monitoring and visualization of readings.	Prototype implementation; quantitative accuracy not verified.	MQ135, I2C LCD, web-based database.	[16]
Local visualization, cloud-based monitoring, and buzzer alerts.	**Functional prototype; accuracy validation using a reference not yet reported.**	**Arduino Uno, MQ135, ESP8266, and ThingSpeak.**	**Proposed system**

In [13] an Arduino based air pollution monitoring system and awareness system was designed by creating an Arduino based system to monitor air pollution levels, a graphical information system and an air quality indicator system using the platform ThingSpeak and an Android application. A system for air pollution monitoring using gas sensors MQ135 and MQ6, Wi-Fi connection, LCD display and an audible alarm, which alerts the user if concentration of air pollutants is greater than a set limit, was proposed by the researchers in [14]. In the same way, the authors of [15] designed an air quality monitoring system for local and remote monitoring based on the Arduino Uno board and its sensors (MQ135 and MQ6), the wireless connectivity module ESP8266, an LCD screen and a buzzer. Lastly, the air quality monitoring system in [16] proposed an IoT based air quality monitoring system, which consisted of an MQ135 gas sensor, an I2C LCD display and the ability to store data online to access air quality readings remotely.

The comparative analysis in Table 1 shows that different air quality monitoring systems using the IoT have adopted different methods in the field of the environment sensing, wireless communication, cloud visualization, and automatic alerts. There are several studies where the integration of low-cost hardware is discussed but there are others that also enable additional features such as machine learning, blockchain integration and mobile pollution mapping. These developments show that the use of traditional microcontrollers, sensors and cloud platforms is well documented in the science literature. Despite the advances, there are still many problems in assessing the accuracy and reliability of the low cost air quality monitoring systems. Comparisons of performance are difficult because of differences in the characteristics of various sensors, calibration procedures, environmental conditions and experimental methods. The MQ135, in particular, can be cross sensitive to other gaseous compounds, and therefore the measurements made by the sensor may be difficult to interpret. While a few previous studies have included calibration and reference-based validation, the reliability of the low cost sensing systems is still dependent on the measurement conditions, calibration procedures, and evaluation methods used. The main objective of the present study is to design and develop a low-cost air quality monitoring system using the Arduino Uno microcontroller, MQ135 gas sensor and ESP8266 Wi-Fi module. It includes local information visualization, threshold-based audible alerts, and remote monitoring in the ThingSpeak cloud platform. The functionalities which have been investigated in the previous studies have been implemented in the developed prototype, which offers a practical platform to research operational capacity and limitation of air quality monitoring using MQ135.

2. Architecture of Air Pollution Surveillance System

The proposed air pollution monitoring system was implemented using low-cost, readily available hardware components that are fully compatible with the Arduino Uno platform as shown in Table 2. Besides that, the hardware configuration was integrated with the ThingSpeak cloud platform in order to transfer data and analysis. Figure 1 shows the connecting of the main hardware components of the system.

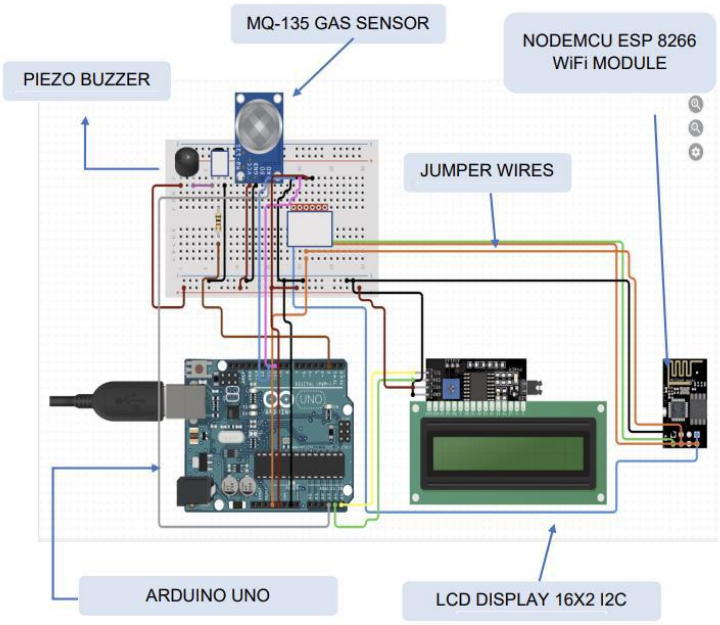


Figure 1: The connection of the system components

Table 2: The hardware components for the system with the benefit for it

Component	Purpose
Arduino Uno	Provides the power supply
MQ135 Gas Sensor	Detects gases from the surroundings
NodeMCU ESP8266 Wi-Fi Device	Stores data and programs and provides microcontroller/Wi-Fi capability
0.5 m Arduino A-B Cable	Connects the Arduino Uno to a laptop
16×2 I2C LCD (Liquid Crystal Display)	Displays the air-quality measurement in PPM and the level of concern
Jumper Wire	Interconnects components on the breadboard
Buzzer	Provides an audible alert when the sensor is triggered
Breadboard	Provides a platform for interconnecting the components

The Arduino Uno board is the central microcontroller unit in the air pollution system, which interfaced with the MQ135 gas sensor by the VCC, GND, and A0 pins. To provide local visualization of the measured air quality parameters, an I2C LCD module screen was connected to the Arduino Uno, with pins A4 and A5 assigned to the SDA and SCL communication lines, respectively. Also, the power and ground ports of the Arduino Uno and the I2C LCD. In addition, a NodeMCU ESP8266 Wi-Fi module was interfaced with the Arduino Uno to provide wireless connectivity to the internet and establish communication between the hardware unit and the database [17][18]. Figure 2 depicts the architecture for the proposed system.

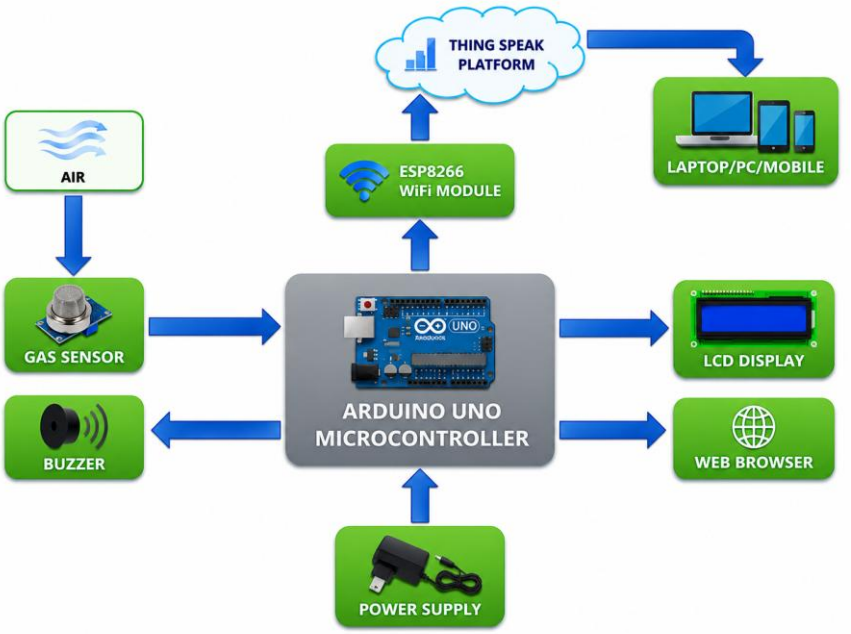


Figure 2: The architecture for the system

Knowing that, the MQ Series gas sensors are semiconductor-based sensors with an internal heating element that maintains the sensing material at a specific operating temperature [19]. Whereas the electrical conductivity of the sensing layer varies depending on the presence and concentration of target gases. In case of clean air conditions, the sensor exhibits relatively low conductivity, but exposure to detectable gases results in increased conductivity that depends on the change in gas concentration. Among the MQ series sensors, the MQ135 is widely famous as a used sensor for air quality monitoring due to its sensitivity to many common air pollutants and gaseous pollutants [20]. Table 3 shows the list of MQ series sensors.

Table 3: The list of MQ series sensors

Model	Target Gases
MQ2	Methane, Butane, LPG, Smoke
MQ3	Alcohol, Ethanol, Smoke
MQ4	Methane, CNG Gas
MQ7	Carbon Monoxide (CO)
MQ135	Air Quality, Benzene, Alcohol, Smoke

3. System design and Implementation

It is worth mentioning that a prototype was developed and implemented to represent the primary operational processes, inputs, and outputs of the proposed system. Additionally, the MQ135 gas sensor and the Wi-Fi module were interfaced with the Arduino Uno board to allow air quality sensing, data collection, and processing [21]. enabling remote air quality monitoring through an IoT-based platform. Afterward, the measured air quality parameters were displayed locally through both the serial monitor and a LCD screen. It can be observed, the system was designed and implemented to continuously monitor variations in air quality and to activate an alert when the measured pollutant level exceeded a predefined threshold. As said earlier, the MQ135 gas sensor was selected because of its sensitivity to a range of gaseous pollutants, including carbon dioxide, smoke, alcohol vapors, benzene, and ammonia [22]. This design allows users to remotely monitor changes in air pollution levels using an internet-connected computer or any other compatible device. Additionally, the proposed system required two primary parts hardware components and software tools, which are required for the design and implementation of the proposed system. The implementation of the prototype included the integration between hardware components and software tools, including the sensing units, ESP8266 Wi-Fi module, and microcontroller, each connected through dedicated interfaces. The C++ programming language was used to develop the necessary code for the proposed system [23]. The MQ135 gas sensor provides an electrical signal due to changes in the surrounding gaseous environment. So, these values are air quality readings data rather than concentrations of approved pollutants and are used to evaluate the operational performance of the proposed monitoring and alert system.

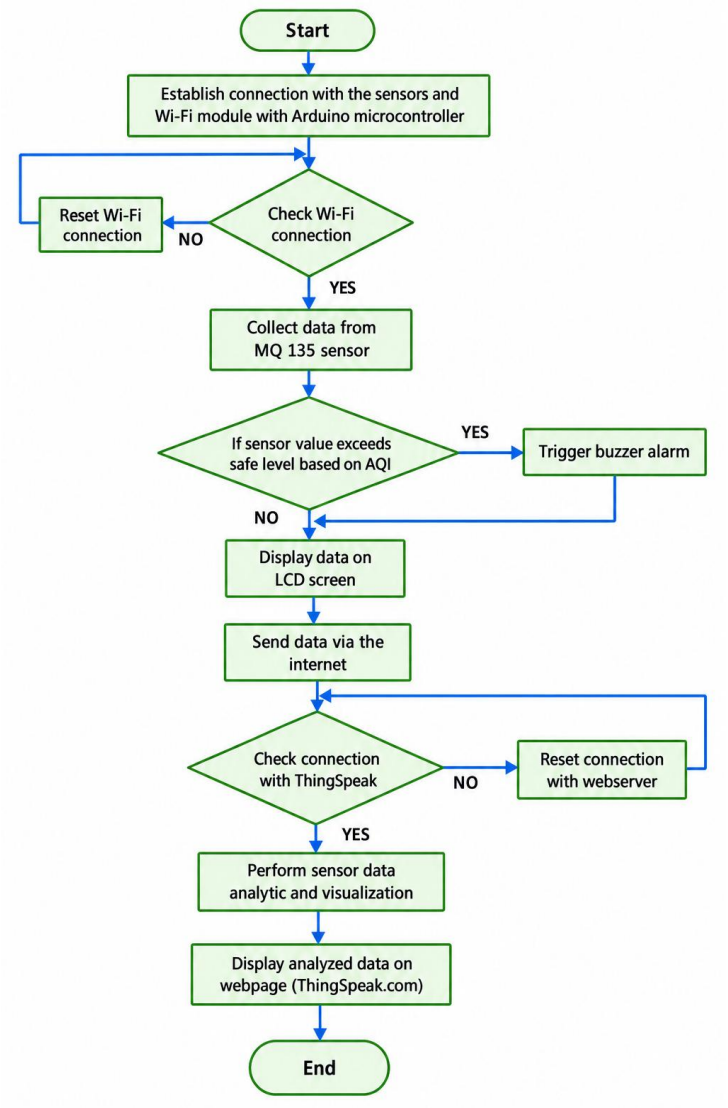


Figure 3: The flow chart for the proposed system

Obviously, the Arduino Uno receives the data acquired from the gas sensor and performs the necessary preprocessing before transmitting the information to the web server. The processed air quality measurements are displayed locally on a LCD screen, which allows users to monitor the measured air quality parameters in real-time [24]. In the proposed system, a threshold value of 250 parts per million (ppm) was chosen as an operational condition to assess the effectiveness of the alert. During prototype tests, this threshold was used to identify when the conditions are abnormal and when they are within the set alarms. Also, the threshold was used to ensure the alarm device was responsive and the air quality monitoring dashboard in the cloud was responsive to the alarm. Figure 3 shows the operating mechanism of the proposed air pollution monitoring system. Firstly, the process begins by creating communication among the Arduino Uno microcontroller, the MQ135 gas sensor, and the Wi-Fi module after the system verifies that the Wi-Fi internet is working and resets it if the connection is interrupted. The air quality data are collected from the MQ135 sensor and compared with a predefined safety threshold [25]. Afterward, if the measured value exceeds the permissible limit, a buzzer alarm is activated to indicate an unsafe air quality condition. The measured data are later displayed on the LCD screen and sent via the Internet to the ThingSpeak platform. Also, the system verifies the connection with the ThingSpeak server and re-establishes the connection whenever necessary. After successful data transmission to the server, the sensor readings are processed, analyzed, and visually presented by the ThingSpeak web interface, thereby allowing real-time remote monitoring of air quality conditions [26].

4.Testing and Cutover

System testing is the essential step after coding is complete in order to identify and rectify all faults and errors. And to ensure the system works smoothly. Consequently, the status for the ESP8266 Wi-Fi module will be checked regularly to ensure network connectivity availability and reliability. The internet connection reset must be performed if the status of the Wi-Fi and web server connections is interrupted at any moment. Hence, the Wi-Fi module's data will be analyzed and visualized by the web server. Additionally, a web page is displayed by entering the IP address into the browser (www. thingspeak.com). Finally, the prototype will be evaluated to ensure that it satisfies all of the requirements. If there are any gaps in the system, it will be improved.

5. Experimental results and discussions

The proposed system was tested to ensure the smooth implementation of the system architecture in monitoring air pollution using Arduino with an information system for data analysis.

5.1 Hardware setup

Figure 4 illustrates the experimental model of the proposed air quality monitoring system. The system integrates sensor, processing, Wi-Fi wireless communication, and data display units to enable real-time monitoring and remote analysis of air quality.

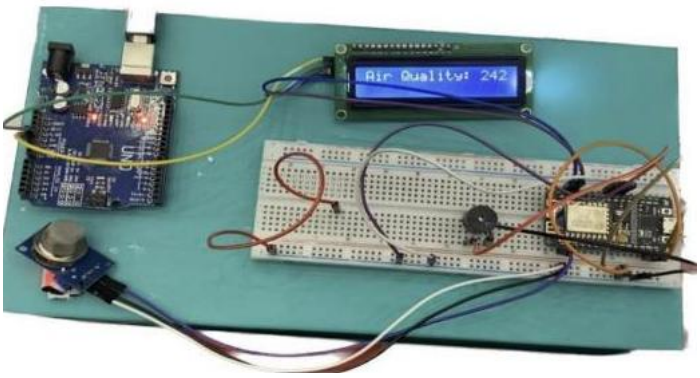


Figure 4: Circuit setup successful based on circuit diagram

After several attempts, the code was successfully compiled and uploaded to the NodeMCU 1.0 (ESP-12E module) and Arduino development environment. The expected outputs were displayed. All data is sent directly to the ThingSpeak channel. The results can be viewed via the web server as shown in Figure 5.

```
Air Quality: 451 PPM.Send to Thingspeak.
AQ Level Danger!
Waiting...
Air Quality: 123
Air Quality: 123 PPM.Send to Thingspeak.
AQ Level Normal
Waiting...
Air Quality: 177
Air Quality: 177 PPM.Send to Thingspeak.
AQ Level Medium
Waiting...
Air Quality: 242
Air Quality: 242 PPM.Send to Thingspeak.
AQ Level Medium
Waiting...
Air Quality: 276
Air Quality: 276 PPM.Send to Thingspeak.
AQ Level Danger!
Waiting...
Air Quality: 307
```

Figure 5: Arduino IDE results

5.2 Air quality graph

Figure 6 shows the result evidence from ThingSpeak platform. The graphs were plotted based on air quality value in ppm against time recorded. This graph is automatically generated after every result interval.

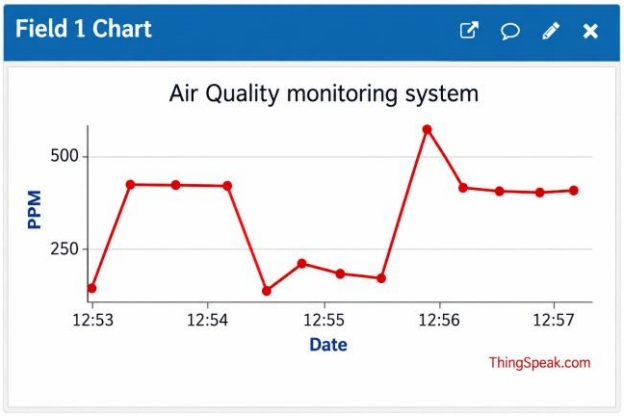


Figure 6: Air quality graph 1 from ThingSpeak

5.3 Data collection dashboard

This data collection dashboard shows real-time air pollution data. There are 4 charts shown here. Air quality graph, channel location, air pollution level in ppm and also signal indicator to show whether it is safe or dangerous. In the Figure 7 below red indicator shown because the ppm value is above threshold level (250 ppm).

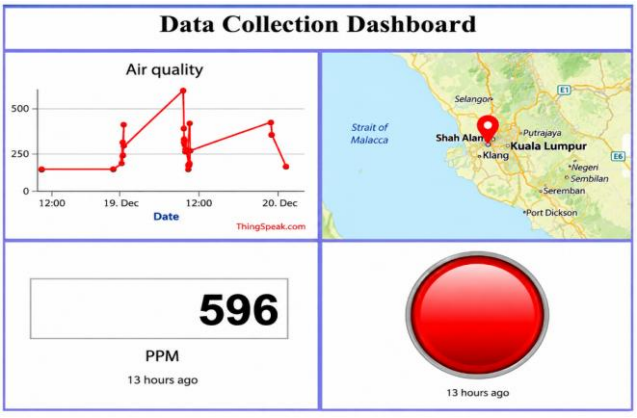


Figure 7: Data collection dashboard page during danger zone

Users can get real-time Air quality level from this dashboard. Figure 8 consist of Air quality graph, location, ppm value, and air quality indicator which shows bright red when the air quality is beyond safe level. Green light indicates the air quality level is safe. Which means the ppm value is below 250.

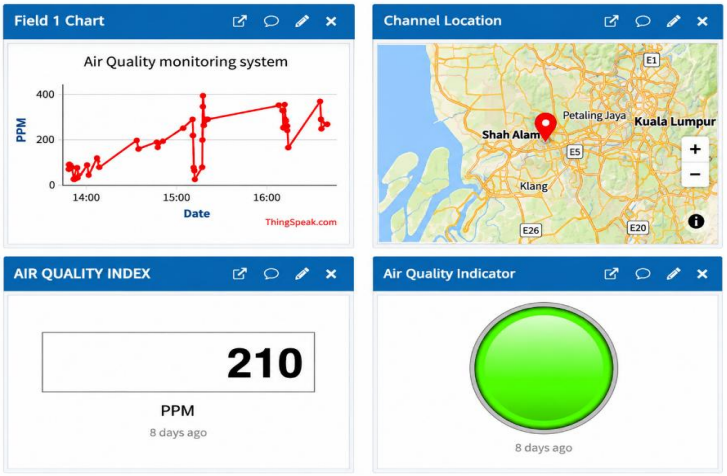
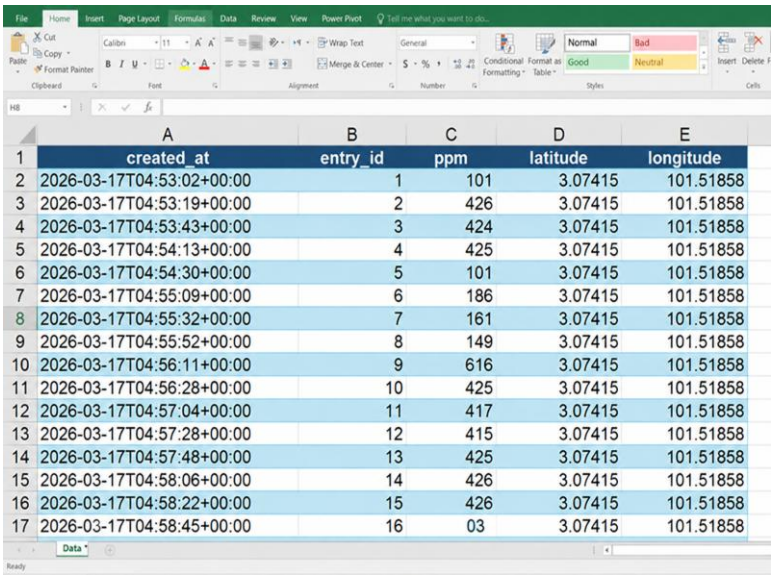


Figure 8: Data collection dashboard page during safe zone.

5.4 Data analysis in excel sheet

Figure 9 shows the data analysis exported from ThingSpeak platform. It contains data including date and time the air quality recorded, number of entries, ppm value, latitude and longitude of channel.



	A	B	C	D	E
1	created_at	entry_id	ppm	latitude	longitude
2	2026-03-17T04:53:02+00:00	1	101	3.07415	101.51858
3	2026-03-17T04:53:19+00:00	2	426	3.07415	101.51858
4	2026-03-17T04:53:43+00:00	3	424	3.07415	101.51858
5	2026-03-17T04:54:13+00:00	4	425	3.07415	101.51858
6	2026-03-17T04:54:30+00:00	5	101	3.07415	101.51858
7	2026-03-17T04:55:09+00:00	6	186	3.07415	101.51858
8	2026-03-17T04:55:32+00:00	7	161	3.07415	101.51858
9	2026-03-17T04:55:52+00:00	8	149	3.07415	101.51858
10	2026-03-17T04:56:11+00:00	9	616	3.07415	101.51858
11	2026-03-17T04:56:28+00:00	10	425	3.07415	101.51858
12	2026-03-17T04:57:04+00:00	11	417	3.07415	101.51858
13	2026-03-17T04:57:28+00:00	12	415	3.07415	101.51858
14	2026-03-17T04:57:48+00:00	13	425	3.07415	101.51858
15	2026-03-17T04:58:06+00:00	14	426	3.07415	101.51858
16	2026-03-17T04:58:22+00:00	15	426	3.07415	101.51858
17	2026-03-17T04:58:45+00:00	16	03	3.07415	101.51858

Figure 9: Air pollution database

6. Conclusion

In this study, the air quality and pollution surveillance system were developed using a wireless sensor network to provide continuously accessible monitoring of air pollution levels. In addition to that, the system allows the collection, processing, analyzing, and transmission of air quality data to users in real time, facilitating early detection of unsafe conditions. The proposed system is also characterized by its low cost, ease of use, and portability compared to traditional monitoring systems. The results demonstrate the possibilities of the proposed system as a practical solution for air quality monitoring and providing simultaneous information to users, with the possibility of future expansion to cover a wider range of pollutants and monitoring locations.

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