

Implement a Real-Time Outdoor Air Pollution Monitoring System Device with Graphical User Interface (GUI) at UTHM Pagoh College

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Abstract

Air is a vital element for human survival, but air pollution caused by human activities such as fossil fuel combustion and construction negatively impacts health. At UTHM Pagoh Campus, the absence of a real-time air monitoring system leads to exposure to pollutants without adequate precautions. The objective of this study is to develop a low-cost IoT-based air monitoring system with a graphical user interface (GUI) to record parameters such as Carbon Monoxide (CO), Ozone (O₃), and Nitrogen Dioxide (NO₂) in real time. The study utilizes the ESP32 microcontroller, gas sensors, and the Blynk application to transmit and display data in the cloud. Data was collected near residential colleges over eight hours and one hour to analyze pollution patterns. The findings indicate shows that the average readings of air quality parameters over a 10-minute interval are as follows: Test 1 (NO₂ = 328 µg/m³, O₃ = 161 µg/m³, CO = 27 mg/m³), Test 2 (NO₂ = 318 µg/m³, O₃ = 208 µg/m³, CO = 37 mg/m³), and Test 3 (NO₂ = 111 µg/m³, O₃ = 112 µg/m³, CO = 14 mg/m³). A comparison with New Malaysia Ambient Air Quality Standard (DoE, 2021) guidelines reveals that the readings for NO₂, O₃, and CO in Test 1 and Test 2 exceed the specified limits during conditions of heavy traffic and hot weather. Conversely, the readings in Test 3 comply with the standards during rainy conditions. Recommendations include improving monitoring for SO₂ and fine particles such as PM₁₀ and PM_{2.5}, which could enhance the system's effectiveness. Therefore, the sensors used such as MQ-131(Ozone), MQ-7(Carbon Monoxide), and MQ-135(Nitrogen dioxide).

1. Introduction

Air is one of the most important components of the human environment. The Earth's atmosphere is filled with gases such as oxygen (O₂), nitrogen (N), carbon monoxide (CO), and traces of other valuable elements. Humans require a contaminant-free environment to sustain life and well-being. Any significant alteration in the natural composition of air can threaten life on the planet. Air pollution occurs when one or more chemical substances, including harmful gases, accumulate in quantities that are detrimental to humans, animals, and plants. These pollutants are measured in parts per million (ppm) or micrograms per cubic meter (µg/m³) [1]. The effects of air pollution include respiratory problems such as difficulty breathing, coughing, and the aggravation of chronic

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conditions like asthma and emphysema [2]. Furthermore, polluted air can reduce visibility, emphasizing its adverse impacts [3]. Globally, researchers have developed models to monitor the emission of various gases such as carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), and sulfur dioxide (SO₂) [4]. The primary sources of air pollution include combustion engines in vehicles, industrial activities, and wildfires. Key pollutants such as particulate matter (PM), nitrogen dioxide (NO₂), and sulfur dioxide (SO₂) pose significant health risks, contributing to respiratory diseases and other health complications. According to the World Health Organization (WHO), air pollution is responsible for approximately 7 million deaths annually, with 99% of the global population exposed to unhealthy air, particularly in low- to middle-income countries. Health impacts include heart disease, stroke, cancer, chronic lung disease, and asthma [5].

Air pollution not only poses a health crisis but also creates environmental and economic concerns. It is a major contributor to phenomena like acid rain, haze, and global climate change. To address this issue, various countries, including Malaysia, have adopted air quality monitoring and indexing systems. In Malaysia, the Air Pollution Index (API) is used to measure air quality, covering pollutants such as PM₁₀, PM_{2.5}, NO₂, SO₂, ozone (O₃), and CO. The API categorizes air quality into five levels: Good, Moderate, Unhealthy, Very Unhealthy, and Hazardous. These categories help governments and communities respond effectively to changing pollution levels. However, continuous advancements in air quality monitoring systems are crucial to adapting to evolving environmental conditions and ensuring public safety. In the context of Universiti Tun Hussein Onn Malaysia (UTHM), particularly at the Pagoh campus, the absence of an efficient real-time air quality monitoring system has raised concerns. Without accurate and up-to-date data, staff, lecturers, and students may unknowingly be exposed to harmful pollutants [6]. Such exposure can lead to various health issues, including asthma, coughing, and difficulty breathing. Additionally, the lack of real-time air quality data prevents campus administrators from making informed decisions regarding environmental management and public health measures. Beyond health implications, air pollution disrupts campus activities by reducing visibility and creating an uncomfortable environment. This study focuses on the development of a real-time air quality monitoring system using Internet of Things (IoT) technology and a graphical user interface (GUI). By integrating IoT sensors, the system monitors pollutants such as carbon monoxide (CO), ozone (O₃), and nitrogen dioxide (NO₂). The collected data is visualized in real time using software like Blynk, providing an intuitive and user-friendly interface. The GUI simplifies data interpretation, enabling faster decision-making and effective communication about air quality levels to the campus community [7]. Air monitoring tests were conducted at UTHM Pagoh Campus, with data collected hourly from 9:00 AM to 5:00 PM over three days. The collected data was compared against Malaysia's New Ambient Air Quality Standards set by the Department of Environment (DoE) to ensure accuracy and relevance. While effective for real-time applications, the system faced several limitations. Its reliance on low-cost sensors for particulate matter (PM) measurements compromised data accuracy and required frequent maintenance. Moreover, the system encountered challenges related to connectivity, data transmission, and cybersecurity, which need to be addressed to enhance reliability and resilience [8].

Conclusion, this study successfully achieved its first objective by developing a low-cost, real-time outdoor air quality monitoring system using the ESP32 microcontroller and a Graphical User Interface (GUI). The system collects air quality data through sensors and displays it in real-time via the Blynk application, offering a cost-effective solution for outdoor air quality assessment. The second objective was met by deploying the system at UTHM Pagoh College to measure air quality parameters such as Nitrogen Dioxide (NO₂), Ozone (O₃), and Carbon Monoxide (CO) in compliance with the New Ambient Air Quality Guidelines (NAAQG). The data collected provided a clear understanding of the air quality in the monitored area, meeting the standards set for these pollutants. The third objective was successfully achieved by analyzing the collected data, identifying trends, and suggesting improvements for future development. Recommendations include integrating higher-precision sensors and enhancing calibration techniques to improve the accuracy and reliability of the system in future studies. Several recommendations have been proposed for future improvements. First, continuous improvements to the IoT monitoring system should be pursued, as it is still in its early stages. Future studies could compare the system with other outdoor air monitoring devices available at UTHM for validation. Relocating the bus parking area further from food-selling operations would help mitigate air pollution caused by vehicle emissions. Additionally, incorporating the monitoring of sulfur dioxide (SO₂), particulate matter (PM₁₀ and PM_{2.5}) into the system could provide a more comprehensive assessment of air quality. Finally, implementing more frequent calibrations and enhancing the cloud connection system would address the limitations of the current system and ensure more reliable data transmission.

2. Material and Method

Design and prototyping using SketchUp involves creating detailed 3D models to visualize concepts, refine designs, and test functionality

2.1 Design Casing

The device has a cube shape with a spot to hang it. The front of the case features various sensors, ozone (O_3), nitrogen (N), carbon monoxide (CO). The device casing design is shown from every perspective view in Fig 1.

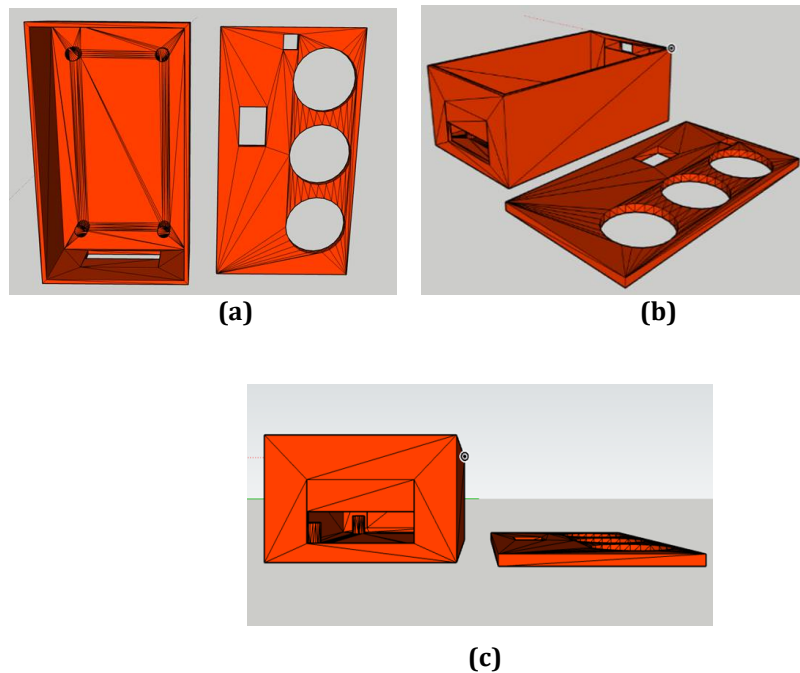


Fig. 1: Design Casing; (a) Top View (b) Side View; (c) Bottom View

2.2 Electronic Device

A microcontroller such as the NodeMCU processes the data collected by the Internet of Things (IoT)-based air monitoring system, which makes use of a variety of sensors ozone (O_3), nitrogen (N), carbon monoxide (CO) as shown in Fig 2. With the help of a Wi-Fi module, this microcontroller sends the processed data to Blynk for instantaneous analysis and visualization. immediately data visualization, logging, and hardware integration are all possible with Blynk. The system also transmits data to the cloud for advance data analytics, accessibility via the internet, and 30k limited storage. With its hanging area and USB port for power, this gadget is easy to install and versatile enough to work in a variety of settings. Through the combining of real-time data processing, cloud-based analytics, and IoT technology, this complete configuration guarantees precise and dependable air quality monitoring.

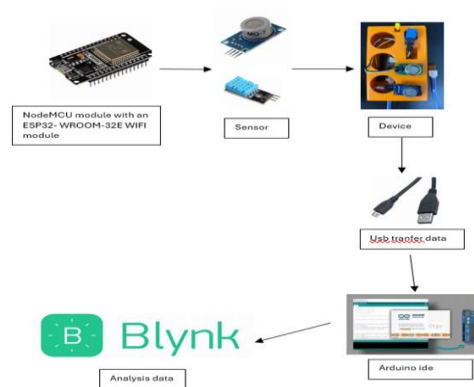


Fig. 2: Electronic Design

2.3 IoT Device Functionality

Figs 3 and 4 show an IoT device assembly with environmental sensor installed within the top panel of the device. The device has an ESP32 Wi-Fi module for data transmission and processing, together with an IoT kit with a NodeMCU. To gather, process, and transmit data via a Wi-Fi network, the device needs a USB 5V connection for power.

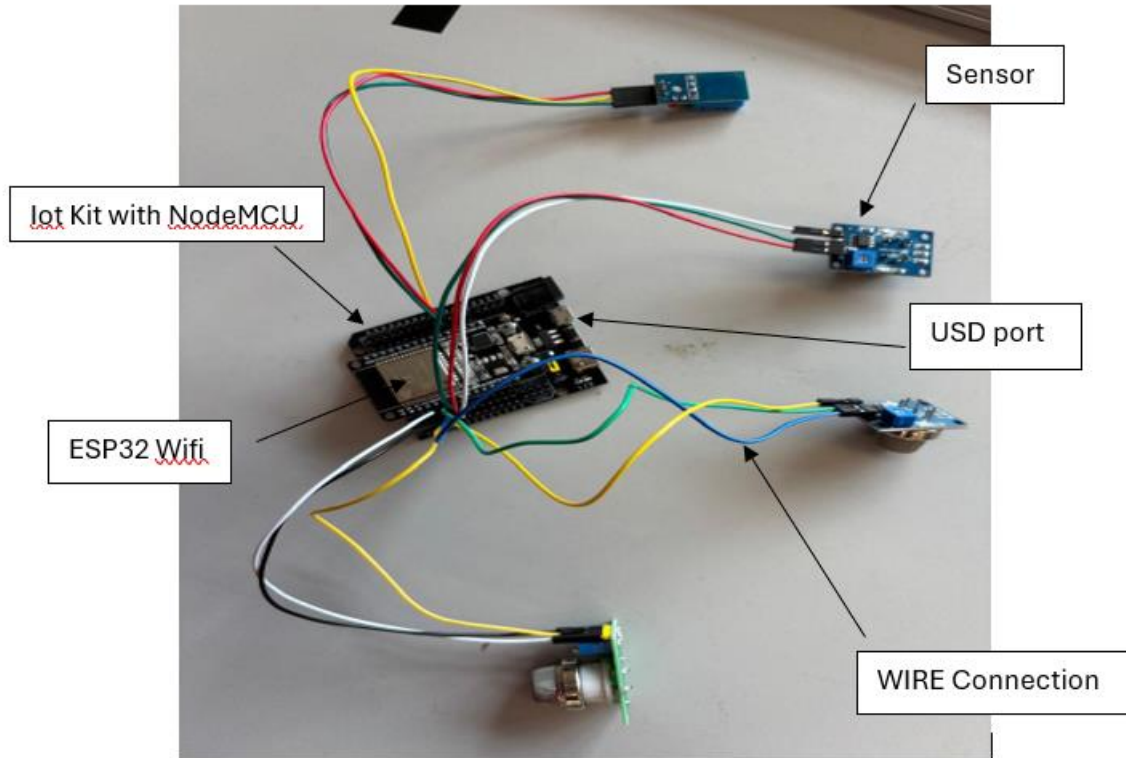


Fig. 3: The component inside the IoT Device

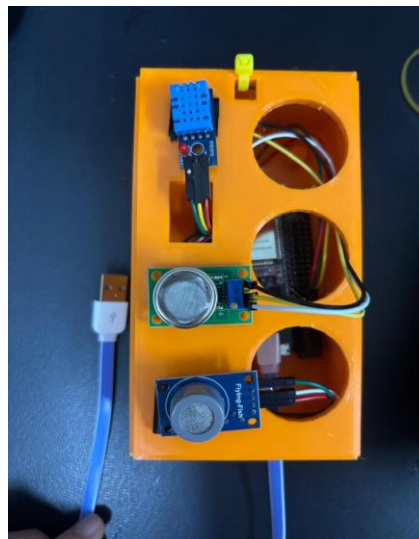


Fig. 4: IoT device prototype

Fig 5 displays a Blynk program's graphical user interface (GUI) for monitoring outdoor air quality. Real-time readings that include several sensors ozone (O_3), nitrogen (NO_2), carbon monoxide (CO) are shown on the interface.

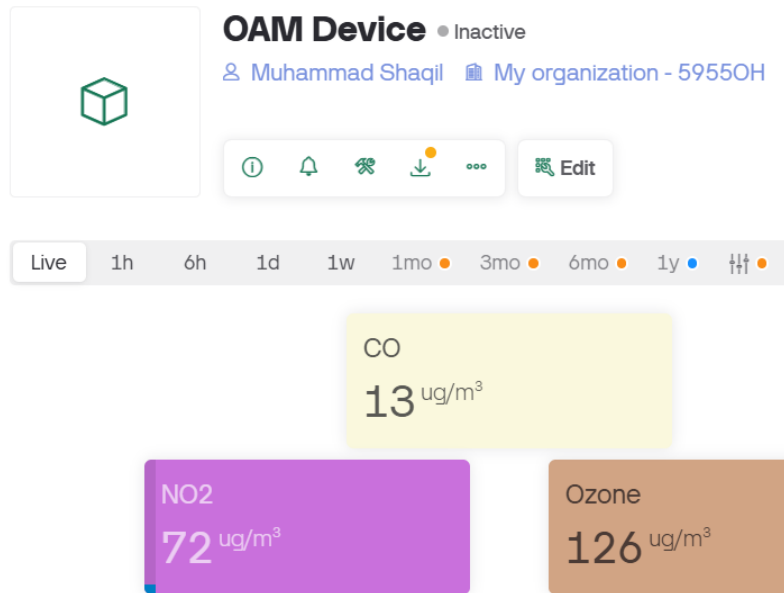


Fig. 5: GUI of Blynk Software

2.4 Type of Data (IoT Device)

In this project, the tools uploaded data to a database that the user can access via Blynk software. There will be ten characteristics included: sensors ozone (O_3), nitrogen (N), carbon monoxide (CO). Table 1 summarizes the various forms of data measured.

Table 1: Type of data

Parameters	Unit
Carbon Monoxide	Micrograms per cubic meter ($\mu\text{g}/\text{m}^3$)
Ozon	Micrograms per cubic meter ($\mu\text{g}/\text{m}^3$)
Nitrogen Dioxide	Micrograms per cubic meter ($\mu\text{g}/\text{m}^3$)

2.5 Installation of IoT Device

Fig 6 below shows the details to install and use the IoT device to monitor the indoor air quality from the start until the analysis data.

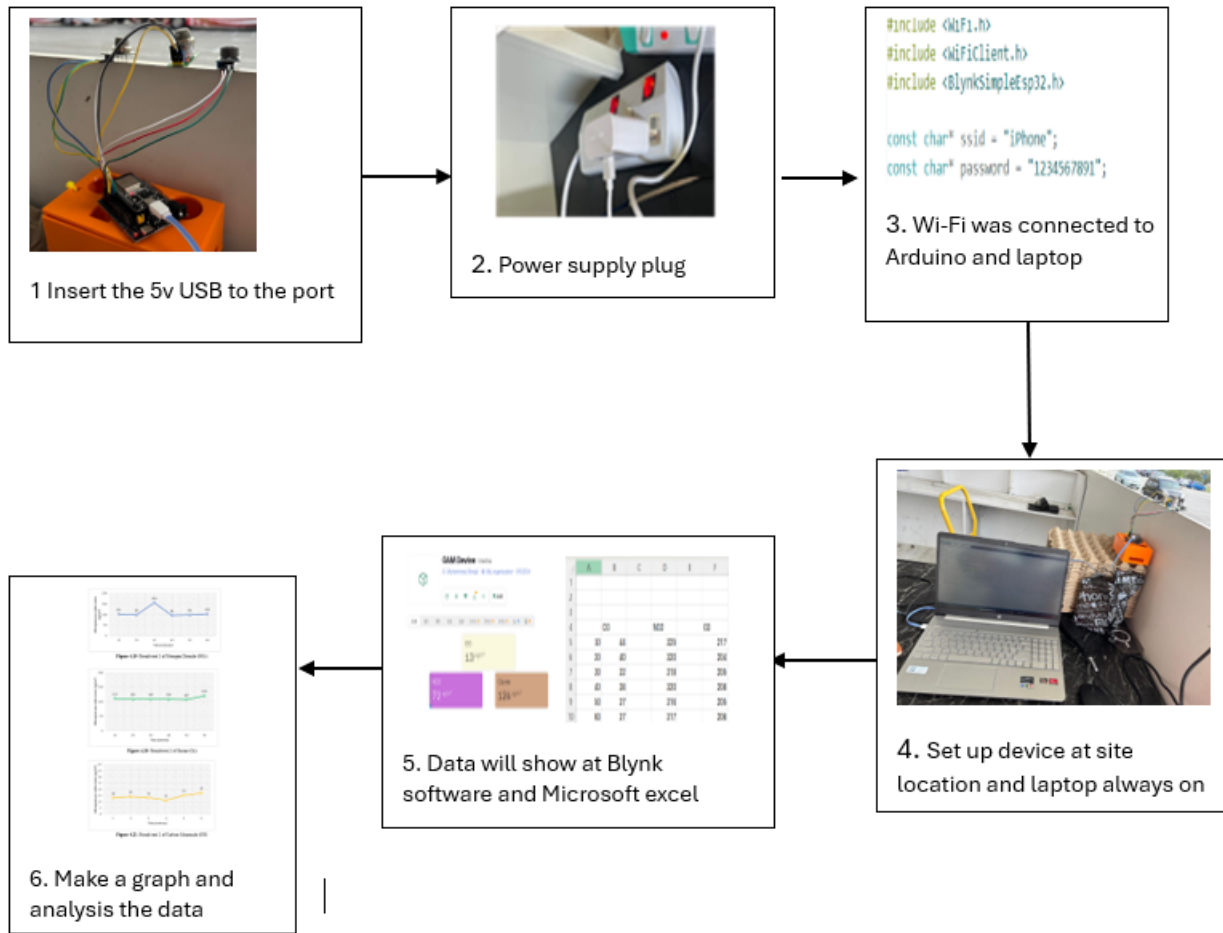


Fig. 6: Step by step to operate the device

2.6 Method of Testing

The test must be performed to show that this tool and its components are working properly and that it can upload data to a database and export data via Blynk software. This IoT-based ambient air monitoring system is a combination of hardware and software. The study site is located near bus waiting areas at Pagoh Campus residential colleges, Universiti Tun Hussein Onn. This study collected data on nitrogen dioxide, carbon monoxide, and ozone at open area. Fig 7 shows the site location of testing.



Fig. 7: Selection of Site

Data collection was conducted at the bus waiting areas near the residential colleges at Pagoh Campus, Universiti Tun Hussein Onn Malaysia. The IoT-based ambient air monitoring system was used to gather data on carbon dioxide (CO₂), carbon monoxide (CO), and ozone (O₃) levels in the air. The system, which combines hardware and software components, was tested to ensure its functionality, including its ability to upload data to a database and export data via the Blynk software.

2.7 Data Analysis

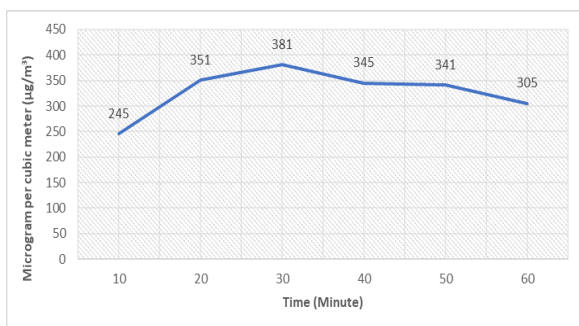
The analysis must be performed to demonstrate and show that the data from this IoT device can be used to monitor nitrogen dioxide, carbon monoxide, and ozone in the air. The analysis provided insight into air pollutant data values as well as demonstrate the dependability of IoT data extraction. To get the results, all the raw data was imported into Microsoft Excel. The line graph is used for presenting the data, and it is straightforward to analyze. The x-axis and y-axis are the horizontal and vertical parts of the graph, respectively.

3. Result and Discussion

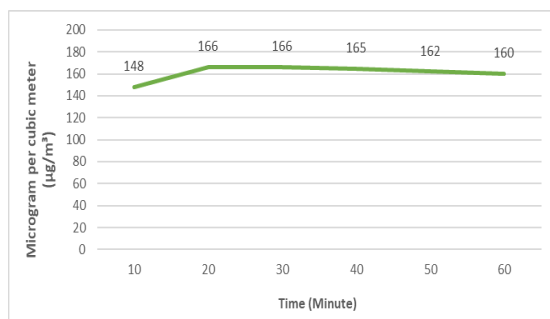
In this project, only one device was used for measurement due to technical issues, such as coding problems. As a result, a comparison with an existing device could not be conducted. The X-axis on the graph represents time, while the Y-axis represents micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). The collected data illustrates parameter values recorded over time. These values were compared with the New Malaysia Ambient Air Quality Standard 2020, which specifies 1-hour average limits as follows: 280 $\mu\text{g}/\text{m}^3$ for Nitrogen Dioxide (NO₂), 180 $\mu\text{g}/\text{m}^3$ for Ground-Level Ozone (O₃), and 30 $\mu\text{g}/\text{m}^3$ for Carbon Monoxide (CO). Two tools were set for testing, and two parameters were displayed on each graph. The X-axis represented time, while the Y-axis indicated the parameter values in their respective units. Different colors were used to represent each parameter, with the corresponding values shown in the same color for clarity. The results of Test 1 is first hour, and test 2 is second hour, were obtained at Café Kolej during working hours, where buses were actively transporting students to and from campus. The weather at the cafe is a litter bit hot and data collection was carried out over a duration of 2 hours from 10 AM to 12 PM with data output recorded at 10-minute intervals

3.1 Test 1- Result of Cafe College with 10-Minutes Intervals

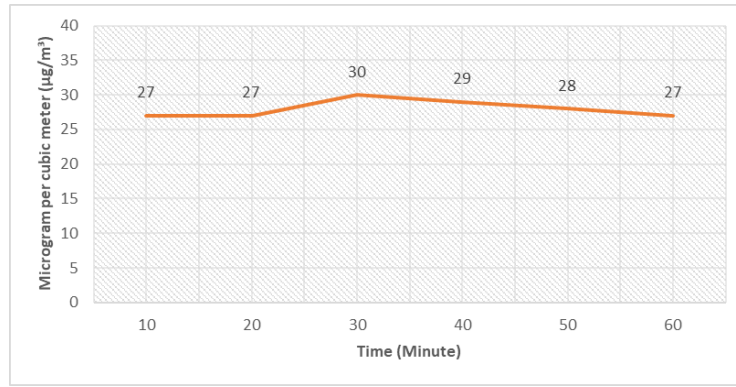
The results of Test 1 is first hour, Café Kolej during working hours where buses were actively transporting students to and from campus. The weather at the cafe is a litter bit hot and data collection was carried out over a duration of 1 hour from 10 AM to 11 AM with data output recorded at 10-minute intervals. The measured parameters included Carbon Monoxide (CO), Ozone (O₃), and Nitrogen Dioxide (NO₂). The figure below shows the measured results. Fig 8 showed the results of Test 1 is first hour and parameters of outdoor air quality at Café College.



(a)



(b)

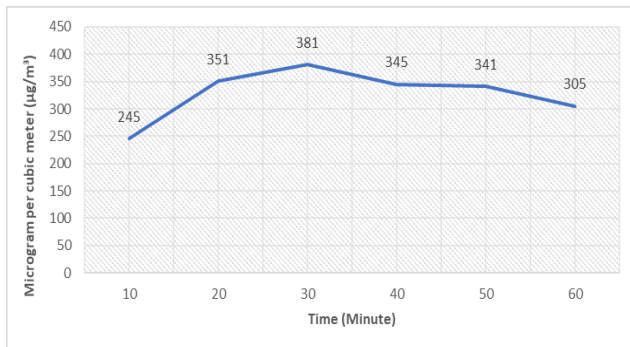


(c)

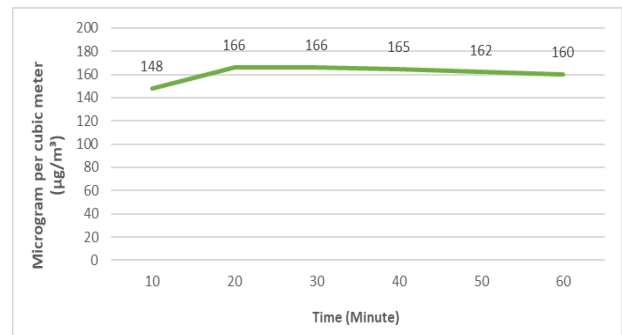
Fig. 8: Graph of; [a]nitrogen (NO_2); [b] ozone (O_3); [c] carbon monoxide (CO)

3.2 Test 2- Result of Cafe College with 10-Minutes Intervals

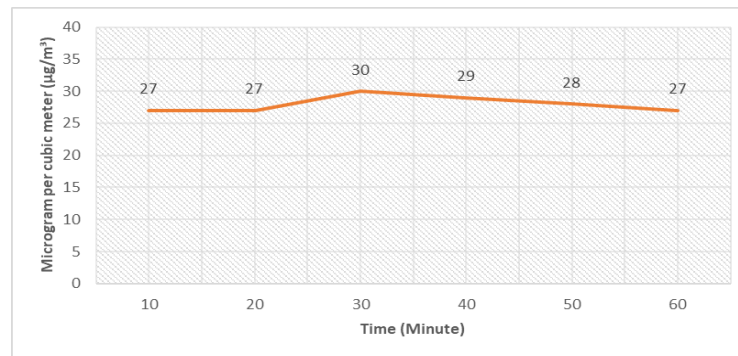
The results of Test 2 is first hour, Café Kolej during working hours where buses were actively transporting students to and from campus. The weather at the cafe is a litter bit hot and data collection was carried out over a duration of 1 hours from 11 AM to 12 PM with data output recorded at 10-minute intervals. The measured parameters included Carbon Monoxide (CO), Ozone (O_3), and Nitrogen Dioxide (NO_2). The figure below shows the measured results. Fig 8 showed the results of Test 2 is second hour and parameters of outdoor air quality at Café College.



(a)



(b)



(c)

Fig. 9: Graph of; [a]nitrogen (NO_2); [b] ozone (O_3); [c] carbon monoxide (CO)

The analysis of the new devices of air quality data analysis conducted at Cafe Kolej involved three distinct tests using 10-minute intervals over a 1-hour period. Data for Tests 1, and 2, were collected over a span of 2 hours, from 10:00 AM to 12:00 PM. In Test 1, Nitrogen Dioxide (NO_2) levels recorded a significant peak of $381 \mu\text{g}/\text{m}^3$ and exceeding the standard limit of $280 \mu\text{g}/\text{m}^3$. This spike indicates that short bursts of traffic congestion can lead to substantial increases in pollution. NO_2 levels fluctuated between $245 \mu\text{g}/\text{m}^3$ and a maximum of $381 \mu\text{g}/\text{m}^3$, highlighting the dynamic nature of air quality in response to traffic patterns. Meanwhile, Ozone (O_3) levels in test 1 showed stability peaking at $166 \mu\text{g}/\text{m}^3$ which is well below the standard limit of $180 \mu\text{g}/\text{m}^3$. This suggests that while O_3 remains a pollutant of concern, it does not pose an immediate risk compared to NO_2 during peak traffic hours. Carbon Monoxide (CO) measurements in test 1 displayed a more consistent pattern, with an average concentration of around $30 \mu\text{g}/\text{m}^3$ and a peak of $32 \mu\text{g}/\text{m}^3$ nearing the standard limit. In test 2, a similar pattern was observed, with NO_2 levels peaking at $325 \mu\text{g}/\text{m}^3$. O_3 levels slightly increased compared to test 1 reaching a peak of $217 \mu\text{g}/\text{m}^3$ but remained within safe limits. CO levels in test 2 also showed stability with an average concentration of approximately $37 \mu\text{g}/\text{m}^3$. Overall, the data from both tests provide a clear picture of how traffic activity impacts air quality in the area. With continuous monitoring and proactive measures, it is possible to mitigate the negative effects of air pollution and improve the health conditions of the local community. The elevated levels of NO_2 , CO, and O_3 at certain times are caused by increased vehicle emissions during peak hours and are influenced by hot weather. This situation highlights the urgent need for more effective air quality management strategies to reduce health risks [10].

3.3 Test 1- Test Result of during a rain with 10-Minutes Intervals

The first hour involved collecting outdoor air quality data with rain. Fig 10 showed the result of all the parameters of outdoor air quality at Café College. The measured parameters included Carbon Monoxide (CO), Ozone (O_3), and Nitrogen Dioxide (NO_2).

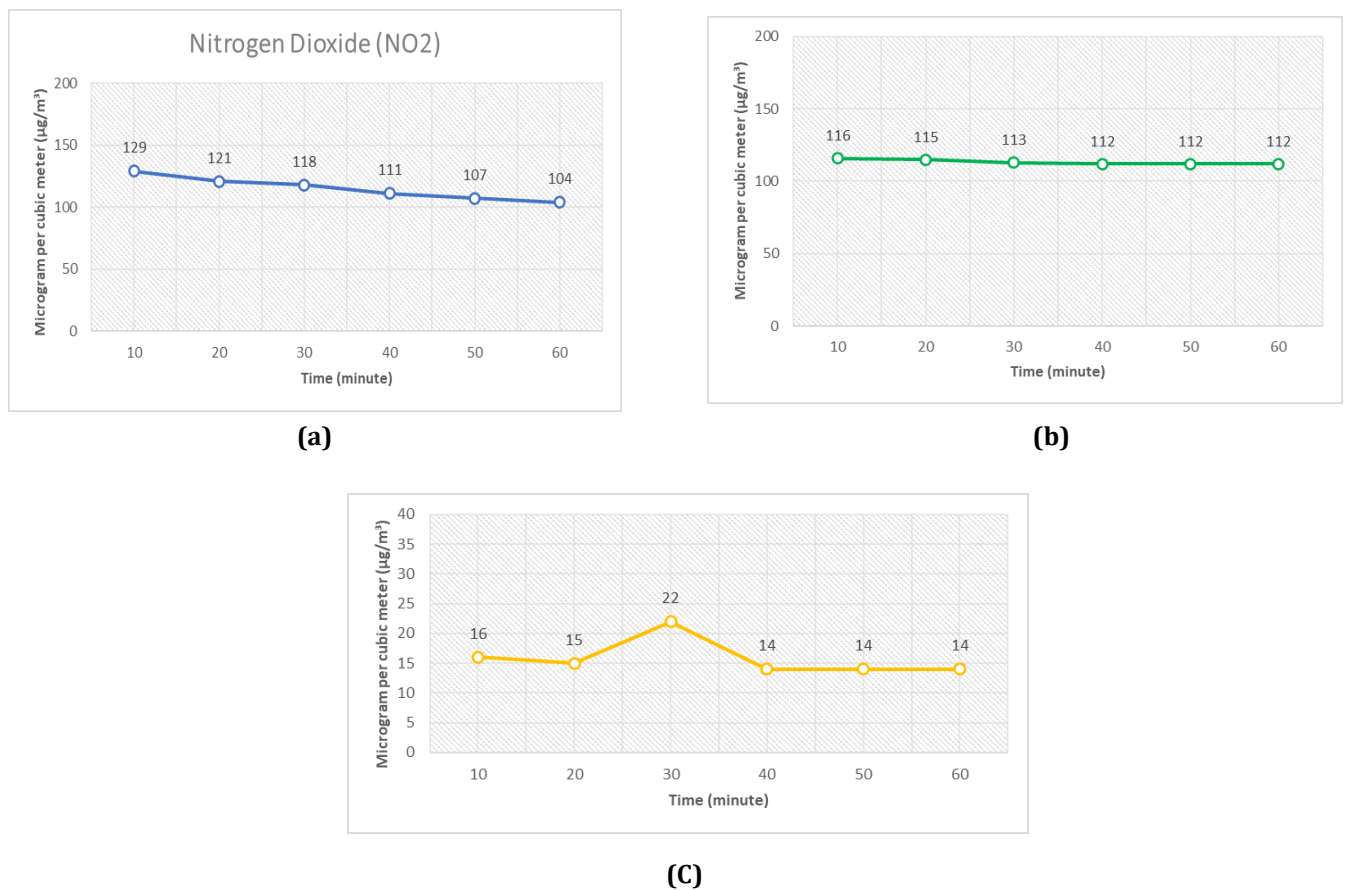


Fig. 10: Graph of; [a]nitrogen (NO_2); [b] ozone (O_3); [c] carbon monoxide (CO)

3.4 Test 2- Test result of during a rain with 10-Minutes Intervals

The second hour involved collecting outdoor air quality data with rain. Fig 11 showed the result of all the parameters of outdoor air quality at Café College. The measured parameters included Carbon Monoxide (CO), Ozone (O₃), and Nitrogen Dioxide (NO₂).

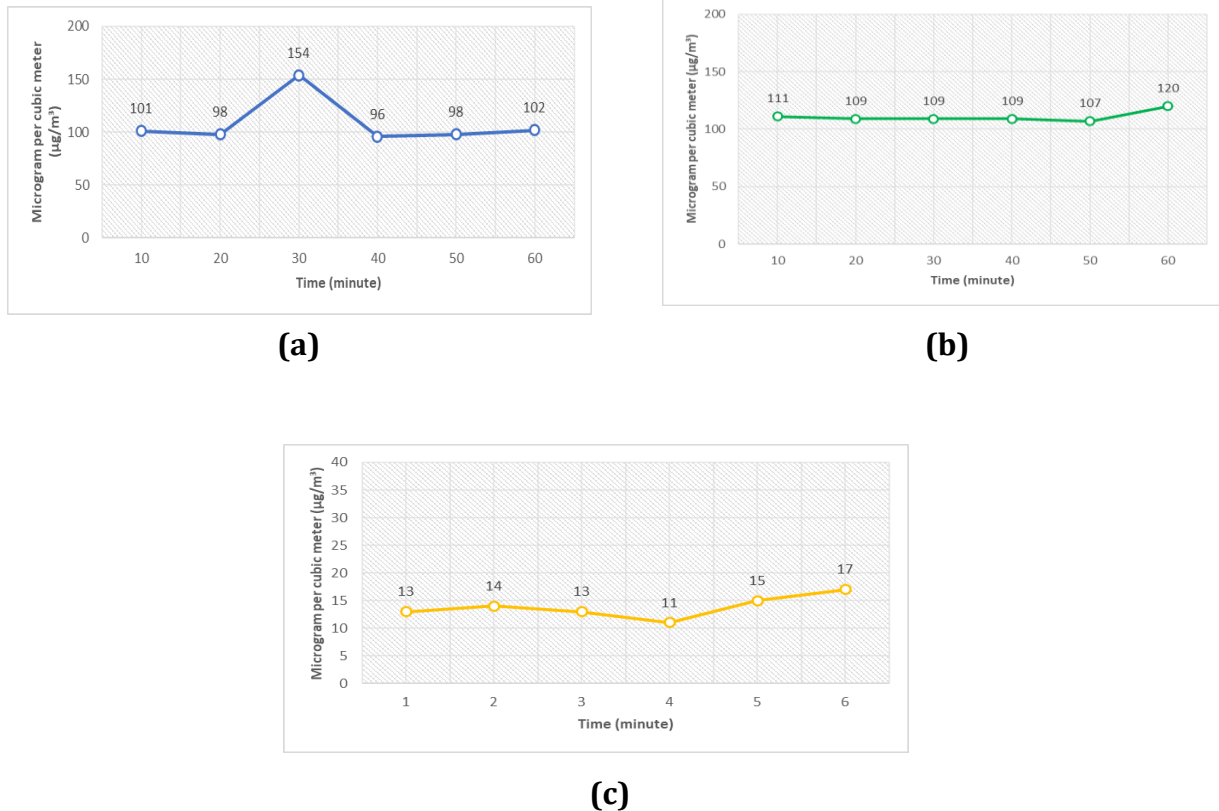


Fig. 11: Graph of; [a]nitrogen (NO₂); [b] ozone (O₃); [c] carbon monoxide (CO)

The air quality data analysis conducted at Cafe Kolej test result of during a rain with 10-Minutes Intervals over a 1-hour period. Test 1 conducted in rainy conditions nitrogen dioxide (NO₂) levels showed a decreasing trend from 129 µg/m³ to 104 µg/m³ by the end of the test, likely due to precipitation removing pollutants from the air ozone (O₃) exhibited a slight decline from 116 µg/m³ to 112 µg/m³, influenced by high humidity disrupting ozone formation. Carbon Monoxide (CO) also decreased from 16 µg/m³ to 14 µg/m³, indicating improved air circulation during the rain. While for test 2, conducted after the rain subsided revealed a sharp increase in NO₂ levels at the 30 minute to 154 µg/m³ before dropping back to 102 µg/m³ potentially due to reduced precipitation allowing pollutants to accumulate. O₃ levels remained steady with a slight decrease from 111 µg/m³ to 107 µg/m³ suggesting that photochemical processes had not fully resumed. Meanwhile, CO levels saw a gradual increase from 13 µg/m³ to 17 µg/m³, possibly due to reduced air dispersion after the rain ended. The results from both tests demonstrate that rainy conditions significantly influence indoor air pollution levels. Overall, rainfall helps reduce pollutant gases such as NO₂ and CO, while O₃ levels show only minor changes. After the rain, the reaccumulation of pollutants, particularly NO₂, becomes apparent due to the reduction in precipitation. This study highlights the importance of understanding weather factors in managing indoor air quality effectively. The levels of NO₂, CO, and O₃ decrease during rainy periods due to the effect of rain which cleans pollutants from the atmosphere through processes such as wet deposition. Rain also increases humidity

which can dilute pollutant concentrations and demonstrates the natural role of rain in improving air quality [11].

3.5 Summary of result findings

The summary of the result findings highlights varying levels of air pollutants under different environmental conditions. Table 2 shows the result summary findings.

Table 2: The result summary findings

Time	CO	NO ₂	O ₃	Finding
8 hours	30	310	192	carbon monoxide (CO) levels remained within the acceptable limit of 30, but nitrogen dioxide (NO ₂) at 310 and ozone (O ₃) at 192 exceeded their respective limits of 280 and 180
1 hour	28	345	165	CO also stayed within the limit, while NO ₂ reached 345, exceeding the limit, and O ₃ measured 165, remaining below the threshold
1 hour in rain	15	118	112	In the rain, all gas levels were significantly reduced with CO at 15, NO ₂ at 118, and O ₃ at 112, all well within their respective limits. This indicates that rain effectively lowers air pollution levels.

4.0 Conclusion

In conclusion, this study successfully developed a low-cost, real-time outdoor air quality monitoring system using an IoT-based ESP32 microcontroller with a Graphical User Interface (GUI). The system was deployed at UTHM Pagoh College, where it measured air quality parameters, comparing results with the New Ambient Air Quality Guidelines (NAAQG). The average readings for the tests were as follows: Test 1 (NO₂ = 328 µg/m³, O₃ = 161 µg/m³, CO = 27 mg/m³), Test 2 (NO₂ = 318 µg/m³, O₃ = 208 µg/m³, CO = 37 mg/m³), and Test 3 (NO₂ = 111 µg/m³, O₃ = 112 µg/m³, CO = 14 mg/m³). The comparison with the New Malaysia Ambient Air Quality Standard (DoE, 2021) showed that NO₂, O₃, and CO levels exceeded the standard limits during peak traffic and hot weather in Test 1 and Test 2. However, test 3 conducted during rainy conditions complied with the standards. These findings highlight the significant impact of traffic and weather conditions on air quality, emphasizing the need for continuous monitoring and further improvements including the integration of additional parameters such as SO₂, PM₁₀, and PM_{2.5} for a more comprehensive assessment of air pollution. In summary, the development of this system paves the way for better air quality management and serves as a valuable tool for monitoring environmental health at UTHM

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