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In-Car Air Quality Notification Using Internet of Things Platform

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***Abstract** – In the development of modern society, transportation is essential to support daily activities. With the existence of vehicles, the activities carried out by the community will be much easier. The car is a means of transportation that is often used by the community to carry out activities related to their respective goals. In-car air quality is very crucial for society because most people spend their time in cars. Often, the air in the car contains not only good air but also bad air for humans. The impact of poor air quality can make people sleepy, as well as cause respiratory problems and several other diseases that can even affect a driver's ability to make decisions. Therefore, there must be a real-time monitoring and notification system for air quality in the car. The purpose of this research is to be able to develop an air quality monitoring system for cars and provide notifications if the air quality worsens in real-time. In this study, researchers developed an air quality monitoring and notification system for cars using the NodeMCU ESP8266 microcontroller, sensors MQ-7, MQ-135, PMS5003, and the IoT platform, namely Blynk and ThingSpeak. The result of this research is a system that can detect, measure, and monitor air quality levels of carbon dioxide (CO), carbon monoxide (CO2), particulate matter (PM10), and particulate matter (PM2.5) via the internet in real-time. and displays air quality data on the dashboard, then provides notifications using the Blynk application if the air quality is low and getting worse.*

Keywords: *In-Car Air Quality; Internet of Things; Sensors; Blynk; ThingSpeak*

I. INTRODUCTION

In the development of modern society, transportation has become an essential element to assist with daily activities. Transportation will make the activities carried out by the community much easier. The car is one of the modes of transportation that is regularly used by people to do activities with their respective goals. For many people, the car is not only used to get from one place to another, but with the car, people can do different activities, such as resting and sleeping in the car. A study in Germany showed that the average person spends 45 minutes in a vehicle (Zulauf et al., 2019).

For the increasing use of cars, it is necessary to be aware of the health and safety factors in the car. One of the factors that must be considered is air. Air is a basic need for living things to sustain life. Air contains oxygen, which is the main component for living things to breathe. The polluted air that enters the body contains various gases such as oxygen, carbon dioxide, argon, nitrogen, and water vapor that can interfere with health (Waworundeng & Lengkong, 2018).

Drivers and passengers often close the car doors and use the car air conditioner to avoid pollution and cool the air when in the car, but without realizing that the air in the car is not good for health. According to research conducted by (Vreeland et al., 2017) in-car air contains twice the amount of chemicals so it can be stated that the air quality in the car can be awful.

Poor in-car air quality can make people drowsy and create health problems such as breathing, irritation of the eyes, nose, nausea, dry skin, or itching. If it occurs in the long term, it can cause several chronic diseases. It may even affect the driver's ability to make decisions.

(Lohani & Acharya, 2016), can also cause oxidative stress, which is thought to increase the risk of diseases such as respiratory diseases, heart diseases, cancer, and some types of neurodegenerative diseases (Vreeland et al., 2017). The World Health Organization (WHO) estimates 2.4 million deaths yearly due to air pollution (Müller et al., 2011). There have been many deaths in and around vehicles caused by accidental inhaling of excessive CO. A study conducted in the US said that there had been 57% of accidental deaths due to CO poisoning in cars (Galatsis & Wlodarski, 2006).

In-car air quality can deteriorate because it is affected by the buildup of carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), and other harmful gases emitted by vehicles (Lohani & Acharya, 2016). In addition, the increase in terrible air quality in the car is influenced by the type of vehicle, breathing, and the number of passengers, and is also caused by the interior materials in the vehicle, the age of the vehicle, the ventilation mode used, and the pollutants outside the cabin (Tong & Liu, 2020). Pollutants can get into the car through the ventilation system (Galatsis & Wlodarski, 2006). So that people who are in the car can breathe air containing PM and gases (CO, CO, NO, NO_2, VOC) (Moreno et al., 2019).

Air quality containing carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter (PM) is difficult to detect because the air is generally invisible, odorless, and colorless, making it difficult to detect. Therefore, it is needed to have a system that can monitor air quality with adequate technology and electronic equipment. There have been many studies that use technology to measure air quality in cars and indoors using the Internet of Things (IoT) paradigm. With this paradigm of IoT, IoT technology allows connecting with objects via the internet (Jeon et al., 2018). So, this study proposes an IoT system to monitor air quality in cars in real-time. Researchers design a solution using sensors to monitor car air quality levels, a microcontroller that will convert data from sensors, and the IoT platform as a monitoring and notification system if air quality is deteriorating.

Several similar studies were conducted to measure air quality using the Internet of Things paradigm. IoT devices have some common electronic components with one or more sensors and have open sockets to connect them to a network by wire (local area network [LAN], wide area network [WAN]) or an additional chip to connect them to a network wirelessly (Bluetooth, Wifi) (Bansal, 2020). Research that has been carried out by Lohani & Acharya (Lohani & Acharya, 2016) built a Vehicle Indoor Air Quality (VIAQ) system that measured air quality in vehicles, measured air parameters such as Carbon Monoxide (CO), Carbon Dioxide (CO_2) using mobile participatory sensing connected to smart devices and Bluetooth sensors. This system will accumulate and report data in real-time data collected in the form of carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter) PM. But this study does not provide notification if the air quality is poor.

Research has been done by (Benammar et al., 2018) The use of the Raspberry Pi and its modular architecture as a model to build an Indoor Air Quality Monitoring system that is integrated with the IoT platform will enable scalability of the capabilities and systems so that the sensor technologies used, such as wireless sensor networks (WSN), and standards mobile phones can be integrated on the cloud server. This research allows the monitoring of six types of gases as well as temperature and humidity in different locations at the same time. This research focuses on CO_2, CO, SO_2, NO_2, O^3, Cl2, air temperature, and humidity. This system does not provide notification or caution to the user if the air condition worsens.

The research from (Goh et al., 2021) proposed a cloud-based real-time in-vehicle air quality monitoring system that allows the prediction of current and future cabin air quality. The designed system provides predictive analytics using machine-learning algorithms to measure driver sleepiness and fatigue based on the quality of the air in the car. The parameters measured were CO_2, PM2.5, PM10, latitude-longitude, vehicle speed, temperature, and relative humidity. The data obtained is then driven to the cloud database where it will be displayed on the web and mobile applications. However, this study has no longer provided notification if the air quality has deteriorated.

Research has been done by (Moreno et al., 2019) researchers conducting air quality research in taxi parameters measured in the form of gas (CO, $CO_{2,}$ NO, NO2, VOC) and PM (Particulate Matter). The tools used to measure gas and PM The instruments used to measure black carbon (BC) used in taxis are the Mini-aethalometer (Magee Scientific) to measure black carbon (BC) used in diesel taxis, the DiSCmini (Matter Aerosol AG, Wohlen AG, Switzerland) to monitor the concentration of the number of particles and the IAQ-track (Model 7545, TSI) for measuring CO_2, CO, temperature and humidity levels. The method used to measure air quality levels is to use taxis of different types, such as diesel, CNG, LPG, electric, and hybrid. The conclusion of this study is the importance of air circulation to maintain the air quality in the vehicle. This research still does not use IoT technology and has not provided air quality notifications if air quality deteriorates.

In this paper, In-Car Air Quality Notification Using the Internet of Things Platform that can monitor the concentration of CO, CO_2, PM 2.5, and PM 10 density. The data obtained by the sensor is then pushed to the cloud server and on the ThingSpeak IoT platform the data is visualized in the form of a graph, when the data exceeds the safe limit, system will provide a notification of worsening. The contributions of this research are:

- Obtain an IoT model that can be used to monitor the air quality in the car in real-time.
- Obtaining a mobile-based application to provide air quality notifications if air quality deteriorates.
- Provide recommendations for actions to be taken to users to improve the air quality in the car.
- A *real-time* internet-based in-car air quality monitoring dashboard is obtained that can help related parties to reduce road accidents caused by the effects of poor air quality such as drowsiness, and lack of focus when driving.

II. METHODS

2.1 Research Stages

Figure 1 shows the research stages in making this system. In the early stages, the researcher must define the background of the problem, then carry out a literature study, followed by system design, system development, testing, data collection, validation of the data collection results, and finally, system evaluation.

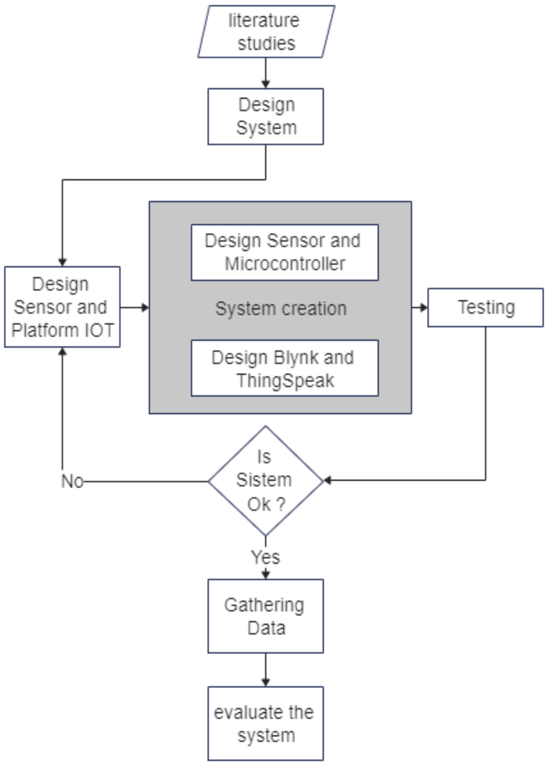


Figure 1. Research Stages

In the early stages of this research, researchers identified a problem that occurred where air quality containing Carbon Monoxide (CO), Carbon Dioxide (CO_2), and Particulate Matter (PM) was difficult to detect because air in general cannot be seen, odorless and colorless, so difficult to avoid, therefore we need a system that can monitor air quality with adequate technology and electronic equipment.

So, a literature study was carried out on research that had been carried out to detect air quality in the car. From the results of a literature study where sensors and microcontrollers can detect air quality and with IoT platforms such as ThingSpeak to display graphic displays and Blynk for air quality notifications.

At the design stage of the system to detect carbon dioxide (CO_2), carbon monoxide (CO), and particulate matter (PM) air quality in cars using the NodeMCU microcontroller, MQ-135 and MQ-7 sensors connected to the IoT platform as an interface and notifications to avoid bad air quality, The system to be created has input, processing, and output sections. The MQ-135 sensor, MQ-7 sensor, and PMS-5003 sensor will be the inputs of this system, and those will detect CO, CO_2, PM 2.5, and PM 10 values. Meanwhile, the NodeMCU ESP8266 in the brain processes data and sends it to ThingSpeak as a monitoring system. and as a notification system, it will use Blynk apps when air quality has significantly increased.

In making the system, the researcher implements a system design to detect air quality in the form of carbon dioxide (CO_2), carbon monoxide (CO), and particulate matter in cars with sensors and microcontrollers that have been programmed and an IoT platform that will display data in the form of graphics and will provide notifications.

After the system is created, a test will be carried out on the system to determine if it has successfully read the data or not and whether it has successfully given notifications if the air quality is deteriorating or not.

In the next stage, the researcher collected data. The data collection process was carried out by placing the tool on the dashboard in the car and then measuring it.

The stages of system evaluation to ensure the achievement of the objectives of this research are carried out in the following stages:

- In the early stages of testing the designed tool, the purpose of testing this tool is to get an accurate value. Researchers will test the MQ-7 sensor, MQ-135 sensor, and PMS-5003 sensor with a calibrated device.
- Then researchers will test the NodeMCU ESP8266 microcontroller at this stage to see if it can read sensor input, connect to wifi, and send data to the IoT platform.
- Researchers then ensure that data from the sensors is received by the IoT platform, providing notifications when air quality deteriorates.

2.2. Purpose System Design

Figure 2 as the design goal of the air quality monitoring system in the car that will be made. This system consists of a combination of *hardware* that uses sensors to read CO, CO_2, PM10, and PM2.5 and an IoT platform. Also, with the use of NodeMCU ESP8266, which has a Wi-Fi module so that the system can be connected to the internet. With this system, you can retrieve data, process, and send data to an IoT server via the internet using a mobile hotspot and display it visually on IoT platforms such as *Blynk* and ThingSpeak.

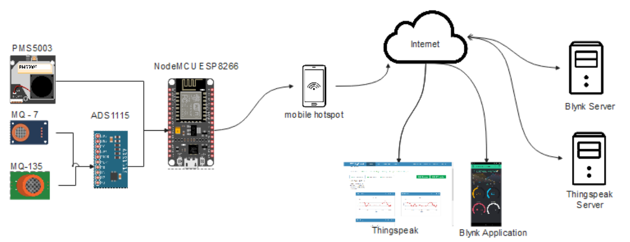


Figure 2. Proposed System Design

2.2.1. Hardware Architecture

It can be seen in Figure 3 which is the architectural design of the hardware used in air quality data collection.

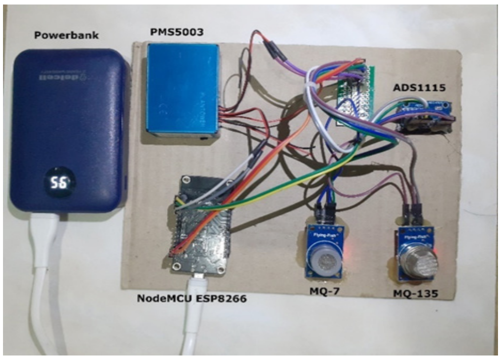


Figure 3. Hardware Architecture

This is the explanation of each hardware component used. A power bank as a power source is used to turn on the system that has been made with 5v power. MQ-135 is Used to measure the CO_2 gas content in the air. This sensor reports the results of air quality detection in the form of changes in the analog resistance value at the output pin (Abbas et al., 2020). The MQ-7 sensor is a gas sensor used to detect carbon monoxide (CO) gas. The MQ-7 CO gas sensor can detect CO gas concentrations in the range of 20 ppm – 2000 ppm (Ibrahim, 2018). The PMS5003 sensor is used to detect dust particles such as PM 1, PM 2.5, and PM 10 (Al-Rawi et al., 2021). This sensor also has a very high level of precision with values below 15 $\mu g/m^3$ or 15% at PM 10 and PM 2.5 sizes (Nguyen et al., 2021). ADS1115 is a low-power analog-to-digital converter (ADC) with an output resolution of 12 bits, the ADS1115 also incorporates a programmable gain amplifier and a digital comparator (Chaudhari, 2019). NodeMCU ESP8266 is an open-source IoT platform, NodeMCU is a board developed with the advantages of the ESP8266 Wifi chip that supports TCP/IP protocols (Visconti et al., 2020) and also has online processing capabilities. strong board (Sung et al., 2019) besides the NodeMCU board can work alone without using an Arduino board (Walia et al., 2016). The NodeMCU can be programmed via the Arduino Integrated Development Environment (IDE) using the LUA language similar to the C language (Vanaja et al., 2018) so that programmers can create computer programs that are then uploaded to the microcontroller board.

2.2.2. IoT Platforms

The Internet of Things (IoT) in general can be interpreted as communication between objects using the internet network (Panduardi & Haq, 2016). The concept of IoT is to combine the physical environment with hardware and software connected via the internet and take input from the real world to make decisions. IoT devices have some common electronic components with one or more sensors and have open sockets to connect them to a network by wires (local area network [LAN], wide area network [WAN]) or additional chips to connect them to a network wirelessly (Bluetooth, Wi-Fi). -Fi) (Bansal, 2020). With the IoT concept, sensors will communicate with each other without human assistance. Users can also access and read the sensor status wherever they are (Kodali et al., 2016). In this study, researchers will use the Blynk and ThingSpeak IoT platforms. The IoT platform aims to connect with other IoT devices so that they can communicate with each other.

Blynk is an application platform with IoS and Android that can control Arduino, Raspberry Pi, and the like via the internet (Doshi et al., 2017). Blynk is designed for IoT and can remotely control hardware remotely, can display sensor data, store data, and visualize data (Durani et al., 2018). In this system, Blynk is used to display data and provide notifications if air quality deteriorates.

ThingSpeak is a cloud-based IoT analytics platform service that can aggregate, visualize, and analyze data streams directly in the cloud (ThingSpeak, 2021). With ThingSpeak, allows developers are able to create logging applications and display them on web-based applications. ThingSpeak is used to display data in the form of graphs, the data is stored in channels from ThingSpeak.

2.3. Data Collection Method

After the system is created, testing will then be carried out to find out whether the system is working properly or not. Data collection methods are carried out by:

- The car is off and there are people in it.
- The car stops, and the engine is on and there are people in the car.
- The vehicle is in motion.

The method of data collection as above has also been carried out as in scenario 3, where the car is running, and the CO value is between 330 PPM and 570 PPM on an open window and 1700 PPM - 3500 PPM on a closed window (Moreno et al., 2019). But this research has not provided notification if air quality deteriorates.

2.4. Notification Rules

Notification rules as a benchmark in providing notifications. Because air contains chemical compounds, a value or index is given to make it easier for people to understand and to indicate the health impact if a chemical element exceeds a certain limit. The air to be measured is CO, CO_2, PM 10, and PM 2.5.

Carbon Monoxide (CO) is a gas produced from the incomplete combustion of coal, wood, and vehicle fuel. Naturally, CO is a colorless, odorless, tasteless ga (Piantadosi et al., 1997) s. Inhaling excessive CO can cause poisoning. The most common symptoms are nausea, headache, shortness of breath, and tachycardia (heart rate exceeding 100 beats per minute, normally 60 beats per minute (Reumuth et al., 2019). CO gas that enters the body binds to hemoglobin, preventing the blood from carrying oxygen. This causes vertigo, loss of consciousness, muscle impotence, coma, and even death (Miles et al., 2019).

Table I. CO Content Level

Level (PPM)	Effects
9	CO Max prolonged exposure (ASHRAE standard)
35	CO Max exposure for 8 hours work day (OSHA)
800	CO Death within 2 to 3 hours
12800	CO Death within 1 to 3 minutes

Based on Table I. Then the system will make CO levels have exceeded 35 then the system will give a notification.

Carbon dioxide (CO_2) is a colorless and odorless natural gas. Carbon dioxide (CO_2) is a chemical compound consisting of 2 oxygen atoms covalently bonded to a carbon atom. The level of CO_2 emissions in vehicles depends on the amount of fuel consumed and the type of fuel used (Rajkumar et al., 2017). The CO_2 concentration limit according to The Federal Environment Agency of Germany and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) is 700 ppm above continuous ambient conditions. Based on the ASHRAE standard 62, if the CO_2 concentration exceeds about 1100 ppm in the house or vehicle cabin, it is necessary to introduce outside air into the house or vehicle cabin to reduce the CO_2 concentration (Mathur, 2019).

Table II. CO_2 Content Level

Level (PPM)	Effect
250-350	Normal background concentration in outdoor ambient air.
350-1000	Concentrations are typical of occupied indoor spaces with good air exchange.
1000-2000	Complaints of drowsiness and poor air.
2000-5000	Headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate, and slight nausea may also be present
5000	Workplace exposure limit (as 8-hour TWA) in most jurisdictions
>40000	Exposure may lead to serious oxygen deprivation resulting in permanent brain damage, coma, and even death.

Based on Table II, the level of danger that will be given when the carbon monoxide (CO_2) level has exceeded 1000 ppm is that the driver and passengers will feel sleepy, and the air quality is already bad.

Particulate Matter (PM) is a mixture of solid particles and liquid droplets in the air including smoke, dust, and ash (Kalia & Ansari, 2020). The particles are so small that they cannot be seen with the naked eye and can only be detected using a microscope. PM 10 has a diameter of fewer than 10 microns and PM 2.5 is a particle with a diameter of fewer than 2.5 microns. PM 10 and PM 2.5 appear to be invisible to the naked eye but can enter further into the lungs. Short-term exposure can cause irritation to the eyes and nose and long-term exposure can cause cardiovascular and respiratory diseases and have a negative impact on lung function. The Threshold Limit Value (NAV) is the air pollution concentration limit that is allowed to be in the ambient air. NAV PM 2.5 = 65 µg/m3 and NAV PM10 = 150 µg/m3. The Air Pollutant Standard Index (ISPU) is an air quality report to the public to explain how clean or polluted the air quality is and how it affects health after breathing the air for several hours or days.

Table III. PM 10 & PM 2,5 Content Level (BMKG, n.d.)

Concentration PM 10 (µg/m³)	Concentration PM 2.5 (µg/m³)	ISPU Category
0-50	0-15	Good
51-150	16-65	Medium
151-350	66-150	Unhealthy
351-420	151-250	Very Unhealthy
>420	>250	Dangerous

Based on Table III, the researcher will make the system provide a notification if the concentration of PM 10 is more than 151 µg/m³ and the concentration of PM 2.5 is more than 65 µg/m³ because the air that has exceeded the concentration value is already unhealthy.

III. RESULTS AND DISCUSSION

3.1. Implementation System

Implementation is done by using a sedan with premium fuel with 2 people in it and the tool is placed on the dashboard of the car. Testing is carried out with several scenarios such as:

- *Scenario 1: The car is stopped, and the engine is on.*
- *Scenario 2: The car is running, and the engine is off.*
- *Scenario 3: The car is running.*

Figure 4. System Implementation

The following are the average results of testing the Air Quality Monitoring and Notification system on cars based on a predetermined scenario, the test is carried out for 15 to 20 minutes:

Table IV. Results of Gathering Data

Scenario	PM 2.5	PM 10	CO	CO_2
The car is stopped and the engine is on	81.56 ***µg/m***³	168 ***µg/m***³	24.29 PPM	567.5 PPM
The car is stopped and the engine is off	45.125 ***µg/m***³	57 ***µg/m***³	36.9 PPM	847.5 PPM
The car is running	101.5 ***µg/m***³	186 ***µg/m***³	24.14 PPM	499 PPM

Based on Table IV, it can be concluded that when the car is stopped and the engine is on, the average value of PM 2.5 and PM 10 is already at an unhealthy level, while in the scenario where the car stops and the engine is off, the PM 2.5 and PM 10 values are still in normal condition but the values of CO and CO_2 have increased. For the

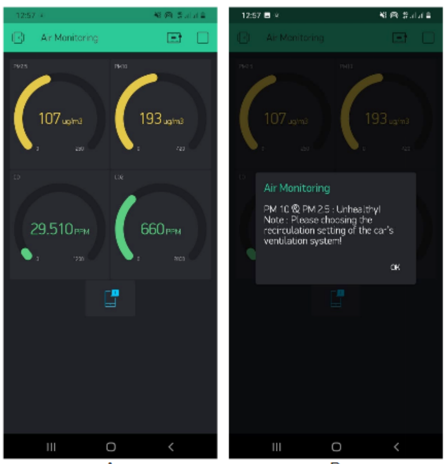
Mobile Scenario, it runs the same as Scenario 1 where PM 2.5 and PM 10 are already at unhealthy levels while CO and CO_2 are still in normal conditions. Based on the results obtained, the sensor can work well and send notifications if the air quality worsens, the value displayed on the Blynk mobile application is real-time and the graphic display of the ThingSpeak IoT platform has successfully gone up or down. However, based on observations on the ThingSpeak IoT platform the value will be updated every 15 seconds. Besides that, the internet connection also affects data transmission from sensors to the IoT platform.

3.2. Gathering Data in Scenario 1.

Figure 5 shows the result of data collection in Scenario 1. Data collection is carried out after the car has been in the state for 30 minutes. then measurements and data collection are carried out. From the graph in Scenario 1 shown, it can be seen that when the car is on, the graph of PM 2.5 and PM 10 goes up, while the graph of CO and CO_2 slowly decreases. The researcher concluded that the results of the study in Scenario 1 the accumulation of concentration was caused by the quality of the car air conditioner not being good and the air recirculation did not work well.

Figure 5. ThingSpeak Display in Scenario 1
(A: PM 2.5 (µg/m3); B : PM 10 (µg/m3); C : CO (PPM); D : CO_2 (PPM))

In Figure 6 there are 2 images on the left, which are graphical displays of the values obtained by the sensor or on the right are notifications if PM 2.5, PM 10, CO, and CO_2 have passed the set limits. Based on data collection when the car is stopped and the engine is running, it can be seen that the air quality for PM 10 and PM 2.5 has exceeded the limit, the system will provide notifications and recommendations for actions to be taken.



A B

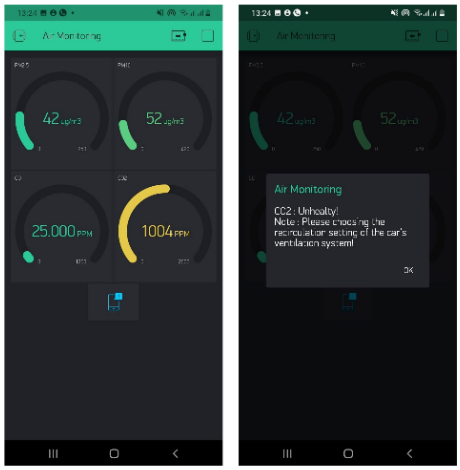
Figure 6. Blynk view in scenario 1.

3.3. Gathering Data in Scenario 2

Figure 7 shows the results of the implementation of the Air Quality Monitoring system with the car in a stopped state and the engine off. Data collection was carried out after 20 minutes the car was off and there were 3 people in the car. It can be seen that there is an increased buildup of concentration of CO_2 but the value of CO is slowly improving and the value of PM 2.5 & PM 10 is in good condition. Researchers concluded that when the car is off and the door is locked, CO_2 levels will increase because there is no air circulation and air buildup is released by people in the car.

Figure 7. ThingSpeak Display in Scenario 2
(A: PM 2.5 (µg/m3); B: PM 10 (µg/m3); C: CO (PPM); D: CO_2 (PPM))

Based on data collection when the car stops and the engine is off, it can be seen in Figure. 8 that the air quality for CO_2 has exceeded the limit, so the system provides notifications and recommendations for CO_2 parameters.



A B

Figure 8. Blynk view in scenario 2.

3.4. Gathering Data in Scenario 3

Data collection was carried out during the day and when the road was congested. Figure 10 shows the result of data collection when the car is running. It can be seen in the graph that there is an increase in the concentration of PM 2.5 and PM 10 compared to CO and CO_2 under normal conditions. Researchers concluded that air containing dust can enter the car through the ventilation duct so air circulation is needed.

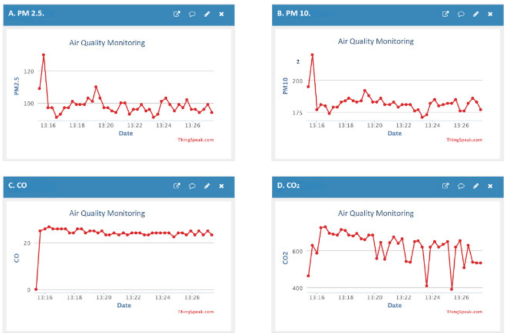
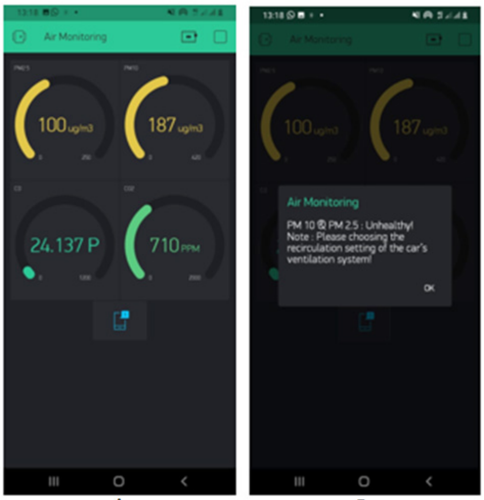


Figure 9. ThingSpeak Display in Scenario 1
(A: PM 2.5 (µg/m3); B: PM 10 (µg/m3); C: CO (PPM); D: CO_2 (PPM))

In Figure 10 based on data collection while the car is running, it can be seen that the air quality for PM 10 and PM 2.5 has exceeded the limit, so the system provides notifications and recommendations for PM 10 and PM 2.5 parameters.



A B

Figure 10. Blynk View in Scenario 3

IV. CONCLUSION

The results of the evaluation of the system that has been made, show that the system works well, on the Blynk IoT platform the system has succeeded in displaying air quality values in real-time and providing notifications if air quality deteriorates. The ThingSpeak IoT platform already displays graphs of each parameter (CO, CO_2, PM 2.5. and PM 10). At the time of implementation and data retrieval for scenarios 1, 2, and 3 the system has successfully sent data to the IoT platform and notifications if the air quality deteriorates. The functionality of this system is in accordance with the research objectives.

However, these studies still have limitations and disadvantages such as having to use internet data consumption in order for data to be stored to appear and provide notification through IoT platforms, Thus for further research researchers suggest adding LCDs and speakers so that if air quality deteriorates it can be seen immediately on LCDs and notifications via speakers and can also add air quality parameters such as Sulfur Dioxide (SO2), Nitrogen Dioxide (NO2), Ozone (O3), and Ozone (O3). The air pollution index (API) can be calculated.

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