International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 14, Issue 1 (Jan.-Feb. 2025), PP. 40-49

Research on Vehicle Cabin Air Quality

Wen-Kung Tseng*, Yan-Zhang Wang**
**Professor, Graduate Institute of Vehicle Engineering, National Changhua University of Education, Taiwan R.O.C.*
*** Postgraduate Student, Graduate Institute of Vehicle Engineering, National Changhua University of Education, Taiwan R.O.C.*
Corresponding Author: andy007@cc.ncue.edu.tw

Abstract: *This study focused on the detection of air comfort within a car's interior environment. The primary goal was to monitor the concentrations of carbon dioxide and carbon monoxide inside the vehicle. The research implemented an indoor CO_2 and CO concentration monitoring system based on the Arduino platform. This system used CO_2 and CO sensors to detect the concentrations of these gases in real-time within the car's environment. When the concentrations exceeded safe levels, indicator lights flashed to alert the occupants, and the ventilation system was activated to enhance air comfort inside the vehicle. High levels of CO_2 and CO inside a car could cause symptoms like dizziness, headaches, or poor health for the driver, potentially leading to dangerous or fatigued driving behaviors. This study collected data from sensors every second and calculated their average to improve the air comfort inside the vehicle, creating a comfortable and safe driving environment. In the experiment, after connecting the sensors, CO_2 and CO concentrations were calculated by measuring their output voltages. When gas concentrations exceeded the set thresholds, corresponding LED indicators lighted up, and the motor activated to improve cabin air comfort. Results showed that the system effectively monitored and displayed changes in CO_2 and CO concentrations, issuing warnings and activating ventilation when levels exceeded safety thresholds.*
Keywords: *Air comfort; car's interior environment; carbon dioxide; carbon monoxide; Arduino; dizziness.*

Date of Submission: 05-02-2025 Date of acceptance: 16-02-2025

I. INTRODUCTION

With the widespread use of cars, vehicles have become an indispensable part of people's daily lives. However, the air quality inside the car directly affects the health of passengers and the safety of drivers. When driving long distances or parking, the concentration of carbon dioxide and carbon monoxide in the car will increase, affecting the driver's health and concentration. Therefore, monitoring and improving air quality in vehicles has become an important research topic. Air pollution in cars comes from multiple sources, including passengers' breathing, smoking, vehicle emissions, external environmental factors, etc. Especially when windows are closed or ventilation is poor, carbon dioxide and carbon monoxide concentrations may rise. High levels of carbon dioxide can cause dizziness, fatigue and difficulty concentrating, while carbon monoxide is a colorless and odorless toxic gas that can lead to poisoning.

In recent years, the importance of monitoring indoor air quality has become increasingly apparent, particularly with the growing awareness of the health impacts associated with poor air quality. Indoor environments, such as homes, offices, and vehicles, can have elevated levels of carbon dioxide and carbon monoxide, which can adversely affect human health. CO_2 , primarily produced by human respiration, can lead to symptoms like dizziness, fatigue, and impaired cognitive function at high concentrations. CO, a byproduct of incomplete combustion, can cause severe health issues, including headaches, dizziness, and even death at high concentrations. Numerous studies have highlighted the health risks associated with high indoor CO_2 and CO levels. According to a study by Satish [1] et al., increased CO_2 levels can significantly impair decision-making performance, even at concentrations commonly found in indoor environments. Another study by Allen [2] et al. demonstrated that high CO_2 levels could reduce cognitive function, particularly in poorly ventilated spaces. Research by Raub [3] et al. focused on the health effects of CO exposure, indicating that even low levels of CO could cause adverse health effects over time. Therefore, real-time monitoring and improvement of in-car air quality is crucial to protect the health and safety of drivers and passengers.

This research developed an in-car air quality monitoring system that instantly detected carbon dioxide and carbon monoxide concentrations and provided warnings and improvements through indicator lights and motors. Known for its open source, low cost, and ease of programming, the Arduino platform is ideal for building such systems. Through this system, drivers could receive timely alerts about air quality problems in the car, reducing health risks and traffic safety hazards. This not only enhances driving and riding comfort, but also improves overall driving safety. This system provided a feasible and effective solution for in-car air quality monitoring and management. The study emphasized the need for continuous monitoring to prevent exposure to harmful CO levels, especially in enclosed spaces like vehicles and residential buildings. By reviewing the existing literatures, this study built upon established knowledge of the health impacts of CO_2 and CO, the technical capabilities of MG811 and MQ9 sensors, and the importance of accurate air quality monitoring.

II. AIR COMFORT IN THE CAR

Cabin air comfort refers to the quality of the air inside a vehicle, encompassing factors such as temperature, humidity, airflow, and pollutant concentrations. High air comfort levels provide a pleasant driving experience, reduce discomfort, and enhance driver alertness and reaction speed, thereby improving driving safety. Air quality inside the car is a key factor affecting passenger comfort. Spending extended periods in an enclosed cabin, especially during long trips, means air quality directly impacts the driver's health and mood. Good air quality increases driver alertness and reduces fatigue, enhancing safety. Conversely, poor air quality can lead to headaches, fatigue, and lack of concentration, increasing the risk of accidents. Cabin air comfort includes multiple factors such as temperature, humidity, airflow, and pollutant concentrations. Through scientific design and technological applications, the air quality inside the car can be significantly improved, thereby enhancing passenger comfort and safety.

The factors affecting the comfort of the car interior air quality include several aspects:

1. Temperature and humidity: The temperature and humidity inside the car are crucial factors affecting passenger comfort. Extreme temperatures and inappropriate humidity levels can cause discomfort for passengers and even affect the driver's attention and judgment.

2. Airflow: The airflow inside the car also affects air comfort. Proper airflow can maintain fresh air and prevent the accumulation of pollutants, but excessive airflow can make passengers uncomfortable.

3. Pollutant concentration: The concentration of pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), etc., inside the car is a key factor affecting air quality.

These pollutants originate from passenger respiration, vehicle emissions, interior materials, and external environment. Carbon dioxide (CO_2) mainly comes from the respiration of passengers. In a closed compartment, especially when there are many passengers or poor ventilation, the CO_2 concentration will rise rapidly. When a vehicle is parked for a long time and the ventilation system fails to work effectively, the CO_2 concentration in the vehicle will increase significantly. Health Effects: CO_2 concentrations have a significant impact on the health of passengers and drivers. When the CO_2 concentration in a car reaches 1,000 ppm, passengers may experience symptoms such as dizziness, fatigue, and difficulty concentrating. When concentrations reach 2,000 ppm, these symptoms become more pronounced and may cause headaches and shortness of breath. If the CO_2 concentration further rises above 5,000 ppm, it may cause coma or even be life-threatening [4, 5]. According to research, Table 1 shows the effects of different CO_2 concentrations on the human body:

Table 1 Effects of different CO_2 concentration ranges on the human body

CO_2 Concentration Range (ppm)	Impact
400-1000	Concentration feels normal.
1000-2000	Mild discomfort, symptoms such as headache, drowsiness, and difficulty concentrating may occur.
2000-5000	Significant discomfort, headache, nausea, shortness of breath and other more serious symptoms.
Above 5000	Highly dangerous, may cause coma or even be life-threatening.

High concentrations of CO_2 will make the air in the car dull and affect the comfort of passengers. When the CO_2 concentration in the car is too high, passengers may feel stuffy and have difficulty breathing, leading to physical discomfort. Drivers' reaction speed and judgment will also be reduced due to high concentrations of CO_2, increasing the risk of traffic accidents. Therefore, maintaining appropriate CO_2 concentrations is critical to the comfort and safety of the vehicle interior environment. By monitoring and managing the CO_2 concentration in the car in real time, the comfort and driving safety in the car can be effectively improved.

Carbon monoxide (CO) is a colorless, odorless, non-irritating toxic gas that is mainly emitted from incomplete combustion car engines. When a vehicle is operated in a closed environment for a long time, or when the vehicle is stuck in traffic or driving at low speed, the concentration of CO emissions will increase significantly. When the ventilation in the car is poor or the air filtration system is imperfect, the risk of CO accumulation in the car will also be greatly increased [5]. CO is extremely harmful to human health. After CO enters the human body, it will combine with hemoglobin in the blood to form carboxyhemoglobin, thereby reducing the oxygen-carrying capacity of hemoglobin and causing tissue hypoxia. The effects of different concentrations of CO on human health are shown in Table 2:

Table 2 Effects of different CO concentration ranges on the human body

CO concentration range (ppm)	Impact
0-9	Normal concentration, generally no symptoms.
10-50	Mild headache and discomfort may occur.
50-100	Causes significant headache, fatigue, nausea and palpitations.
100-200	Causes more severe symptoms such as heart palpitations, nausea, and difficulty breathing.
200-400	May cause fainting, coma, or even death.
Above 400	Extremely dangerous and rapidly fatal.

High concentrations of CO in the car will seriously affect passenger comfort. The presence of CO may cause passengers to experience headaches, dizziness, fatigue and difficulty breathing. These discomforts can significantly reduce the passenger's ride experience. For drivers, the symptoms of CO poisoning can greatly affect driving safety because the driver's reaction time and judgment will be affected, thereby increasing the risk of traffic accidents. Therefore, it is crucial to control the CO concentration in the car. Therefore, it is crucial to control the CO concentration in the car. Carbon dioxide and carbon monoxide have a significant impact on the comfort and safety of the air in the car. High concentrations of CO_2 will make passengers feel uncomfortable and affect their attention and reaction time. High concentrations of CO_2 will pose serious threats to health and even lead to fatal dangers. Therefore, real-time monitoring of CO_2 and CO concentration in the car and timely adjustment and ventilation are key measures to ensure the air quality in the car.

Maintaining appropriate CO_2 and CO concentrations is critical to the comfort and safety of the vehicle interior environment. High concentrations of CO_2 will reduce air quality and affect the breathing comfort of passengers and the concentration of drivers. The presence of CO may cause acute poisoning, causing serious health hazards and driving safety hazards. To improve in-car air comfort and driving safety, a CO_2 and CO concentration monitoring system was developed. Such a system can promptly detect and remind drivers to pay attention to air quality problems in the car, thereby effectively preventing potential health risks and traffic accidents, and improving the overall riding experience and driving safety. Effective monitoring and management measures can not only ensure the best air quality in the car, but also dynamically adjust the ventilation system in the car through automation, further optimizing the interior environment and improving the comfort and safety of passengers and drivers.

III. EXPERIMENT AND RESULTS

This experiment aimed to establish a platform for measuring and analyzing changes in carbon dioxide (CO_2) and carbon monoxide (CO) concentrations in the car cabin. By using MG811 and MQ9 sensors, it monitored these gas concentrations in real-time [6, 7, 8, 9]. The recorded data and analysis results were then used for the car cabin monitoring applications.

The specific objectives include:

1. Designing and implementing a gas detection system based on MG811 and MQ9 sensors.
2. Developing data collection and processing algorithms to accurately calculate gas concentrations.
3. Evaluating the performance and accuracy of the system and verifying its reliability through multiple experiments.

The experimental platform consists of two main components: hardware and software. The experiment flow chart is shown in Figure 1.

1.Hardware design:

- Sensors: Including MG811 sensor and MQ9 sensor.
- Microcontroller: Using Arduino as the data processing unit.
- Power management: Power supply module to ensure stable operation of the system.

2. Software design:

- Data collection: Embedded software to acquire voltage data from MG811 and MQ9 sensors and perform preliminary processing.
- Concentration calculation: Converting voltage data to gas concentration, calculating CO_2 and CO

concentrations based on the sensor calibration curves.

- Data analysis: Using data analysis software to analyze the data and generate reports.

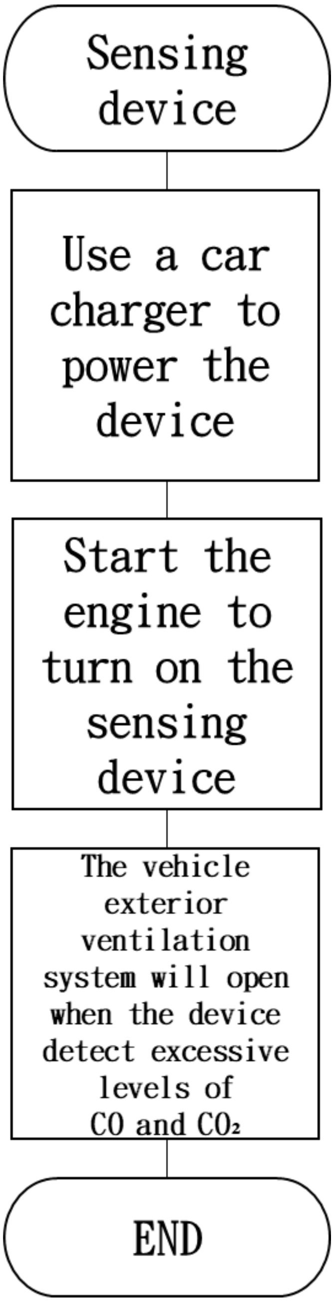

Fig. 1. Experiment flow chart

MG811 is a carbon dioxide (CO_2) sensor, and the relationship between its output voltage and CO_2 concentration can be accurately determined through the calibration curve. The working principle of MG811 is based on solid electrolyte. When the CO_2 concentration in the environment changes, the output voltage of the sensor will also change. This change is often nonlinear and requires calibration to determine the specific voltage-to-concentration relationship. During the calibration process, the sensor is typically tested in a standard environment with a known CO_2 concentration, its output voltage is recorded, and then a data fitting method is used to establish an accurate voltage versus concentration curve. Such calibration not only improves the measurement accuracy of the sensor, but also ensures stability and reliability under different environmental conditions.

The relationship between the voltage of the MG811 sensor and the CO_2 concentration (ppm) is as follows:

1. Calibration procedure:
   - Known concentration environment test: Test the MG811 sensor in a standard environment with known

CO_2 concentration and record its output voltage.

- Data fitting: Collect multiple sets of output voltage data at different concentrations and use linear regression or other data fitting methods to determine the relationship between voltage and concentration.

2. Data processing:
- Reading voltage data: Read the output voltage of the MG811 sensor via Arduino or another microcontroller.
- Concentration calculation: Convert the output voltage to CO_2 concentration based on the calibration formula or curve. The common calibration formula is [9]:

$$\mathbf{CO_2 \ concentration \ (ppm)} = A \times (V\mathbf{out} - B) \quad (1)$$

Where:

- A and B are calibration constants.
- Vout is the output voltage of the MG811 in volts.

3. Determine calibration constants:
- Determination of constants A and B: These constants were determined by conducting multiple tests at known CO_2 concentrations and using data fitting methods. For example, linear regression can be used to determine the optimal values of A and B so that the formula accurately reflects CO_2 concentrations at different concentrations.

4. Data Analysis and Processing:
- Average Calculation: Calculate the average of multiple readings to eliminate random errors.
- Trend Analysis: Analyze the data trends over time to determine if there are abnormal concentration changes.
- Anomaly Detection: Set a safety threshold for CO_2 concentration and trigger an alarm mechanism when the read data exceeds this threshold.

Through the above process, the output voltage of the MG811 sensor can be accurately converted into the actual CO_2 concentration, enabling effective monitoring of CO_2 levels in the environment. This has important applications in environmental monitoring, industrial production, and in-vehicle air quality control. The variation of CO_2 concentration with voltage and time is shown in Figures 2, 3 and 4.

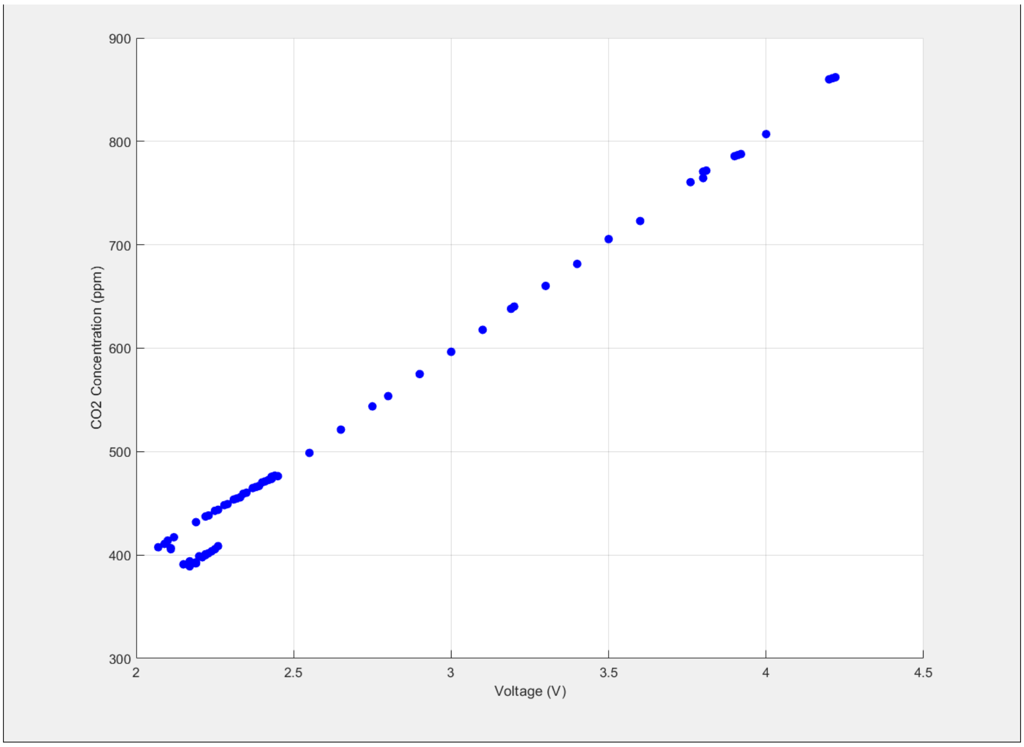

Fig. 2. Relationship between voltage and CO_2 concentration

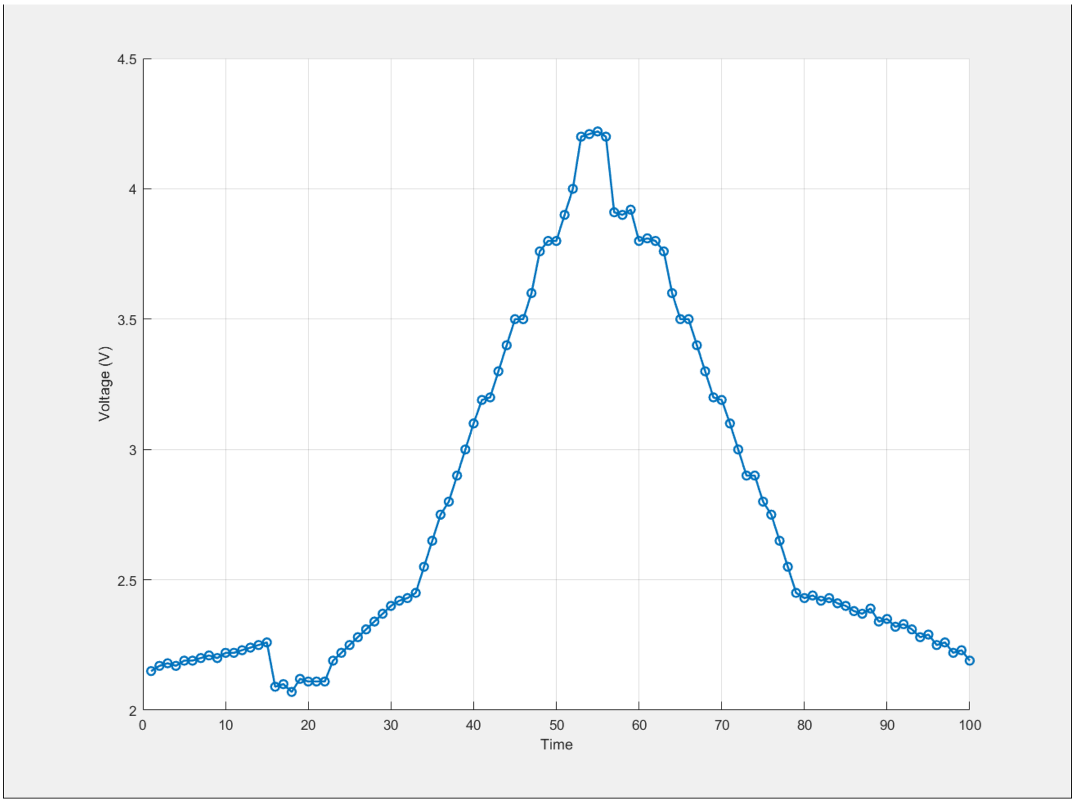

Fig. 3. Time versus voltage graph for CO_2 concentration

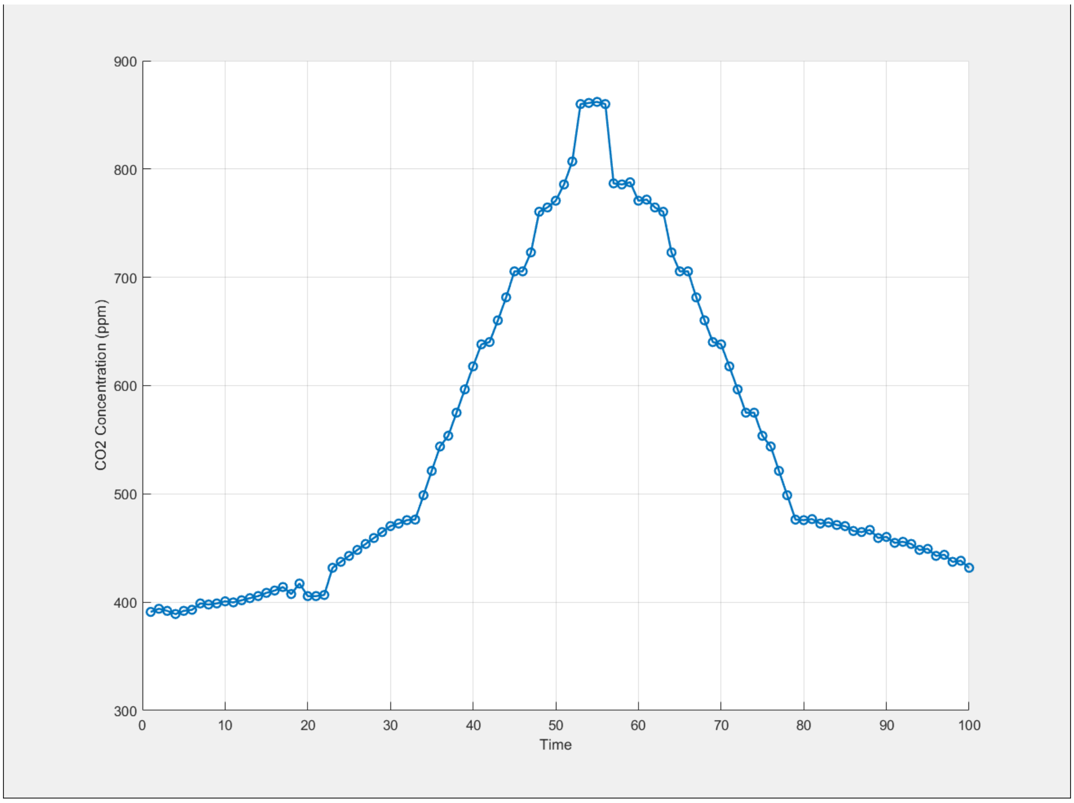

Fig. 4. Time versus CO_2 concentration graph

The MQ9 is a multifunctional gas sensor designed to detect carbon monoxide and combustible gases. There is a certain relationship between its output voltage and gas concentration, and the relationship is determined through a calibration formula [8].

1. The calibration process mainly involves testing the sensor in an environment with known concentrations to determine the relationship between voltage and concentration. Here are the specific steps:
   - Concentration environment test: Test the MQ9 sensor in an environment with known CO concentration and record the output voltage Vout [9].
   - Data fitting: Collect output voltage data at different concentrations and determine the relationship between voltage and concentration through data fitting.
2. Data processing process:
   - Read voltage: Read the output voltage of the MQ9 sensor through Arduino.
   - Concentration calculation: Convert the output voltage to CO concentration according to the calibration formula.

The common calibration formula is [9]:

$$\textbf{CO concentration(ppm)= 10}\ \left(\frac{V_{out}-V_{ref}}{K}\right) \quad (2)$$

Where:

- Vout is the output voltage of MQ9 in volts.
- Vref is the reference voltage.
- K is a constant determined through calibration. It depends on factors such as the sensitivity of the sensor and the environmental conditions during the calibration process.

3. Determination of the calibration constant K requires multiple tests in an environment with known CO concentrations and is determined using data fitting methods. For example, based on multiple sets of output voltage data at known concentrations, regression analysis is used to determine the optimal K value so that the formula can accurately reflect the CO concentration at different concentrations.
4. The data analysis phase includes the following steps:
   - Average calculation: Averaging data from multiple readings to eliminate chance errors.
   - Anomaly detection: Set a safety threshold for CO concentration. When the read data exceeds this threshold, the alarm mechanism is triggered.

Through the above process, the output voltage of the MQ9 sensor can be accurately converted into the actual CO concentration, thereby achieving effective monitoring of the CO concentration in the environment. It has important application value in home security, industrial production and indoor air quality control. The variation of CO concentration with voltage and time is shown in Figures 5, 6 and 7.

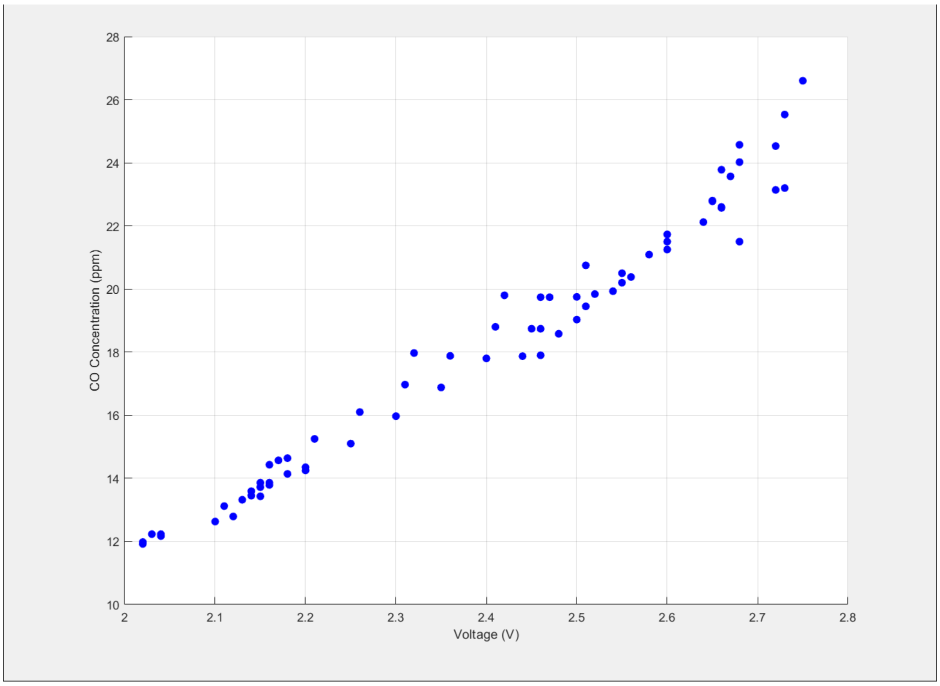

Figure 4-Fig. 5. Relationship Between Voltage and CO Concentration

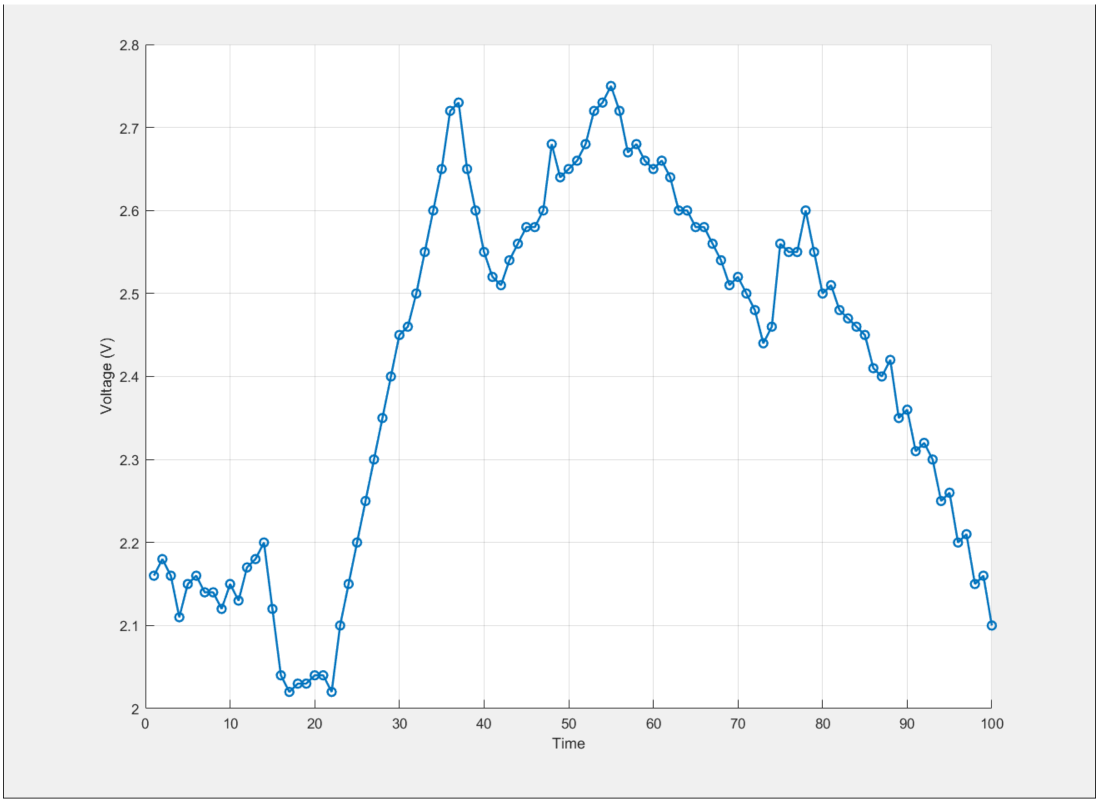

Fig. 6. Time Versus Voltage Graph

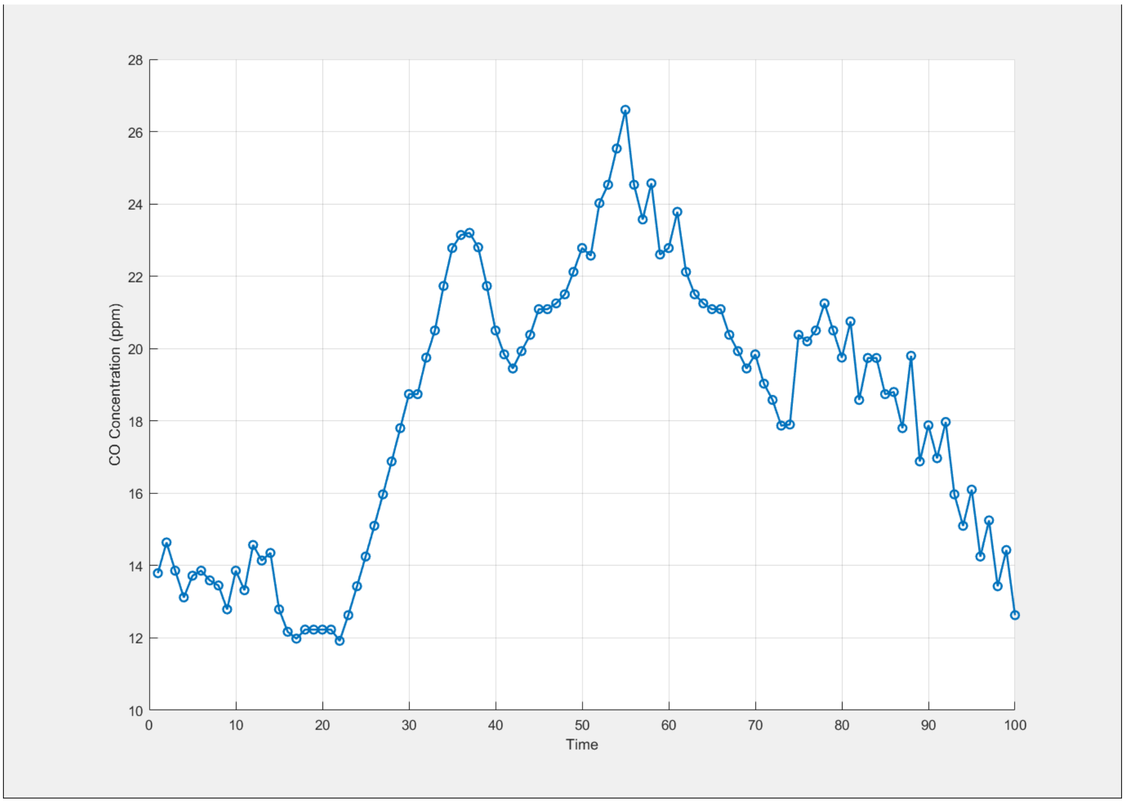

Fig. 7. Time Versus CO Concentration Graph

This study aimed to experimentally verify and analyze the performance of a gas detection system based on MG811 and MQ9 sensors. System performance evaluation includes four aspects: accuracy, stability, response speed and practical application potential.

1. Accuracy evaluation: To evaluate the accuracy of the system, multiple experiments were conducted, and the measurement results were compared with standard concentration values. In the experiment, the calibration constants of the MG811 and MQ9 sensors were determined through calibration with standard gas samples of known concentrations. The experimental results showed that the error between the system's measurement results and the standard value is within the acceptable range, proving that the system has high accuracy in gas concentration measurement.
2. Stability assessment: Evaluate the stability of the system through multiple long-term running tests. During the test, there was no obvious drift or abnormality in the sensor output data, indicating that the system has good stability. In addition, the system was tested under different environmental conditions (such as temperature and humidity changes) and the results showed that the system was able to adapt to these changes and maintain stable output results.
3. Response speed evaluation: Evaluate the system's response speed to changes in gas concentration by measuring the time interval between data processing and result display after the sensor detects a change in gas concentration. Experimental results show that the system has fast response speed, can instantly reflect gas concentration changes, and meets the requirements of real-time monitoring.
4. Practical application potential: Evaluate the practicality of the system through experimental results and performance evaluation. Experimental data shows that the system has huge application potential in various scenarios such as in-car air quality monitoring and industrial safety monitoring. The system's high precision, stability and rapid response capabilities enable it to meet the needs of different application scenarios.

To verify the practicability of the system, various methods were used to analyze the data. The experimental data were compared with standard data to verify the accuracy of the system. The logic analyzer confirms that the received data is consistent with the actual data, proving the reliability of the system's data transmission. After the data were measured and calibrated, a series of experiments were conducted. The results showed that when the concentrations exceeded safe levels, indicator lights flashed to alert the occupants, and the ventilation system was activated to enhance air comfort inside the vehicle.

IV. CONCLUDING REMARKS

This research aimed to construct a gas detection system based on MG811 and MQ9 sensors to monitor and analyze the concentration of carbon dioxide (CO_2) and carbon monoxide (CO) in real-time. Through a series of experiments, we have reached the following conclusions:

1.System reliability and accuracy: The performance of the MG811 and MQ9 sensors was stable across multiple tests, with data fluctuations within an acceptable range, demonstrating their reliability and accuracy in measuring environmental gas concentrations.

2.Impact of ventilation on air quality: In a confined car environment, the concentrations of CO_2 and CO were significantly higher than in well-ventilated environments. This highlights the importance of ventilation in maintaining good air quality.

3. Data processing and calibration methods: The methods were used to convert the voltage output of the MG811 and MQ9 sensors into concentration data, and the subsequent data conversion and analysis through calibration formulas, proved to be effective and feasible.

In summary, this study validated the effectiveness of the gas detection system based on MG811 and MQ9 sensors through experiments and data analysis and reveals the changes in gas concentrations under different environmental conditions. These findings were of significant reference values for monitoring and improving air quality in vehicles.

REFERENCES

[1]. Satish, U., et al. (2012), "Is CO_2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO_2 Concentrations on Human Decision-Making Performance", *Environmental Health Perspectives*, 2012, 25-33

[2]. Allen, J. G., et al. (2016), "Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments", *Environmental Health Perspectives*, 2016, 45-52

[3]. Raub, J. A., et al. (2000), "Carbon Monoxide Poisoning—A Public Health Perspective", *Toxicology*, 2000, 22-36.

[4]. Abdul Syafiq Abdull Sukor, (2022), "Predictive Analysis of In-Vehicle Air Quality Monitoring System Using Deep Learning Technique", *Air Quality Prediction and Modeling*, 2022, 12-20.

[5]. Luigi Russi, (2021), "Air Quality and Comfort Characterisation within an Electric Vehicle Cabin in Heating and Cooling Operations", *2021 IEEE International Workshop on Metrology for Automotive*, 2021.
[6]. Gravity: Analog CO2 Gas Sensor for Arduino (MG-811 Sensor), Available: https://www.farnell.com/datasheets/3176108.pdf.
[7]. Interface the MQ9 Gas Sensor with Arduino, Available:https://www.electrovigyan.com/arduino/mq9-gas-sensor/.
[8]. Wang, X. et al. (2019), "A Review of Carbon Dioxide Detection Technologies. Sensors", *Basel Switzerland*, 2019, 19(14), 3033. doi:10.3390/s19143033.
[9]. Shigeru Muto and Kunihiko Seiyama, (2012), "Semiconductor Gas Sensors", *Chemical Sensor Technology*, 2012.