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Development of Carbon Monoxide Gas Detection and Monitoring System in Vehicle Cabin with Auto Ventilation and Auto Engine Switch Off

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Abstract

The development of an effective carbon monoxide (CO) detection system in vehicle cabins is crucial to ensure passenger safety. This project aims to design and implement a system that not only monitors CO levels but also takes automated actions to mitigate potential hazards. Elevated CO levels in enclosed vehicle cabins can lead to serious health issues or fatalities, and existing solutions either focus on monitoring or providing alarms without integrating comprehensive automated responses. This project addresses the gap by offering an all-in-one solution that ensures immediate action when hazardous conditions are detected. The objective is to develop a reliable CO detection system for vehicle cabins that alerts occupants and initiates automated safety measures to reduce CO exposure. Using an Arduino Uno, MQ-9 gas sensor, LCD display, and dual-channel relay, the system is designed to monitor CO levels continuously and activate the relay to cut off the engine and roll down the windows if CO concentrations exceed 70 ppm for more than 30 seconds. Rigorous testing was conducted to ensure the system's responsiveness and reliability under various scenarios, refining the algorithm to minimize false positives and negatives. The results indicate that the system effectively detects CO levels above the threshold and initiates the safety measures within the specified time frame, with the LCD display providing clear real-time feedback. In conclusion, the CO detection system with automated ventilation and engine switch-off functions significantly improves vehicular safety by reducing the risks associated with CO exposure. It is recommended that future studies explore integrating additional safety features, such as emergency notification modules and enhancements in sensor accuracy and response times, to further enhance the system's effectiveness and reliability.

1. Introduction

Carbon Monoxide gas is a toxic, odorless, and colorless byproduct of incomplete combustion of fuel, posing severe health risks, including breathing difficulties, drowsiness, and death upon prolonged exposure [1][2]. Carbon Monoxide higher affinity for hemoglobin than oxygen leads to carboxyhemoglobin formation, reducing oxygen transport in the body and impairing cellular function [1]. Symptoms of Carbon Monoxide poisoning range from mild to severe, with noticeable effects beginning at levels above 70 ppm, leading to headaches, fatigue, nausea, disorientation, unconsciousness, and death at sustained concentrations of 150 to 200 ppm [1][2].

Vehicle-related Carbon Monoxide exposure often results from faulty exhaust systems or poorly tuned engines, allowing Carbon Monoxide to enter the cabin undetected [3][4]. Since Carbon Monoxide is odorless and colorless, it is challenging to detect without specialized equipment, making it a silent killer [2]. Exposed individuals often mistake symptoms for fatigue or illness, increasing the risk of death as Carbon Monoxide continues to poison the body [2]. This research aims to develop a comprehensive Carbon Monoxide detection and monitoring system using MQ-9 gas sensors and Arduino technology. The system monitors Carbon Monoxide levels in the vehicle cabin and activates automated ventilation and engine shutdown mechanisms when dangerous Carbon Monoxide levels are detected [3][4]. The detection system triggers at 70 ppm, the threshold where symptoms begin [3]. The solution integrates Carbon Monoxide sensors with the vehicle's power window and ignition systems, allowing it to open windows and shut down the engine to introduce fresh air and eliminate the CO source [3][4].

The system also aims to prevent long-term health effects associated with chronic low-level Carbon Monoxide exposure, which can lead to neurological damage and other severe health conditions [5].

This study emphasizes the necessity of incorporating such detection systems in all vehicles as a standard safety feature [6]. Addressing this safety gap is crucial for protecting passengers from Carbon Monoxide poisoning as automotive technology advances. Implementing this Carbon Monoxide detection and ventilation system can significantly enhance passenger safety and reduce Carbon Monoxide -related risks. The research provides a clear and systematic approach to developing and integrating the system, ensuring precise and reliable results. The system's ability to detect Carbon Monoxide, switch off the engine, and ventilate cabin air will serve as a critical safety measure, preventing fatalities and long-term health issues caused by Carbon Monoxide exposure.

2. Materials and Methods

2.1 Experiment Framework

Figure 1 displays the workflow for developing and validating the Carbon Monoxide detection and monitoring system begins with setting project goals and initial setup. It involves identifying factors contributing to Carbon Monoxide poisoning in vehicle cabins, selecting appropriate hardware like the MQ-9 gas sensor and Arduino microcontroller, and integrating these components into a functional system. Validation ensures all parts work correctly before testing begins. Baseline data on Carbon Monoxide levels is collected first, followed by introducing Carbon Monoxide and measuring the system's response after 30 seconds. Data validation confirms accuracy and reliability in detecting and responding to Carbon Monoxide. The process concludes with a detailed analysis to refine system performance and enhance passenger safety against Carbon Monoxide exposure risks.

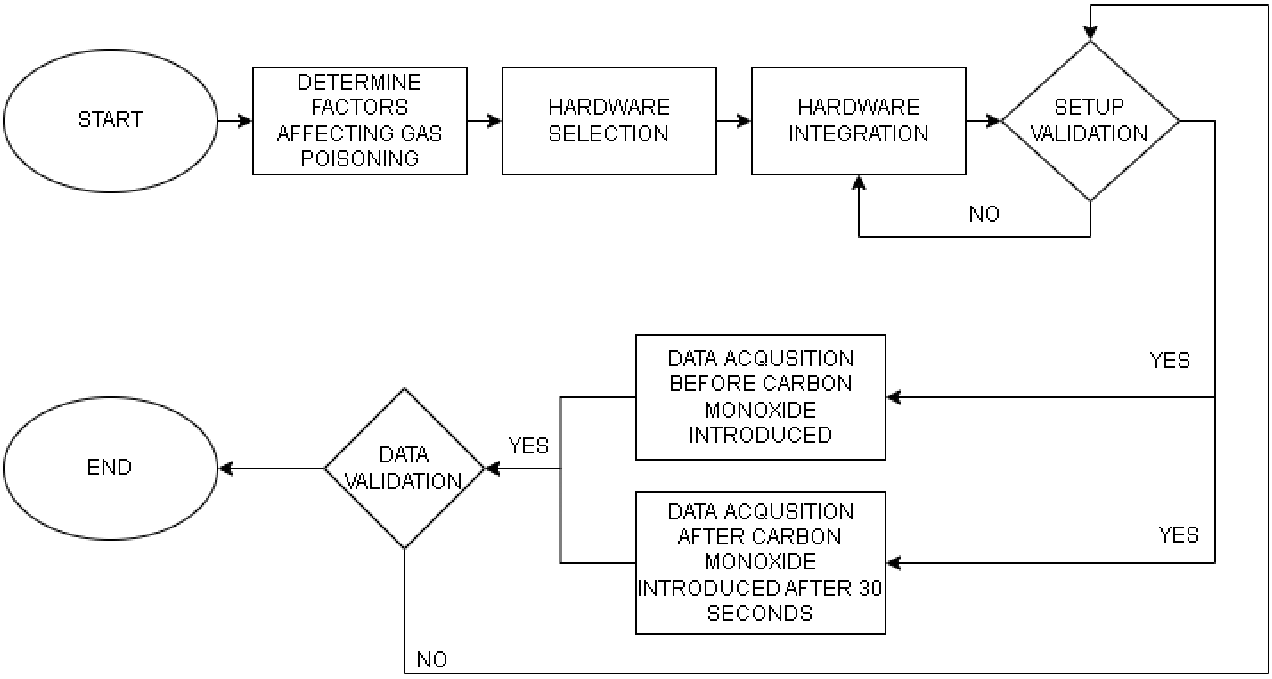


Fig. 1 *Flow chart of the experiment*

2.2 Factors Affecting Gas Poisoning

2.2.1 Temperature

According to the ideal gas law, as the temperature of a gas increases, the kinetic energy of its molecules also increases, which causes the molecules to move faster and collide more frequently and more forcefully with the walls of the container. If the volume of the container is held constant, the increased collisions will result in a higher pressure on the walls of the container. Figure 2 displays four different curves, each one representing the total population of molecules in a sample of material. The area under the curves illustrates this population. At the coldest temperature, T1, the spread of kinetic energy among the molecules in the sample is limited, resulting in most of the molecules having energies that are close to the average kinetic energy of the sample. As the temperature increases, the range of kinetic energy values becomes wider. At T3, the average kinetic energy is higher than it was at T1 and T2, but lower than the average kinetic energy at T4. However, there are still some molecules in the sample that have energies below the averages of T1 and T2, and others that have energies greater than the average of the sample at T4 [7]. This study used average range for Malaysian's surrounding temperature.

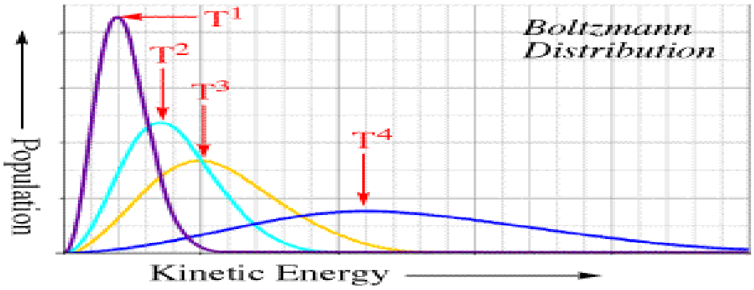


Fig. 2 *An illustrated work on how the kinetic energy varies from each range of temperature*

2.2.2 Humidity

In general, as temperature increases, the air can hold more water vapour, which can cause the relative humidity to decrease. Conversely, as temperature decreases, the air can hold less water vapour, which can cause the relative humidity to increase. This relationship is known as the moisture saturation curve or the psychometric curve. Additionally, this inverse proportionality can be observed through the formula:

$$RH = \frac{100e^{-A(T-Td)}}{e^{-A*(T-Td)}}$$

where RH is the relative humidity, A is the psychometric constant, T is the temperature, Td is the dew point temperature [8]. The range for the relative humidity for Malaysia is around 67% to 95% [9]. Hence this study follow the relative humidity said for this study setup.

2.2.3 Pressure

As shown in Figure 3, the effect of gas pressure on Carbon Monoxide (CO) poisoning is intricately tied to the principles governing gas exchange and hemoglobin's affinity for Carbon Monoxide. When individuals are exposed to environments with elevated levels of Carbon Monoxide, the likelihood of CO molecules binding to hemoglobin in the blood increases [10]. This affinity for hemoglobin is exceptionally high, approximately 200-250 times greater than that of oxygen, leading to the formation of carboxyhemoglobin (COHb). As Carbon Monoxide binds to hemoglobin, it forms a stable complex that diminishes the blood's capacity to transport oxygen, resulting in tissue hypoxia and the onset of poisoning symptoms. Consequently, as the partial pressure of Carbon Monoxide increases, either due to higher concentrations or elevated environmental pressures, more CO molecules are available to bind with hemoglobin, accelerating the formation of COHb and intensifying the severity and rapidity of CO poisoning.

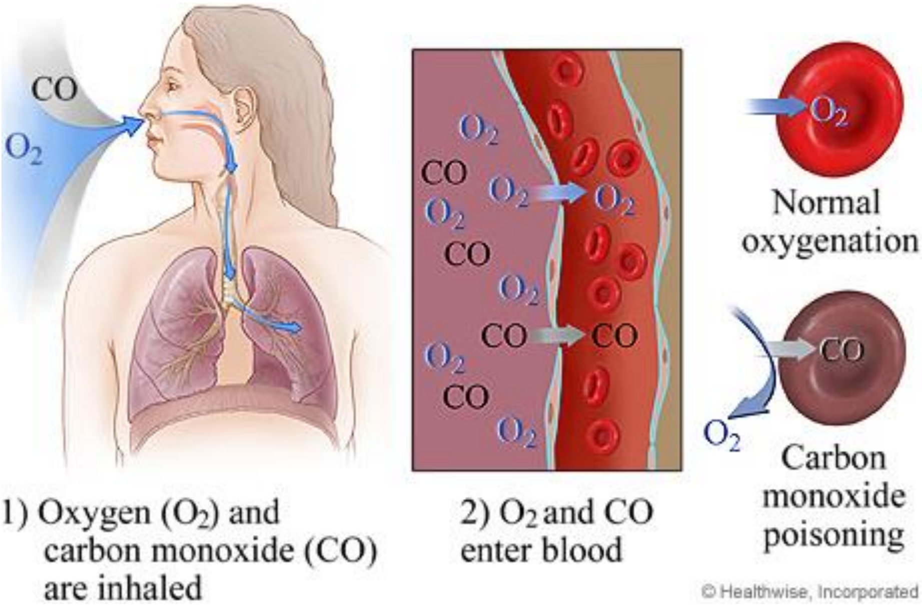


Figure 3 *Carbon Monoxide in hemoglobin compare to oxygen*

This relationship underscores the critical importance of understanding the dynamics of gas pressure in environments where CO exposure is a concern, informing diagnostic and therapeutic interventions to mitigate the risk of poisoning and ensure occupational and environmental safety. Therefore, this study is fixed on atmospheric pressure at 101 kPa [11].

2.2.4 Gas Concentration Level

Based on the Figure 4, we can divide the concentration level of into 4 different parts. From the lowest concentration, we can see it starts from 0 ppm to 9 ppm. The second part which is lower medium concentration, it starts from 25 ppm to 35 ppm. The higher medium concentration starts from 50 ppm to 400ppm. Lastly followed by high concentration level which starts from 800 ppm to 12800 ppm. Hence the limit of ppm for Carbon monoxide gas for this study will be set at 70 ppm.

The concentration level of gas that can be toxic to human is differ from each type of the gases. Some gases, such as Carbon monoxide gas, can be toxic at relatively low concentrations, while others, like oxygen, are essential for life but can become harmful at high concentrations. Toxic gas exposure limits are different for each gas because the toxicity level, or the degree to which a gas can harm human health, varies among different gases. The toxicity of a gas can be determined by its chemical properties and how it affects the body. For example, some gases may cause irritation of the eyes and respiratory system at lower concentrations, while others may have more severe effects such as neurological damage or death at higher concentrations. Therefore, the exposure limits for each gas are determined based on its specific toxicity level to protect human health and safety. Hence to speak, we cannot take the same concentration level for each gas that can be dangerous to us [12]

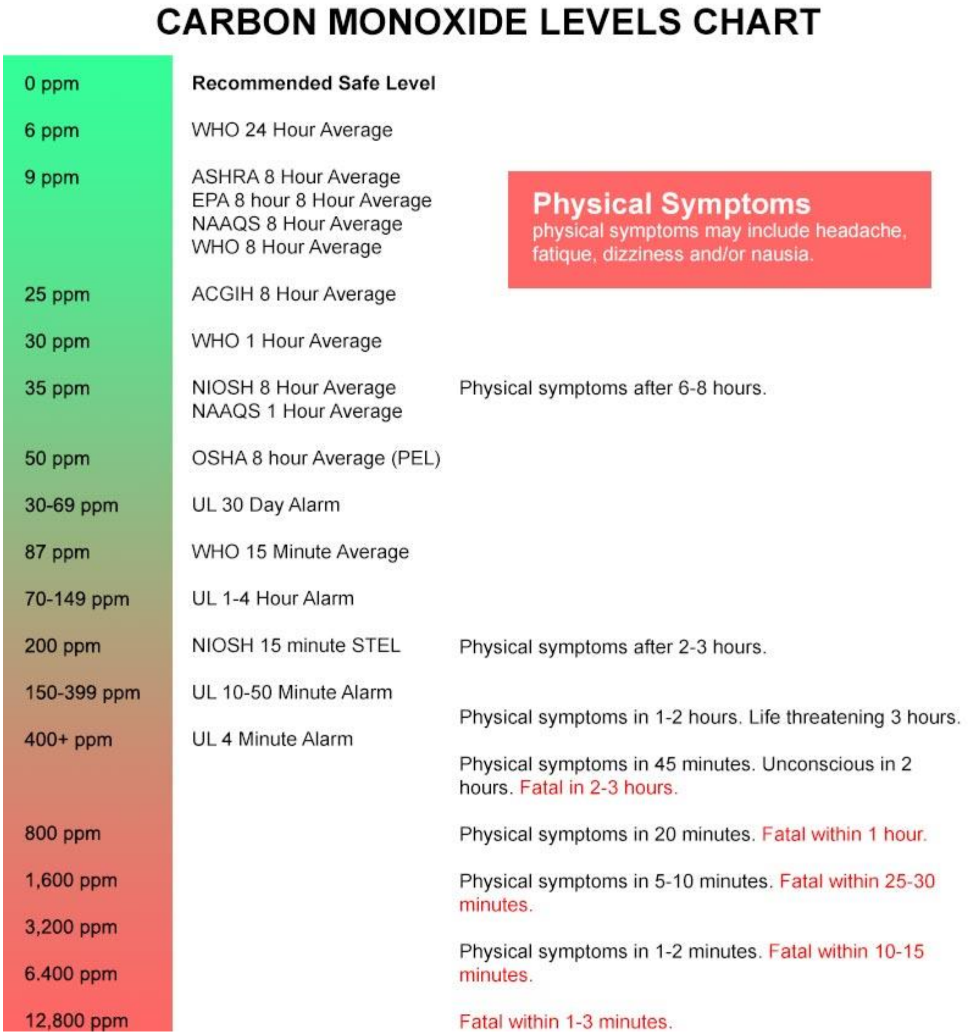


Figure 4 *A level chart for the concentration level of Carbon monoxide gas that can effect human*

For Carbon monoxide gas, the low levels of Carbon Monoxide gas exposure can lead to tiredness in healthy people and chest pains in individuals with heart problems. At moderate concentrations, symptoms such as angina, poor vision, and reduced cognitive function may occur. High concentrations of Carbon Monoxide can result in problems with coordination and vision, headaches, dizziness, confusion, nausea, and flu-like symptoms. At very high concentrations, it can be fatal [13]. This study set the trigger for the mechanism of power window and ignition at 70 PPM after 30 seconds.

2.3 Hardware Used

In table 1 show the list of hardware used and their quantity.

TABLE 1 *List of hardware used*

NAME	QUANTITY
Arduino Uno	1
I2C 16x2 LCD	1
MQ-9	1
Dual Channel Relay	1
LED	2
Mini Breadboard	4

2.4 Hardware Integration

Figure 5 shows the connection of all of the hardware to the Arduino Uno. The LEDs are connected to the Dual Channel Relay as they are controlled by the relay.

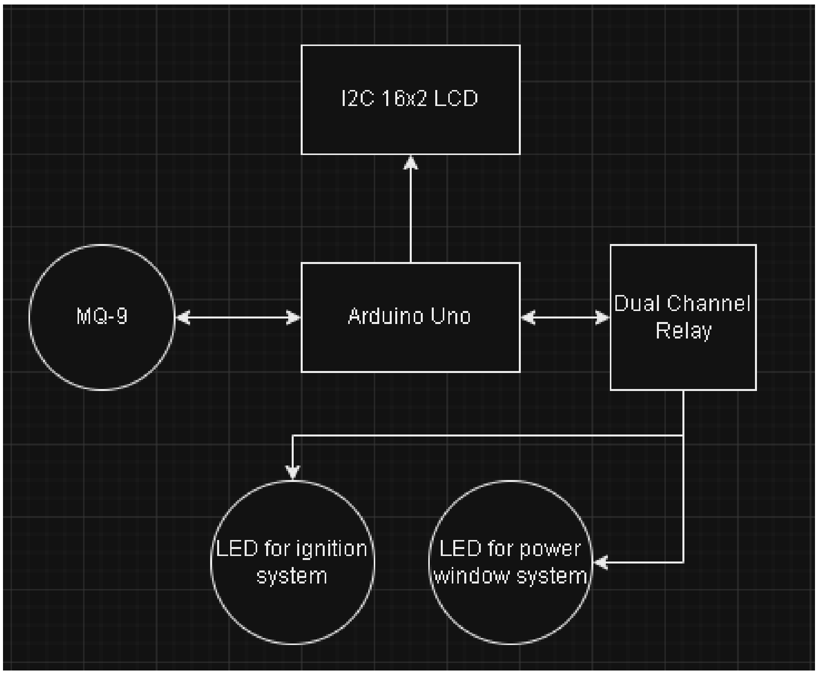


Figure 5 *Hardware integration*

3. Results and Discussion

The experiment setup based on simulation in real life will be discussed briefly in this subtopic. The results were divided into two section for analysis which are the reading before Carbon Monoxide introduced and reading after Carbon Monoxide introduced after 30 seconds.

3.1 Experiment Setup

In Figure 6 show the experiment setup for this study

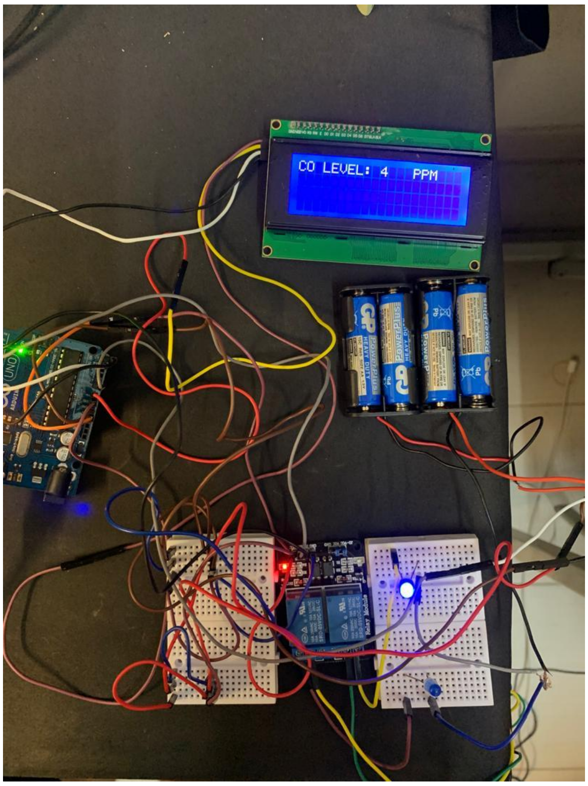
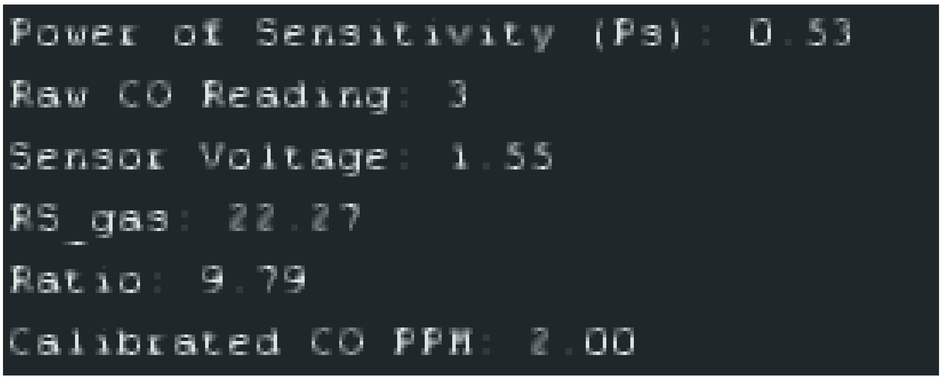


Figure 6 *Experiment setup*

3.1.1 Reading Before Carbon Monoxide Introduced

The initial reading and calculations from the MQ-9 gas sensor before introducing Carbon Monoxide shown in Figure 7 provide insights into the sensor's baseline performance. The raw analog reading from the sensor was 3, which, when converted to a voltage, was approximately 1.55V. This voltage is then used to calculate the sensor's resistance in the presence of clean air, resulting in sensor resistance in the presence of gas, Rs gas value of 22.27 kΩ. The ratio of Rs_gas to calibrated resistance in clean air , R0 was found to be 9.79. Given that the ratio in clean air is expected to be significantly higher than in the presence of Carbon Monoxide, this high ratio aligns with the absence of Carbon Monoxide, indicating that the sensor is functioning as expected under baseline conditions. The calculated Power of Sensitivity (Ps) was approximately 0.53. This value indicates the power consumption characteristics of the sensor, which in this context, is within an acceptable range for the MQ-9 sensor, known for its relatively low power requirements compared to other gas sensors. The calibrated Carbon Monoxide concentration in parts per million (PPM) was determined to be 2.00 PPM, reflecting the ambient air conditions without additional Carbon Monoxide introduced. This low PPM value is expected in clean air and aligns with typical atmospheric conditions where Carbon Monoxide levels are usually minimal.



```
Power of Sensitivity (Ps): 0.53
Raw CO Reading: 3
Sensor Voltage: 1.55
RS_gas: 22.27
Ratio: 9.79
Calibrated CO PPM: 2.00
```

Figure 7 *Reading of Carbon Monoxide in normal air*

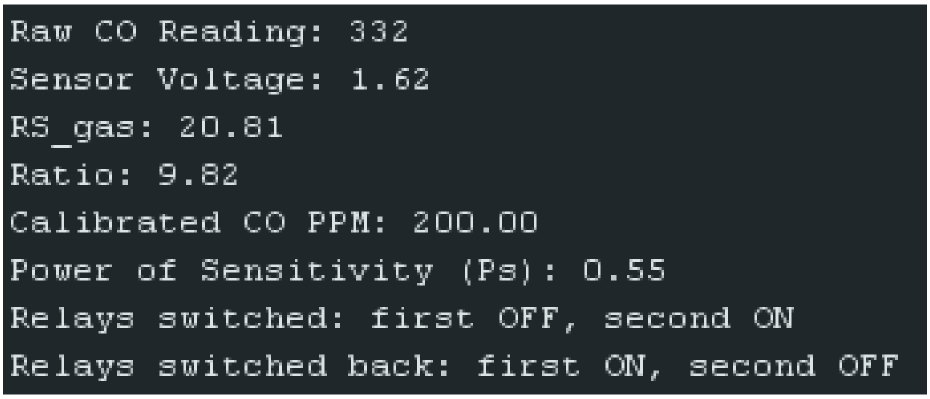
3.1.2 Reading After Carbon Monoxide Introduced After 30 seconds

The observed data from the MQ-9 gas sensor after introducing Carbon Monoxide shown in Figure 8 reflects significant changes in the sensor's readings, indicating an elevated Carbon Monoxide level in the environment.

The raw analog reading increased to 332, which corresponds to a sensor voltage of approximately 1.62V. This voltage suggests that the sensor is detecting more Carbon Monoxide, as the presence of Carbon Monoxide reduces the resistance of the sensor. Consequently, the calculated sensor resistance in the presence of gas, Rs_gas decreased to 20.81 kΩ. The Rs_gas/ to calibrated resistance in clean air, R0 ratio remained high at 9.82, similar to the baseline, indicating that the sensor's sensitivity to Carbon Monoxide might need further calibration or adjustment for more accurate differentiation at this level of Carbon Monoxide exposure. The calibrated Carbon Monoxide concentration reached 200 PPM, a substantial increase from the baseline reading of 2.00 PPM. This sharp rise indicates the sensor's ability to detect significant Carbon Monoxide presence. In practical applications, a Carbon Monoxide concentration of 200 PPM is hazardous, as it can cause serious health effects over prolonged exposure. The sensor's response, reflected in the substantial jump in PPM, underscores its critical role in detecting dangerous levels of Carbon Monoxide and triggering necessary alarms or actions.

The Power of Sensitivity (Ps) slightly increased to 0.55, which still falls within an acceptable range for the sensor's power consumption. This consistency in Ps indicates that the sensor maintains a stable power profile even when exposed to elevated Carbon Monoxide levels.

As a result of the high Carbon Monoxide reading, the relay logic in the system was activated. Initially, the first relay was switched off, and the second relay was switched on. This sequence means that the ignition system going off and power window system turned



```
Raw CO Reading: 332
Sensor Voltage: 1.62
RS_gas: 20.81
Ratio: 9.82
Calibrated CO PPM: 200.00
Power of Sensitivity (Ps): 0.55
Relays switched: first OFF, second ON
Relays switched back: first ON, second OFF
```

Figure 8 *Reading of Carbon Monoxide introduced after 30 seconds*

3.1.3 Discussion

In Table 2 shows comparison to the data obtain throughout the experiment.

Table 2 *Data obtain from experiment*

Perimeters	Before CO introduced	After CO introduced and stay above 70PPM for 30 seconds
Sensor voltage	1.55 V	1.62 V
Calculated sensor resistance in the presence of gas (Rs)	22.27 kΩ	20.81 kΩ
Calibrated resistance in clean air (R0)	2.27 kΩ	2.12 kΩ
Ratio (Rs/R0)	9.79	9.82
Gas concentration (PPM)	2.0	200.0
Power sensitivity (Ps)	0.53	0.55
LED 1(Ignition system)	ON	OFF
LED 2 (Power window system)	OFF	ON

The results presented in the table illustrate the performance of the CO detection system under two conditions: before the introduction of CO and after CO levels remain above 70 PPM for 30 seconds. The sensor voltage increased from 1.55V to 1.62V when CO was introduced and sustained at high levels, while the sensor resistance in the presence of gas (RsR_sRs) decreased from 22.27 kΩ to 20.81 kΩ. These changes indicate that the MQ-9 sensor responds appropriately to elevated CO concentrations, reflecting its ability to detect variations in the environment. However, the relatively small change in sensor voltage suggests that the sensor's response may need to be more sensitive for detecting lower concentrations or more gradual increases in CO levels. The calibrated resistance in clean air (R0R_0R0) decreased slightly from 2.27 kΩ to 2.12 kΩ after the introduction of CO, maintaining a stable ratio (Rs/R0R_s/R_0Rs/R0) around 9.8. This stability indicates that the sensor calibration is consistent, ensuring reliable detection over time. The slight decrease in R0R_0R0 after CO exposure could be attributed to the sensor's interaction with the gas, necessitating periodic recalibration for sustained accuracy.

The gas concentration measurement showed a dramatic increase from 2.0 PPM to 200.0 PPM due to the direct CO introduced aimed at the sensor in the CO chamber, effectively demonstrating the system's ability to detect hazardous levels of CO. This significant change confirms the system's sensitivity to high CO concentrations and its capacity to trigger safety measures promptly. The accuracy of these readings is crucial for ensuring that occupants are alerted in a timely manner to take necessary precautions. The power sensitivity remained relatively stable, with a slight decrease from 0.53 to 0.52. This stability is essential for the system's reliability, indicating that the power consumption does not fluctuate significantly with the sensor's operation, ensuring consistent performance without draining the vehicle's battery excessively.

The activation of the ignition system (LED-1) and power window system (LED-2) upon detecting CO levels above 70 PPM for 30 seconds demonstrates the system's capability to implement automated safety responses. The ignition system turning OFF (indicated by LED-1 being ON) and the power windows lowering (indicated by LED-2 being ON) effectively mitigate CO exposure risks by stopping the source of CO and allowing ventilation. The results highlight the effectiveness of the CO detection system in identifying and responding to elevated CO levels.

The system's design ensures that critical safety measures are activated when dangerous CO concentrations are detected, thus enhancing vehicle safety. However, the slight changes in sensor voltage and resistance suggest that further improvements in sensor sensitivity and recalibration protocols could enhance the system's responsiveness and accuracy. Future work should focus on optimizing sensor sensitivity to detect lower CO concentrations and more gradual increases. Additionally, incorporating periodic recalibration routines will help maintain sensor accuracy over time. Exploring advanced sensor technologies or integrating multiple sensors could provide more comprehensive monitoring and further enhance the system's reliability and effectiveness in protecting vehicle occupants from CO exposure.

4. Conclusion

The successful completion of this project marks a significant advancement in vehicle safety through the development of an effective carbon monoxide (CO) detection and monitoring system. The primary objectives were twofold: first, to develop a system capable of accurately detecting and monitoring CO levels within a vehicle cabin using the MQ-9 gas sensor and an Arduino microcontroller; and second, to implement an automated response system that activates ventilation and switches off the engine when dangerous levels of CO are detected.

The integration of the MQ-9 gas sensor with the Arduino microcontroller resulted in a reliable and sensitive system capable of real-time CO level detection. Initial baseline measurements demonstrated the sensor's capability to detect minimal CO levels, ensuring the accuracy and dependability of the system under normal conditions. When CO was introduced into the environment, the sensor readings showed a significant increase, validating its sensitivity and accuracy in detecting elevated and potentially hazardous CO concentrations. This capability is crucial for early detection and prevention of CO poisoning, which can be particularly dangerous in enclosed spaces such as vehicle cabins.

Additionally, the project achieved the development of an automated system that activates ventilation and shuts down the engine in response to dangerous CO levels. The implementation of relay logic allowed for seamless control of these safety measures. When CO levels exceeded the predefined safety threshold of 200 ppm, the system promptly triggered the ventilation system and turned off the engine, effectively mitigating the risk of CO exposure to the vehicle occupants. This automated response mechanism enhances vehicle safety by ensuring that potentially life-threatening situations are addressed immediately and without requiring driver intervention.

In summary, the development of this CO detection and monitoring system, combined with the automated ventilation and engine shutdown capabilities, represents a significant improvement in vehicular safety. The system's ability to detect CO on the spot, switch off the engine, and ventilate the cabin air will serve as a critical safety measure, preventing potential fatalities and long-term health issues caused by CO exposure.

Acknowledgment

I wish to express my appreciation to people who wish and pray for my success in study. Also to those that helped me, pushing me forward to my success. I will continue to strive forward and learn from my past mistakes.

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