

Electronic Circuitry and Material Integration for Enhanced Gas Detection Windows

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Abstract

Liquefied Petroleum Gas (LPG) and propane, being flammable mixtures of hydrocarbon gases, are widely used as fuel in various applications such as homes, hostels, and industries. Our main objective for this project is to design and fabricate a gas sensing window that will autonomously open upon detecting any leakage of gases like LPG, CO₂, alcohol, propane, etc. The heart of our system is the MQ-9 gas sensor, known for its high sensitivity and fast response time to various gases. This sensor will detect the presence of gas and send a signal to a microcontroller, which is pre-programmed with an algorithm to interpret these signals accurately. Upon detecting a hazardous gas concentration, the microcontroller will trigger a linear actuator to open the sliding window, thereby ventilating the area and preventing potential explosions. This innovative approach not only enhances the safety of individuals working in environments with potential gas exposure but also offers a practical solution for mitigating the risks associated with gas leaks. The system's design integrates modern sensor technology, microcontroller programming, and mechanical actuation to create a reliable, efficient, and cost-effective gas leak mitigation tool. The anticipated outcomes of this project include increased awareness of gas safety, reduced incidence of gas-related accidents, and the provision of a blueprint for future developments in automated safety systems. By focusing on the design and fabrication of this gas sensing window, we aim to contribute to the broader field of safety engineering and promote the adoption of smarter safety solutions in various industries. Windows are essential for ventilation in homes, offices, and industrial spaces. Gas cylinders, widely used in these environments, pose a leakage risk that can cause significant harm. By designing a window that responds to gas leaks, this project aims to enhance safety and reduce accidents. In conclusion, the smart gas sensing window enhances safety by detecting gas leaks and ensuring proper ventilation. It offers a practical, cost-effective solution for mitigating gas leak risks, aiming to improve safety awareness and reduce gas-related accidents.

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INTRODUCTION

Gas sensing technology is a crucial innovation in modern safety systems, particularly for environments where gas leaks can pose significant risks. However, the high risk of gas leakage from these cylinders can lead to accidents, causing material loss and serious injuries. The ability to detect gas leaks swiftly and efficiently is essential for preventing these hazardous situations [2].

Gas cylinders are widely used in homes, hotels, restaurants, and various industrial applications, but they carry a significant risk of gas leakage. This can

lead to accidents resulting in material loss and human injuries. Subpar cylinders, outdated valves, worn-out regulators, and carelessness when handling gas cylinders are the main causes of these explosions. To prevent such incidents, trapped gas should be released promptly. Windows, being the main source of ventilation, play a critical role in mitigating hazardous situations. Therefore, there is a need for a gas sensing window that can detect gas leakage and automatically open, providing immediate ventilation and preventing accidents. This solution not only enhances safety but also brings peace of mind to individuals working in environments prone to gas exposure.

The capacity of gas sensing equipment to detect and warn of gas leaks early on is what makes it significant. This technology utilizes sensors that detect the presence of hazardous gases such as LPG, CO₂, methane, and propane. By identifying gas concentrations in the air, these sensors can trigger safety mechanisms, such as alarms or ventilation systems, to mitigate the risk of explosions and health hazards [1-5].

Applications for gas sensing technologies are numerous, ranging from industrial settings to residential and commercial buildings. In homes and apartments, gas sensors can detect leaks from kitchen appliances, ensuring the safety of residents. In hotels and restaurants, these sensors can monitor gas levels in kitchens and storage areas, preventing potential disasters. Industrial facilities, where gases are used extensively, rely on gas sensing technology to maintain safe working conditions and protect workers from exposure to harmful gases.

This project aims to design and fabricate a smart gas sensing window that will detect gas leakage and automatically open to ventilate the area, thus preventing accidents. By integrating an MQ-9 gas sensor with a microcontroller and a linear actuator, the system will provide a reliable and efficient solution for gas leak detection and ventilation. The components are designed to be easily manufactured and affordable, making the technology accessible to a wide range of users.

LITERATURE REVIEW

Overview of Gas Sensing Technologies

Gas sensing technologies have evolved significantly over the years, providing critical solutions for detecting hazardous gases and preventing accidents. Early gas sensors, such as the catalytic combustion (LEL) sensor developed in the 1920s by Dr. Oliver Johnson, marked the beginning of modern gas detection. These sensors work by detecting combustible mixtures in the air, helping to prevent explosions in fuel storage tanks. While effective, these early sensors had limitations in terms of sensitivity and the range of detectable gases [1, 6].

Modern gas sensors, such as metal oxide semiconductor sensors (like the MQ-9), offer higher sensitivity and can detect a broader range of gases, including LPG, CO₂, methane, and propane. These sensors work by changing their resistance when exposed to certain gases, allowing for precise detection and monitoring. Despite these advancements, current gas sensing technologies still face challenges such as false alarms, sensor degradation over time, and the need for regular calibration [7].

PREVIOUS WORK

Significant research has been conducted to improve gas sensing technologies and their applications. In 1962, Harvard Stuarts proposed a hydraulic drive system for lowering windows using hydraulic pressure. While innovative, this system had issues with fluid leakage and complexity, leading to the development of more reliable mechanisms like the rack and pinion design.

In 2005, Doug Ramussen introduced an automatic sliding door system that uses sensors to detect body proximity and open the door automatically. This system also featured safety mechanisms to prevent motor lock conditions and could be enhanced with counting arrangements for tracking entry and exit.

Abubakar Yakub Nasir and associates recently conducted research on creating an Arduino-based system for temperature monitoring and gas leak management. This system used MQ-5 and MQ-6 sensors to detect gas leaks and monitor temperature, triggering alarms and ventilation systems when dangerous conditions were detected. This research highlighted the effectiveness of integrating gas sensors with control systems for improved safety.

GAP ANALYSIS

While significant progress has been made in gas sensing technologies, there remain gaps in the current research. Current gas sensors still need to be calibrated frequently to maintain accuracy and can still generate false alarms. Additionally, many gas sensing systems are not easily accessible or affordable for widespread use in residential and commercial settings.

This project aims to address these gaps by designing and fabricating a smart gas sensing window that combines high sensitivity with affordability. By integrating modern sensor technology (MQ-9), microcontroller programming, and mechanical actuation, the project seeks to create a reliable and efficient solution for gas leak detection and ventilation. The goal is to make this technology accessible to a wide range of users, enhancing safety and reducing the incidence of gas-related accidents.

MATERIALS AND METHODS

Materials

The design and fabrication of the gas sensing window involve several key components and materials:

MQ-9 Gas Sensor

Introduction The MQ-9 Gas Sensor is a type of metal oxide semiconductor sensor, commonly referred to as a chemiresistor. This sensor detects gases by observing changes in the resistance of its sensing material when gas molecules come into contact with it. Operating at 5V DC and drawing approximately 800mW, the MQ-9 sensor is capable of detecting various gases including LPG, smoke, propane, methane, and carbon monoxide within a concentration range of 200 to 1000 ppm [8].

Specifications

Operating Voltage: 5V
Load Resistance: 22k Ω
Heat Resistance: 330 Ω
Heating Consumption: <800mW
Concentration Range: 200-1000 ppm

Working Principle

When heated in air at high temperatures, tin dioxide (semiconductor particles) adsorbs oxygen on its surface. In a clean air environment, donor electrons in the tin dioxide are drawn towards the adsorbed oxygen, inhibiting the flow of electric current. Adsorbed oxygen's surface density drops as it reacts with reducing gases when they are present. Electric current can easily flow through the sensor as a result of this reaction, which releases electrons into the tin dioxide [9].

Internal Structure

Two layers of fine stainless-steel mesh, referred to as an anti-explosion network, surround the sensor. This enclosure ensures the internal heater element does not cause an explosion when detecting flammable gases. Only gaseous elements are allowed to enter the chamber since the mesh shields the sensor and filters out suspended particles. This mesh is secured to the rest of the sensor body by a copper-plated clamping ring.

The sensor element's star-shaped structure and its six connecting legs that extend past the Bakelite base are visible when the outer mesh is removed. Two of these leads (H), which are coupled by a nickel-

chromium coil, are in charge of heating the sensor element. Platinum wires connect the final four leads (A and B), which control the output signals. The tubular sensing element itself is made from aluminum oxide (Al_2O_3) ceramic and coated with tin dioxide (SnO_2), the critical material sensitive to combustible gases. The nickel-chromium coil combined with the aluminum oxide forms the heating system, while the platinum wires and tin dioxide coating constitute the sensing system. Sensor with Mesh and without mesh is shown in Figure 1 and 2 respectively.

Hardware Overview

Since the MQ-9 sensor is not breadboard compatible, using a breakout board is recommended for ease of integration. The breakout board offers an analog depiction of the concentration of flammable gases in the air as well as a binary indicator of their existence. The analog output voltage varies in direct proportion to the gas concentration—higher concentrations result in higher output voltages and vice versa. The analog signal from the MQ-9 sensor is then fed to an LM393 high-precision comparator to digitize the signal. Additionally, a potentiometer is included to adjust the sensor's sensitivity, allowing for the detection of specific gas concentrations [10].

Linear Actuator

One crucial tool for converting rotary motion into linear motion is a linear actuator. Unlike rotary motors, which produce rotational movement, linear actuators provide straight-line movement. This feature is especially useful for applications requiring precise control of position and movement, such as in robotics, industrial machinery, and automated windows.

Voltage Regulator 7805

The 7805 voltage regulator is a linchpin in power regulation for electronic circuits. It takes an unregulated input voltage, typically ranging from 7V to 25V, and provides a steady 5V output. This consistency is crucial for the stable operation of components sensitive to voltage fluctuations. The 7805 is sturdy and dependable for a range of applications since it has inherent thermal overload and short-circuit protection.

It ensures that downstream components receive a clean, regulated supply, which is essential for maintaining the integrity and performance of the circuit.

Motor Driver L293D

A multipurpose part, the L293D motor driver IC regulates the direction and speed of one stepper motor or two DC motors. It has two H-bridge designs that enable the motors to be controlled in both directions. This means you can drive the motors forward or reverse, making it ideal for applications like robotic arms, conveyor belts, and automated systems. With peak currents of up to 1.2A, the L293D can manage currents of up to 600mA per channel. It also has built-in diodes to protect against back EMF generated by the motors, ensuring the safety of the circuit [11].



Figure 1. Sensor with Mesh.

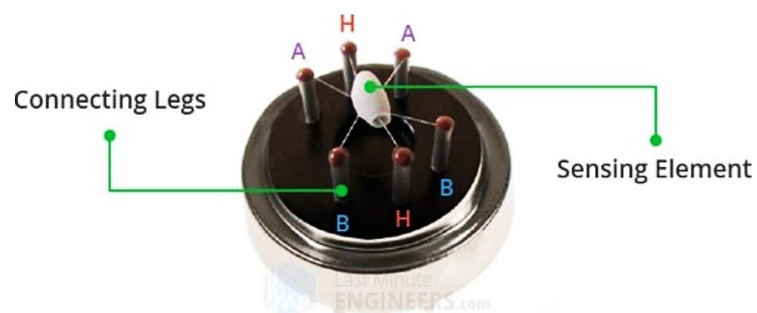


Figure 2. Sensor without mesh.

Crystal Oscillator

In electronic circuits, a crystal oscillator is a crucial part for producing accurate time signals. It generates a steady-frequency electrical signal by harnessing the mechanical resonance of a vibrating crystal, usually quartz. For applications where precise time is essential, including microcontrollers, digital clocks, and communication systems, this stability is essential. The crystal oscillator maintains a consistent oscillation frequency, ensuring that all timed operations in the circuit occur synchronously and reliably.

Capacitor 25V 470 μ F

With a 470 microfarad capacitance and a 25 volt voltage rating, this electrolytic capacitor is essential for stabilizing and filtering power supplies. By storing and releasing charge as needed, it reduces voltage swings in power supply circuits and contributes to a stable output voltage. This is particularly important in circuits with high transient loads, where rapid changes in current demand could otherwise cause significant voltage drops or spikes. The capacitor's large capacitance value allows it to store a substantial amount of energy, which it can quickly release to stabilize the voltage. These components collectively ensure that the gas sensing window operates efficiently and reliably, providing accurate gas detection and automatic ventilation to enhance safety. Intricate [4].

SMPS (Switched Mode Power Supply)

A switching regulator is used by the SMPS, a very effective power supply, to transform electrical power. Unlike linear regulators, it switches rapidly on and off to maintain the desired output voltage, thereby minimizing energy loss as heat. SMPSs can efficiently convert AC to DC or DC to DC, providing a regulated output voltage different from the input voltage. This capability is crucial for powering components in our gas sensing window system, ensuring consistent and reliable operation. The SMPS employed here provides 12V, 10A output, which is sufficient to power the microcontroller, sensor, and actuator.

Arduino Atmega328p Microcontroller

The Atmega328p microcontroller is the brain of our system. It has a 28-pin package with an 8-bit AVR RISC architecture, 32KB of flash memory, 1KB EEPROM, and 2KB SRAM. Operating between 1.8 to 5 volts, it can interface with various sensors and actuators, making it versatile for multiple applications. The microcontroller processes the signals from the MQ-9 sensor, executes programmed algorithms to interpret gas concentrations, and controls the linear actuator and relay module accordingly. Its capabilities ensure precise control and responsiveness of the gas sensing window.

PCB (Printed Circuit Board)

The PCB acts as the backbone of our electronic system, providing a structured platform for mounting and interconnecting components. It guarantees dependable electrical connections and signal integrity because it is made up of several layers of conductive and insulating materials. Multi-layer PCBs, used in our design, allow higher component density by utilizing inner layers for routing circuit traces, leaving the surface for component placement. The PCB design includes vias, plated-through holes that facilitate connections between different layers, ensuring a compact and efficient layout for our gas sensing window circuitry.

Two-Channel Relay Module

A relay module is an electrically operated switch that enables low-power control signals from the microcontroller to switch high-power devices like the linear actuator. Each of the two relays in our two-channel relay module can manage loads with high voltage and current. It allows the microcontroller to independently control two different devices. The relay module includes optoisolators to protect the microcontroller from high voltage spikes, ensuring safe and reliable operation. The module's ability to interface seamlessly with the microcontroller makes it an essential component in automating the window opening mechanism upon gas detection.

Methods

Design Process

Component Selection

The first step is to choose the appropriate components. We start by identifying parts like the MQ-9 gas sensor, which is known for its high sensitivity and reliability in detecting various gases such as LPG, CO₂, methane, and propane. Other critical components include the linear actuator, which provides the necessary mechanical movement to open the window, and the Arduino Atmega328p microcontroller, which serves as the brain of the system. We also select supporting components like the voltage regulator 7805, motor driver L293D, crystal oscillator, and capacitors, ensuring each part meets our performance and cost criteria.

Circuit Design

The circuit must then be designed after the components have been chosen. This process ensures all components are integrated effectively. The MQ-9 sensor is connected to the microcontroller, which processes the gas concentration signals. The motor driver is linked to the linear actuator to control the window's movement, and the SMPS is incorporated to provide a stable power supply. The circuit design also includes protective measures like diodes and fuses to safeguard against electrical faults. 3D AutoCAD Design of Model is shown in Figure 3.

Mechanical Design

The mechanical design focuses on the window's physical structure. We design an aluminium-framed sliding window (720mm x 300mm) that houses the actuator and sensor while maintaining durability and aesthetic appeal. The frame is designed to ensure smooth and reliable movement of the window. Special attention is given to the actuator's placement to optimize its performance and conceal it for a clean look. Front View of Sliding Window is shown in Figure 4. Top View of Sliding Window is shown in Figure 5.

FABRICATION PROCESS

PCB Fabrication

The first step in fabrication is creating the Printed Circuit Board (PCB). The circuit design is translated into a PCB layout, which includes placing and routing all components. This layout is sent to a manufacturer, where the PCB is fabricated by layering conductive and insulating materials. Once the PCB is ready, components such as the MQ-9 sensor, Arduino Atmega328p microcontroller, and other electronic parts are soldered onto it. Careful attention is paid to ensure all connections are secure and reliable.

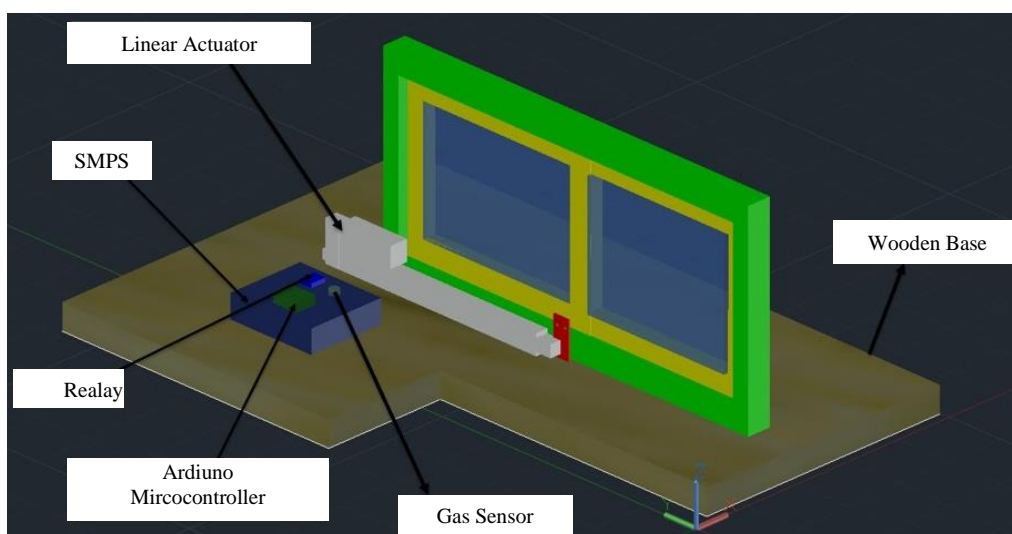


Figure 3. 3D AutoCAD design of model.

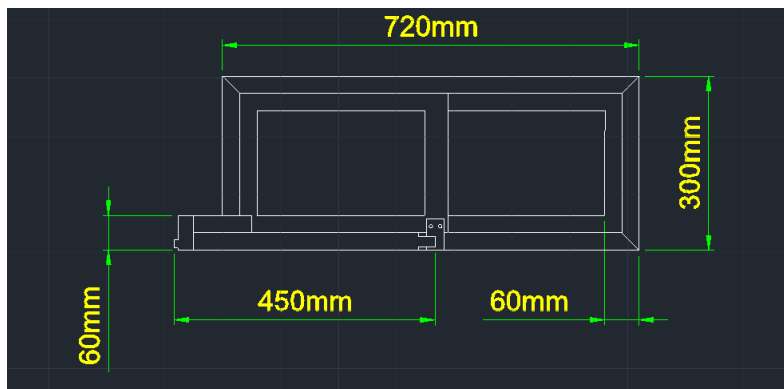


Figure 4. Front view of sliding window.

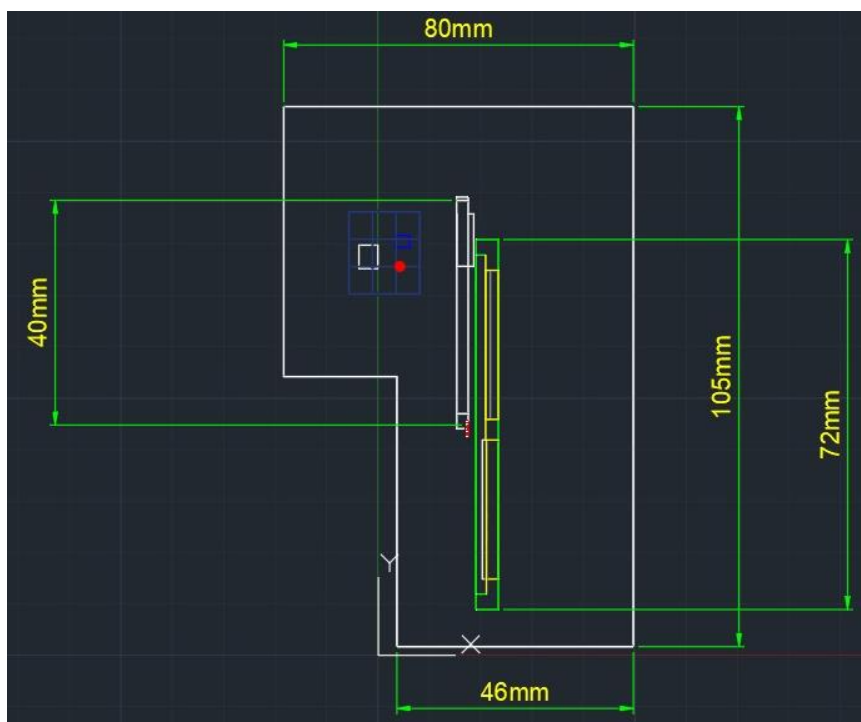


Figure 5. Top view of sliding window.

Mechanical Assembly

The mechanical assembly starts with preparing the aluminium-framed sliding window. The frame is cut and assembled to the specified dimensions (700mm x 300mm). After that, the linear actuator is placed onto the frame, making sure it is perfectly aligned and firmly fastened. For the window to operate smoothly and dependably, this step is essential.

Sensor Integration

The MQ-9 gas sensor is integrated into the window frame. It is positioned in a way that allows it to effectively detect gas concentrations in the surrounding environment. The sensor is connected to the PCB, ensuring that the signal can be processed by the microcontroller.

Power Supply Integration

Installing a Switched Mode Power Supply (SMPS) gives the system as a whole a reliable power source. By connecting to the PCB, the SMPS makes sure that every component gets the voltage and current it needs to function. The voltage regulator 7805 is also integrated to maintain a constant 5V supply for sensitive components.

Actuator and Relay Module Connection

The linear actuator is connected to the motor driver L293D, which is mounted on the PCB. The two-channel relay module is also installed, allowing the microcontroller to control the actuator's movement. This setup ensures that the actuator can open the window automatically upon detecting a gas leak.

Programming and Testing

With all components in place, the Arduino Atmega328p microcontroller is programmed with the necessary code to process signals from the MQ-9 sensor and control the linear actuator. The system's functionality is then confirmed by testing in a controlled setting. The sensor is calibrated to ensure accurate gas detection, and adjustments are made to the microcontroller program as needed.

Final Assembly and Installation

After successful testing, the final assembly is completed. The window frame, actuator, and sensor are securely fixed in place, and all electrical connections are double-checked. The gas sensing window is then installed in a real-world environment, such as a kitchen or industrial setting, ensuring it is ready for operation. Experimental Setup with Linear Actuator and MQ-9 Gas Sensor is shown in Figure 6.

TESTING AND RESULTS

Experimental Setup

A linear actuator is installed horizontally on a typical sliding window to assist in automatic window opening and closing. The window will open prior to the gas leak accumulating in the enclosed space. Additionally, the sensor will be positioned in close proximity to the gas cylinder and below the surface in case there is a possibility of a gas leak. Additionally, the linear actuator micro controller Arduino needs 5 volts of power to operate in this setup, which requires a 12 volt power connection. The experiment was started by spraying alcohol at different distances from the sensor, and we recorded the time intervals between the sensor and the detection in seconds.

Observation Table

Observation table is shown in Table 1.

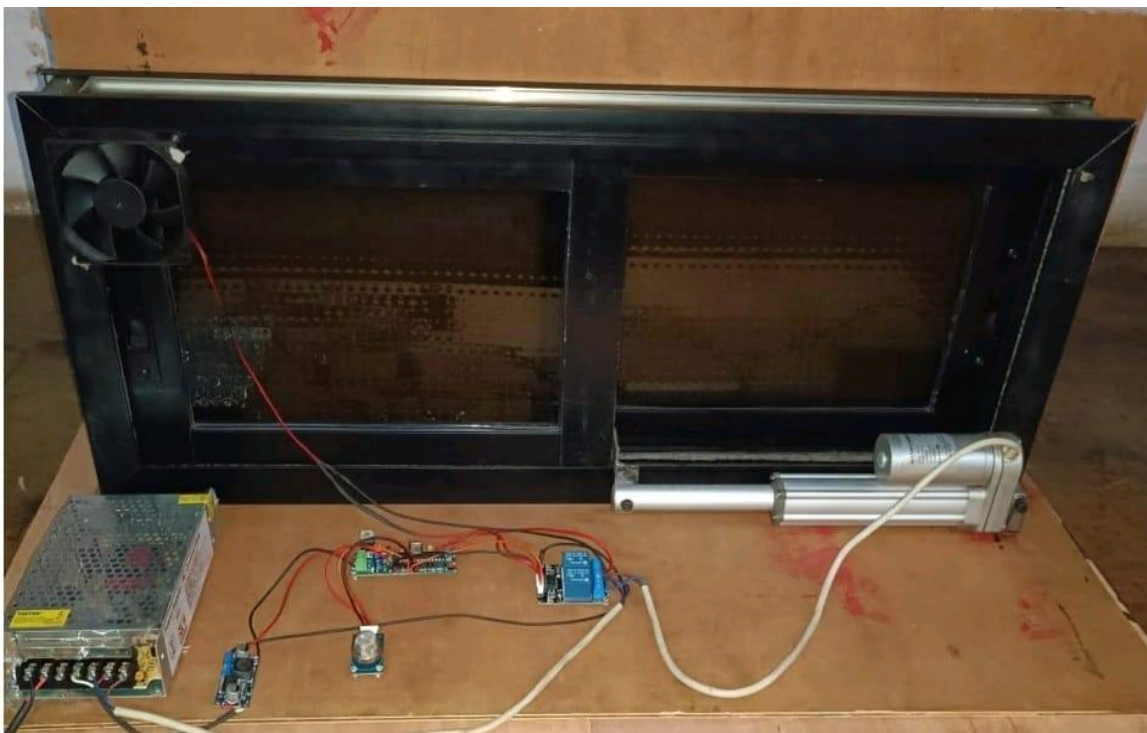


Figure 6. Experimental setup with linear actuator and MQ-9 gas sensor.

Table 1. Distance vs Detection.

No.	Distance (mm)	Detection
1	5	Detected
2	10	Detected
3	15	Detected
4	25	Detected
5	35	Undetected
6	40	Undetected

RESULTS

We sprayed alcohol at the sensors in the first stage, and it was detected in three seconds. The second time, we repeated the process, but this time we kept the distance from the sensor far away about 10 cm and the detection period was ten seconds. Additionally, we maintained a distance of about 25 cm in the third stage and sprayed alcohol there. The detection time was 13 seconds, and the results were fairly good and the detection was excellent. The distance was maintained at a considerable distance of around 40 cm at the fourth attempt, and the detection timing was a little off, taking 17 seconds. Also, it was undetectable at 50 cm. therefore the reading's average 10.75sec. It is evident from the results that the sensor should be positioned close to the object or in areas where pipes may leak. Here, a number of factors, including the environment, gas concentration level, sample rate, and sensor reaction time, affect when gas is detected.

CONCLUSION

The gas sensor smart window project is a low-cost, lightweight, portable, safe, easy-to-use, effective, and straightforward system for detecting smoke and gasses. In addition to being important for the health department, smoke detection will boost our economy because gas leaks not only poison the atmosphere but also waste money.

It is evident from the accessible literature that not much effort has been done on the design and construction of smart windows that use gas sensors. In future, more advanced features such as nitrogen flush, carbon dioxide flush with integrated of vacuum or air scrubbing for pure ventilation within the system and will be integrated with this system which will provide on base which gas is leaked and all, which will overall provide users with more safety and relaxation. Over the upcoming years, the market is anticipated to be primarily driven by the requirement to ensure worker safety.

RESEARCH GAP

Current Limitations

- *False Alarms:* Many existing gas sensors are prone to false alarms, which can cause unnecessary panic and disrupt operations.
- *Sensor Degradation:* Over time, sensors can degrade, leading to reduced sensitivity and accuracy. This impacts their reliability and effectiveness.
- *Needs for Calibration:* Maintaining accuracy frequently necessitates frequent calibration, which can be expensive and time-consuming.
- *Accessibility and Affordability:* High-quality gas detection systems can be expensive and not easily accessible to the average consumer or small businesses.
- *Integration and Automation:* Current systems may lack seamless integration with automated responses, such as opening windows or activating ventilation systems.

RESEARCH GAP

Our project aims to bridge these gaps by developing a gas sensing window that combines high sensitivity with affordability and ease of use. Specifically, we address the following:

- *Enhanced Accuracy and Reliability:* By using the MQ-9 gas sensor, known for its high sensitivity and low false alarm rate, we ensure more accurate detection of hazardous gases.

- *Durability*: The sensor's design and materials are chosen to minimize degradation over time, maintaining its sensitivity and accuracy for longer periods.
- *Reduced Calibration Needs*: Our system is designed to require minimal calibration, making it more user-friendly and cost-effective.
- *Affordability*: By selecting cost-effective components and optimizing the design, we make the technology accessible to a broader range of users, including households and small businesses.
- *Automated Response*: The integration of the sensor with a microcontroller and linear actuator ensures that upon detecting gas, the window opens automatically, providing immediate ventilation and enhancing safety.

FUTURE SCOPE

The future scope of the gas sensing window project is extensive, offering numerous opportunities for enhancement and development. The system as a whole can be greatly enhanced by adding extra software with clever features. Future iterations of the system may include features for notifying emergency services automatically in case of detected gas leaks or accidents. A mobile app and web-based application will be developed for real-time monitoring, providing users with instant alerts and updates. These apps will include smart features, enhancing user interaction and making the system even safer and more user-friendly.

The system will be optimized for various applications, including cars, homes, industries, and other locations where gas leaks pose a risk. Following the construction of the final prototype with clever multipurpose characteristics, it will be used as a pilot project in real-world situations. To verify the system's dependability and functionality, this will entail testing it in various settings. Before deploying the system, a survey will be conducted to gather initial user feedback and establish key performance indicators (KPIs). A follow-up survey will be carried out following implementation to assess user satisfaction and the system's efficacy. These surveys will help in identifying areas for improvement and validating the system's performance.

Analyzing the data and summarizing all the findings and results will yield insightful information for further study. The final product's features will be compared with those of available gas detection systems, highlighting its advantages and unique capabilities. This forward-looking approach ensures continuous improvement and adaptation, making the gas sensing window a vital part of modern safety solutions.

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