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Design and Implementation of a Low-Cost Gas Leakage Detection System Using MQ-5 Sensor

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Abstract

Gas leakage accidents involving flammable gases such as liquefied petroleum gas (LPG), methane, and gasoline vapors pose serious risks to human life, property, and the environment. Conventional analytical instruments used for gas detection, such as gas chromatography and infrared spectrometers, provide high sensitivity and selectivity but are expensive, bulky, and unsuitable for continuous monitoring in domestic and small-scale industrial settings. In this work, we design and implement a low-cost gas leakage detection system based on an MQ-5 metal oxide semiconductor gas sensor integrated with an Arduino microcontroller, an audible alarm (buzzer), visual indicators (LEDs), and an LCD display. After a short warm-up period, the sensor exhibits a stable baseline in clean air with readings of approximately 150–200 (arbitrary units). When exposed to flammable gases, the sensor output increases rapidly, reaching values between 700 and 900 depending on the gas type, with the highest response observed for gasoline vapors. After the gas source is taken off, the values are gradually returning to their baseline level, while recovery is faster in well-ventilated conditions. Upon sensor reading exceeding a set threshold, the integrated system emits an immediate audio and visual alarm and displays the status on the LCD simultaneously. Results demonstrate that the proposed platform provides a fast reaction, unequivocal warning of hazardous gas presence, and straightforward application at low cost, rendering it a potential home, laboratory, or small business early warning system. Future developments could include precise calibration of gas concentration, wireless connectivity for remote monitoring, and adjustment for environmental changes such as temperature and humidity.

Keywords: *gas leakage detection; MQ-5 sensor; metal oxide semiconductor; Arduino; low-cost alarm system; flammable gases; environmental monitoring*

1. Introduction

Gas leakages of flammable gases, for instance, liquefied petroleum gas (LPG), methane, and gasoline vapors, are a significant hazard threat to human life, property and environment. Gases are often used in cooking, heating and other technical settings at both household, restaurant, lab, small industrial place or other home type operational facilities. Gas can accumulate in confined spaces and create an explosive or unsafe environment when it escapes due to broken connections, damaged hoses, lack of maintenance, or mistake by other human error.

In addition, any leaks or emissions, even little ones, which remain undiscovered, can cause fires, explosions or health problems—especially in highly populated and ill ventilated areas, reviews about gas sensors and volatile organic compounds (VOCs) monitoring have found (Zainab et al. 2014, Elia et al. 2024, Yan & Zhou 2022). For that reason, accuracy of gas leak detection and warning signal is important for safety management from domestic and industrial point of view. Traditional gas monitoring and analysis are typically performed with next generation gas analysers (e.g. GC and MS and IR analyzers). These techniques have potential to provide remarkable sensitivity and selectivity, and accurate detection of different gases, and are commonly employed in laboratory-based environmental assessment and industrial process regulation (Bogris et al., 2017; Chen et al., 2025; Ghazi et al., 2022). However, the equipment is often expensive, heavy, requiring stable operation conditions and trained workers.

They are too expensive, powerful, or complex to be used for continuous, decentralized monitoring in dwellings, small scale

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craft and many institutions in developing regions, which requires basic and rugged measures for daily security (Bogris et al., 2017; Chen et al., 2025). To meet these limitations, several well defined solid-state gas sensors, including optical, electrochemical, and chemiresistive, are proposed (Zainab et al., 2014; Hierlemann & Gutierrez-Osuna, 2008). Metal oxide semiconductor (MOS) chemiresistive gas sensors are also investigated due to their simple structure, low fabrication cost, and compatibility to traditional microelectronic protocols (Wang et al., 2010; Fine et al., 2010; Korotcenkov, 2007).

Based on the concept that the electrical resistance of a sensing film (normatively composed of SnO_2, ZnO or other metal oxides) varies with adsorption of target gas molecules to a surface by oxygen species, the sensors are used for redox reactions (Barsan & Weimar, 2001; Ghafarinia et al., 2023; Gupta & Zou, 2025; Zhang et al., 2017). For clean air, the sensor has a stable baseline resistance resulting from its material properties and operating temperature; however, exposure to reducing gases such as LPG, hydrogen or gasoline vapors leads to a measurable variation in resistance that can be converted into a value of voltage or digital value that is easily read by short interfaces (Wang et al., 2010; Fine et al., 2010).Recent research has showed considerable advancements in gas sensor performance through the fabrication of nanostructured materials, heterojunctions, and porous frameworks. To improve sensitivity, selectivity, and operational stability toward VOCs and other target gases, for instance, yolk–shell $LaFeO_3$ microspheres, MOF-derived porous nanocomposites, and MIL-101(Cr)-based nanosensors have been employed (Wang et al., 2018; Duan et al., 2024; Mousavi & Zeinali, 2022). Other studies have examined flexible and wearable sensing platforms, as well as self-powered or low-power devices, to enable continuous monitoring in smart textiles, portable electronics, and distributed sensor networks (Luo et al., 2023; Kim et al., 2020; Wu et al., 2023; Xue et al., 2020). In order to lower power consumption while maintaining or enhancing sensing performance, energy-saving techniques utilizing microheaters, optimized device designs, and cutting-edge materials have also been studied (Zhou et al., 2015; Majhi et al., 2021; Xue et al., 2020). In parallel, pattern recognition, machine learning, and electronic-nose concepts have been introduced to improve multi-gas discrimination and compensate for sensor drift and cross-sensitivity in complex environments (Hierlemann & Gutierrez-Osuna, 2008; Mei et al., 2024; Ni et al., 2024; Acharyya et al., 2023; Shen et al., 2022b). These breakthroughs highlight the quick growth in the field of gas sensing and point toward intelligent, networked sensing systems for advanced applications.

Despite this rich body of work, there remains a strong need for simple, affordable, and easy-to-implement gas leakage detection systems that can be deployed in ordinary domestic and small-scale industrial settings. Commercial detectors are accessible; however, many of these devices remain relatively expensive, proprietary design products that are also difficult to maintain or adjust in low-resource settings (Fine et al., 2010; Majhi et al., 2021). A practical system needs to marry cost-effective, assembly-simple and clear user communication with the ability to reliably send warnings early when gas is reaching dangerous levels, particularly in developing areas. Educational prototypes & locally generated systems based on commercially available sensing modules are a promising way to bridge this gap by demonstrating how basic components of electronic technologies can be integrated into an operational safety instrument (Zainab et al., 2014; Fine et al., 2010). LPG, natural gas, hydrogen, and other combustible gases are recognized by the MQ-5 sensor, which is a well known MOS gas sensor with chemiresistive properties.

It combines a tin oxide–based sensing layer with an integrated heater in a compact device and is typically provided as an inexpensive module with simple signal conditioning features. This architecture makes it simple for the sensor to interface with microcontrollers (e.g., Arduino) for low cost systems for gas leakage detection systems with audio alarms and visual indicators and with a high level of panel display (Wang et al., 2010; Fine et al., 2010; El-Muraikhi et al., 2025). But the sensor needs to work within a well-organized apparatus that sets appropriate warning thresholds, manages power usage and tells users what it can or cannot read, whether they need it or not. With this in mind, the current study will concentrate on the construction & implementation of an economical gas leakage detection system based on a MQ-5 sensor and Arduino microcontroller framework. Its proposed system will utilize a buzzer, multi-color LEDs, and an LCD display to provide emergency visual and aural alerts once gas concentrations come within the specified measurement range.

The performance of the system is realized using experimentally the baseline behavior of the sensor in clean air and the sensor response and recovery under different ignitable gases in different ventilation situation. The main goal is to prove that easy integration of commercially available component can be a developed early warning system adapted to home, laboratory and small workshops, and to show practical concerns and limitations to be addressed in the future with a further improvement of the approach (e.g., calibration, environmental compensation, and the possibility of wireless connectivity, Majhi et al., 2021; Zhou et al., 2015; Xue et al., 2020).

2. Literature Review

The design and tuning of gas sensors were the subject of a lot of attention with respect to environmental monitoring, industrial safety, and healthcare applications. The major principles, materials, and device structures applied in optical, electrochemical, and chemiresistive sensors for gas sensing technologies have been discussed in general literature from the perspective of general approach in the review section, alongside the performance comparison of sensitivity, selectivity, cost, and integration capability in trade-offs (Zainab et al., 2014; Fine et al., 2010; Korotcenkov, 2007). Metal oxide semiconductor (MOS) chemiresistive sensors based on materials such as SnO_2, ZnO, and perovskite-type oxides have received heavy attention for their simplicity, low cost, straightforward structure, and compatibility with

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microelectronic fabrication, thus providing the backbone (Wang et al., 2010; Barsan & Weimar, 2001; Fine et al., 2010).

Building on this foundation, many works focus on improving sensitivity, selectivity, and response/recovery dynamics through advanced materials and nanostructuring strategies. For instance, yolk–shell $LaFeO_3$ microspheres, carbon-modified SnO_2 nanowires, ZnO nanowires with resistive switching, and MIL-101(Cr)-based metal–organic framework (MOF) nanosensors have all shown enhanced performance toward various volatile organic compounds (VOCs) and flammable gases (Wang et al., 2018; Tonezzer et al., 2019; Zhang et al., 2017; Mousavi & Zeinali, 2022). Other studies report highly selective sensors based on TiO_2/PtO–Pt dual-layer films or MOF-derived porous nanocomposites, demonstrating that heterostructures and tailored energy-level alignment can significantly enhance gas discrimination and lower detection limits (Du et al., 2002; Duan et al., 2024; Chen et al., 2018). More recent reviews have surveyed nanostructured Bi_2O_3, Bi_2WO_6, and $BiVO_4$ as promising resistive gas sensing materials and discussed how composition, morphology, and defect engineering influence performance (El-Muraikhi et al., 2025).

VOCs and related pollutants have also been studied extensively in the context of indoor air quality and medical diagnostics. Quantum-chemical and experimental investigations of porphyrin-based sensors, MOF-based optical sensors, two-dimensional monolayers, and graphene-oxide-coated microfluidic sensors have demonstrated high sensitivity and tailored selectivity for different VOC species (Anju et al., 2024; Shen et al., 2022a; Guo et al., 2024; Ghazi et al., 2022). Other research have utilized VOC sensing to practical settings, such as identifying emission sources from indoor building materials or monitoring exhaled breath for disease diagnosis and health assessment (Elia et al., 2024; Yan & Zhou, 2022; Xiang et al., 2024). These contributions demonstrate the variety of gas sensing applications that go beyond straightforward leak detection and the potential differences in sensor performance requirements between industrial hygiene, biomedical, and environmental monitoring contexts.

In addition to these findings, interest in low-power, wearable, and flexible gas sensing technologies has also emerged. Technology roadmaps and recent demonstrations propose flexible sensor architectures, dye-loaded nanofiber yarns, and self-powered hydrogel patches, which could be woven into textiles or worn directly onto the body for ongoing detection (Luo et al., 2023; Kim et al., 2020; Wu et al., 2023). Microfabricated thermoresistive flow sensors integrated with MEMS microheaters have been suggested to reduce power consumption and allow small, high-yield devices suitable for mass production (Zhou et al., 2015; Xue et al., 2020). Reviews on energy-saving chemiresistive gas sensors further emphasise strategies such as optimised heater design, nanostructured films, and intermittent operation modes to minimise energy usage without sacrificing sensing performance (Majhi et al., 2021). Additionally, mid-infrared quantum cascade laser sensors and portable infrared gas analysers have been developed to provide high-performance optical detection in compact formats, though these solutions generally remain more complex and costly than simple MOS-based systems (Bogris et al., 2017; Chen et al., 2025).

Another important trend in the literature is the integration of pattern recognition and machine learning with gas sensor arrays. The concept of higher-order and electronic-nose sensing, in which multiple partially selective sensors are combined with advanced signal processing, has been widely explored to address cross-sensitivity and improve multi-gas discrimination (Hierlemann & Gutierrez-Osuna, 2008; Shen et al., 2022b). Recent works have reported pattern recognition methods for chemiresistive arrays, semi-supervised ensemble classifiers for drift compensation, and multi-task deep learning models that fuse features from electronic noses to quantify VOC mixtures (Mei et al., 2024; Jiang et al., 2025; Ni et al., 2024). Metal nanoparticle-decorated hollow-sphere sensors and MOF-based devices have also been combined with machine learning to achieve selective identification and quantification of VOCs (Acharyya et al., 2023; Shen et al., 2022b). These approaches show how algorithmic advances can significantly extend the capabilities of conventional gas sensors, especially in complex or dynamic environments.

Despite impressive strides made in materials and device engineering as well as in the intelligent data processing aspect, most of these systems are research prototypes and have complex fabrication or work on sophisticated platforms for high performance use. In most practical applications (e.g., interior homes, small workshops, and resource-limited areas), there is still a demand for simple and inexpensive gas leakage detection systems that can be constructed from easily accessible components, and easy to install, maintain, and give clear audible and visual warnings when high gas concentrations are being presented (Zainab et al., 2014; Fine et al., 2010; Majhi et al., 2021). In this regard, the current effort is not to design the new sensing material, but instead to illustrate how a commercially accessible MQ-5 MOS gas sensor can be coupled with an Arduino microcontroller, buzzer, LEDs, and LCD display to a working, affordable, feasible form of early warning system for home and small-scale industrial applications.

3. Methods

3.1 Problem Statement

Gas sensors are in widespread use in industrial settings and environmental applications to identify hazardous gases and avoid accidents. Nevertheless, there are still significant barriers of commercially available systems which restrict their effectiveness and widespread deployment, particularly in low-resource settings. Frequent problems include limited selectivity, making it hard for a sensor to differentiate various gases which have similar chemical characteristics, and insufficient sensitivity at low concentrations, which is key to detect gas conditions early. Furthermore, the readings of a gas sensor are highly sensitive to environmental parameters, such as temperature, humidity, and air flow, which can cause

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fluctuations and discrepancies in the measured signal. Some sensing components also present slow response and recovery times or aging of the sensitive material over time can decrease performance. Practical implementation is further complicated due to high operational power, especially when integrated heaters need to be built in, and the fact that it is hard and difficult to miniaturise and integrate sensor technologies into simple inexpensive systems. There is consequently an urgent necessity of a gas detection system that is relatively simple, inexpensive and still offers adequate performance in early detection of flammable gas leakage in common situations.

3.2 Research Aims

- Specifically, in this work is proposed a cost-effective gas leakage detection system design and experiment design developed using a commercially available MQ-5 metal oxide semiconductor gas sensor and Arduino microcontroller platform. The specific objectives are:

1. Early identification of hazardous gases:

- To identify flammable gases including LPG, methane and fuel vapours at elevated levels and trigger an alarm before they reach dangerous concentrations, in order to protect an individual and their property.

2. Monitoring air quality in practical installations:

- To show the applicability of the proposed monitoring system to normal environments which include homes, laboratories and small workshops to measure gas concentration and to monitor when the atmosphere deviates significantly from normal, safe conditions.

3. Creating an effective, efficient and user-friendly prototype:

- A system which provides stable baseline reading in clean air, a quick response and quick reproducibility to gas exposure, a well-functioning system under moderate environmental changes (in case temperature and humidity), and easy construction and operation.

3.3 System Design and Hardware Components

- The gas leak detection system uses an MQ-5 gas sensor module connected to an Arduino microcontroller, alarm and display system. The main hardware elements are:
- **Gas sensor:**
  An MQ-5 metal oxide semiconductor gas sensor module, used to detect flammable gases (e.g., LPG, methane, and gasoline vapours). The module provides an analog output voltage that varies with gas concentration.

Microcontroller:
An Arduino Uno (or Arduino Nano) board, which serves as the core control unit. It reads the analog signal from the MQ-5 sensor, processes it, compares it to a predefined threshold, and controls the alarm and display outputs.

- **Audible alarm:**

A piezoelectric buzzer that generates a loud sound when an alarm condition (gas leakage) is detected.

- **Visual indicators:**

Light-emitting diodes (LEDs) in different colours (e.g., green, yellow, red) are used to indicate the system status: normal operation, warning, and alarm. Each LED is connected in series with an appropriate current-limiting resistor (approximately 220 Ω).

- **Display unit:**

A 16×2 liquid crystal display (LCD) mounted on the top of the device enclosure. It shows real-time sensor readings and system messages such as “NORMAL”, “WARNING”, or “GAS LEAK”.

- **Power supply and switches:**

A 9 V battery or a small lithium polymer battery is used to supply power to the Arduino and sensor module. An on/off switch is included to control the main power, and an optional push-button or switch can be used as a user input (e.g., to mute the buzzer or reset the alarm state).

- **Interconnections:**
  Jumper wires and a small prototyping board are used to connect the components. All connections are designed to be simple and reproducible for educational and prototyping purposes.

3.4 System Connections and Circuit Configuration

The main connections in the system are organised as follows:

1. **Power connections:**

The positive terminal of the battery (red wire) is connected to the Arduino’s VIN or 5 V input (depending on the regulator configuration), while the negative terminal (black wire) is connected to the Arduino GND pin. The MQ-5 sensor module and other components receive power from the Arduino’s regulated 5 V and GND lines.

2. **Sensor connection:**

The analog output pin of the MQ-5 sensor module is connected to one of the Arduino’s analog input pins (e.g., A0). This allows the microcontroller to read the sensor voltage corresponding to gas concentration.

3. **LCD connection:**

The 16×2 LCD is connected to the Arduino using standard digital I/O pins for data and control lines (for example, D4–D7 for data and two additional pins for RS and EN). A contrast-adjusting potentiometer may be added if required by the specific LCD module.

4. **Buzzer connection:**

The positive terminal of the buzzer is connected to one of the Arduino’s digital output pins (e.g., D8), and the negative terminal is connected to GND. The Arduino drives this pin HIGH or LOW to enable or disable the audible alarm.

5. **LED connections:**

Each LED is connected in series with a current-limiting resistor (approximately 220 Ω). The anode of each LED is

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connected to a dedicated digital output pin (for example, D9 for the red LED, D10 for the yellow LED, and D11 for the green LED), while the cathode is connected to GND. This configuration allows the Arduino to control the status indicators individually.

6. **Switch connection:**

A simple push-button or toggle switch can be connected between 5 V and a digital input pin (e.g., D13), with an appropriate pull-down or pull-up configuration, to serve as a user input for acknowledging alarms or toggling specific functions if desired.

3.5 Working Mechanism and Control Logic

While running the system, the analog output from the MQ-5 sensor is monitored continuously. It takes a short warm-up time for the sensor to stabilise in clean air when turned on for the first time. Then, the Arduino records typical baseline readings, which in the experiments presented here were found to lie in the approximate range of 150–200 (arbitrary units) under normal ambient conditions.

The control logic implemented in the Arduino firmware can be summarised as follows:

1. **Continuous sampling:**

The Arduino repeatedly reads the analog value from the MQ-5 sensor at regular intervals.

2. **Baseline and threshold comparison:**

The measured value is compared against one or more predefined thresholds. Values close to the baseline are interpreted as normal conditions. When the reading begins to rise significantly above the baseline, the system can enter a "warning" state, and when it exceeds a higher threshold (selected based on experimental observations of typical leak conditions), the system enters an "alarm" state.

3. **Status indication:**

- In the **normal** state, the green LED is turned on, the buzzer is off, and the LCD displays the current reading along with a "NORMAL" message.
- In the **warning** state (slightly elevated readings), the yellow LED may be activated and a corresponding message displayed on the LCD, without yet triggering the buzzer.
- On the **alarm** state (readings well above the threshold, typically in the range of 700–900 during tests with gas exposure), the red LED lights up, the buzzer is activated to generate an audible alarm, and the LCD displays a "GAS LEAK" or similar warning message.

4. **Alarm reset and recovery:**

When the gas source is removed and the environment becomes cleaner, the sensor readings gradually decrease toward the baseline. Once the value falls below the alarm threshold, the Arduino deactivates the buzzer and red LED and returns the system to a normal or warning state, depending on the residual level. If a manual reset or mute button is implemented, the user can temporarily silence the buzzer while the visual indicators continue to display the hazard status.

3.6 Experimental Procedure

To evaluate the performance of the proposed system, a series of experiments was conducted under controlled conditions. The procedure consisted of the following steps:

1. **Warm-up and baseline measurement:**

The system was turned on in a well-ventilated room free of intentional sources of flammable gas. The MQ-5 sensor was allowed to warm up for several minutes, after which its readings stabilized. This baseline range was then observed and recorded in clean air, which was used as a reference for normal operating conditions.

2. **Exposure to flammable gases**:

In the vicinity of the sensor, different sources of flammable gas were introduced such as cooking gas (LPG), methane from common fuel sources, and gasoline vapours. The gas source was briefly brought near the sensor for a short distance and then removed after each test. Sensor readings were continuously recorded from the Arduino, which were also displayed on the LCD. Special attention was paid to the maximum values reached during exposure (in the range 700-900) and the transition from baseline to peak values.

3. **Recovery and ventilation tests:**

The gas source was removed following exposures and the sensor was allowed to recover while its readings were monitored over time. Tests were performed under both well-ventilated and relatively enclosed conditions to observe the effect of air exchange on recovery speed and residual readings. This enabled comparison of how quickly the sensor signal returned toward the baseline under different environmental conditions.

4. **System response verification:**

Throughout the experiments, proper operation of the control logic and alarm outputs was checked. More precisely, it was verified that the buzzer as well as the red LED were turned on when the sensor output exceeded the alarm threshold and also turned off when the readings returned to safe levels. Moreover, the behaviour of the warning and normal indicators was also checked to verify that the system gave clear and consistent feedback to users in different situations.

This experimental strategy gives hands-on experience of the ability of the system to detect flammable gas leakage and alarm early when this leakage occurs, and return to normal operation when the hazard is removed, under conditions expected for possible practical applicability to homes, laboratories, and small workshops.

4. Results

Experimental studies with the proposed gas leakage detection system mainly were conducted for three tasks: evaluating baseline performance of the MQ-5 sensor in clean air, response to different flammable gases, and recovery under different ventilation conditions.

Upon start up under proper conditions (ventilation, no gas sources of the system) the MQ-5 sensor had to come to the stable operation mode after a very short warm up. After a few minutes, clean air readings became fixed within the normal

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conditions range (150–200 arbitrary units). In that range, minor variations were recorded, and no alert or alarm was raised. In such conditions, the green LED was perpetually bright with the LCD displaying the baseline and 'NORMAL' status message, such that the system was able to keep it in a stable reference state without the leak of gas. If the sensor was made to run on flammable gas, an explosive rise in the output could be observed.

The readings increased significantly from the baseline range and were generally between 700 and 900 values according to gas type and exposure distance to the sensor for the cooking gas (LPG), methane from common fuel sources, and gasoline vapours. Gasoline vapours had the highest response, followed by LPG and methane. Whenever the read received from the sensor exceeded the preset alarm threshold the control unit triggered the red LED and buzzer, and the LCD displayed a warning of the "GAS LEAK", allowing immediate audible and visual indication. Table 1 summarises the major experimental observations made from the various test conditions.

Table 1. Summary of MQ-5 sensor response under different test conditions.

Test condition	Gas type	Typical reading range (a.u.)	Qualitative response	Alarm state	Recovery behaviour / ventilation effect
Clean air, well ventilated	None (background)	150–200	Stable baseline, small fluctuations	No alarm (NORMAL status)	Readings remain within baseline range; rapid stabilisation after warm-up.
Gas exposure, short duration	LPG (cooking gas)	700–850	Rapid increase from baseline	Alarm triggered	Readings decrease to baseline after gas removal; faster with ventilation.
Gas exposure, short duration	Methane / fuel gas	700–850	Clear rise above baseline	Alarm triggered	Similar to LPG; recovery depends on air exchange.
Gas exposure, short duration	Gasoline vapours	750–900	Highest response among tested gases	Alarm triggered	Gradual decrease; recovery slower if vapours persist in the environment.
Post-exposure, well ventilated	Residual mixed gases	Returning to 150–200	Smooth recovery towards baseline	Alarm cleared automatically	Sensor returns to NORMAL state within a short time.
Post-exposure, enclosed space	Residual mixed gases	Above 200 for extended time	Slow decrease; readings remain elevated longer	Alarm state may persist	Recovery significantly slower; highlights importance of good ventilation.

As described in Table 1, the MQ-5 sensor was able to clearly differentiate normal and hazardous conditions. While in clean air the reading was similar to the baseline value, flammable gases caused the reading to shoot up well above the alarm setting. The system was stable and reproducible across repeated tests; similar response patterns were observed for all gas types. The high response to gasoline vapours of interest indicates that the MQ-5 sensor system is especially sensitive to these types of hydrocarbons, favorable in environments where fuel storage and handling is typical. The sensor recovery effects are strongly related to ventilation. The readings decreased quite rapidly after gas removal under well-ventilated conditions and returned back to baseline in a short time period, and the alarm could be automatically cleared and the gas readings returned to baseline. In narrow spaces, with little to no air flow, levels persisted and maintained until the alarm state could be cleared via adequate ventilation. This operation reveals the dual role of sensor performance and environmental effects on robust gas leakage detection. In summary, according to these findings, the proposed MQ-5 system yields a good baseline, rapid and observable reaction to flammable gases without significant disturbances and is effective in producing such alarm, thus is capable to be a practical low-cost early warning instrument for domestic and small sized industrial application.

5. Discussion

The experimental results presented in this study confirm that a simple system based on a commercially available MQ-5 metal oxide semiconductor gas sensor and an Arduino microcontroller can provide reliable early warning of flammable gas leakage in small-scale environments. The stable baseline observed in clean air (approximately 150–200 a.u.), together with the rapid and pronounced increase in sensor output upon exposure to LPG, methane, and gasoline vapours, is consistent with the general chemiresistive behaviour of metal oxide gas sensors reported in the literature (Barsan & Weimar, 2001; Wang et al., 2010; Fine et al., 2010). In these sensors, changes in surface adsorption and depletion-layer width lead to a strong modulation of resistance when reducing gases interact with adsorbed oxygen species, giving rise to the large signal variations exploited for gas detection (Barsan & Weimar, 2001; Ghafarinia et al., 2023).

Table 1 clearly illustrates that the MQ-5 sensor is able to distinguish between normal conditions and hazardous situations through a significant shift in its output signal. In

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clean, well-ventilated air, the sensor remains within the baseline range and the system correctly stays in the "NORMAL" state. When flammable gases are present, the output rapidly rises into the 700–900 a.u. range and triggers both audible and visual alarms. The particularly high readings observed for gasoline vapours indicate that the MQ-5 module is especially sensitive to this type of hydrocarbon mixture. Similar observations have been reported for other tin-oxide-based and perovskite-type sensors, where specific gas–material interactions and catalytic effects lead to enhanced responses to certain VOCs or fuel-related species (Wang et al., 2018; Tonezzer et al., 2019; Zhang et al., 2017; Mousavi & Zeinali, 2022). Although the present work does not attempt a detailed selectivity study, the qualitative ranking of responses across the tested gases agrees with the expected sensitivity profile of MQ-series sensors supplied for LPG and fuel gas detection.

The recovery behaviour observed after removal of the gas source also aligns with established understanding of chemiresistive gas sensors. In well-ventilated environments, the sensor readings decrease relatively quickly toward the baseline as the ambient atmosphere is purged of flammable vapours, allowing the device to return to its normal state. In contrast, slow recovery and prolonged elevation of readings in enclosed spaces reflect the persistence of residual gas in the surrounding air rather than an intrinsic limitation of the sensing element itself. A similar influence on response and recovery times by ventilation has been emphasized in studies of nanostructured metal oxide sensors and energy-saving chemiresistive platforms (Majhi et al., 2021; Xue et al., 2020; Zhou et al., 2015), where gas diffusion and removal strongly affect the dynamic characteristics of the device. From a practical perspective, these findings emphasise that even a well-designed detector must be complemented by adequate ventilation and safe installation practices to ensure effective hazard mitigation.

Compared with more advanced gas sensing systems described in the literature, the present prototype deliberately prioritises simplicity, cost-effectiveness, and educational value over maximum performance. Recent work has demonstrated impressive enhancements in sensitivity, selectivity, and operating stability through the use of complex nanostructures, MOF-derived materials, and heteroatom-doped semiconducting frameworks (Duan et al., 2024; El-Muraikhi et al., 2025; Chen et al., 2018). Likewise, flexible and wearable sensors, self-powered patches, and microheater-based low-power platforms have been proposed for continuous monitoring in smart textiles and portable devices (Luo et al., 2023; Kim et al., 2020; Wu et al., 2023; Zhou et al., 2015; Xue et al., 2020). In addition, pattern recognition and machine learning techniques have been integrated with sensor arrays to address cross-sensitivity, drift, and multi-gas discrimination in complex VOC mixtures (Hierlemann & Gutierrez-Osuna, 2008; Mei et al., 2024; Jiang et al., 2025; Ni et al., 2024; Acharyya et al., 2023). By contrast, the system reported here uses a single, low-cost MOS sensor and straightforward threshold-based logic.

Nevertheless, this simplicity is also the main strength of the proposed design in the targeted application context. In many domestic and small workshop environments, the primary requirement is not precise gas quantification or sophisticated pattern recognition, but rather a robust indication that a flammable gas concentration has risen significantly above normal background levels. As illustrated here, a single MQ-5 sensor with very clear audible and visual alarms—as implemented in this work—can yield a significant safety benefit with almost no cost. This is consistent with the wider recommendations of academic literature, highlighting the necessity for inexpensive metal oxide sensors that can be easily incorporated into real-life environments for environmental and safety monitoring, especially in low-resource applications (Zainab et al., 2014; Fine et al., 2010; Korotcenkov, 2007). Furthermore, the Arduino-based implementation is easily reproducible and adaptable in educational laboratories and engineering training programmes, contributing to accessibility. Meanwhile, a number of limitations of the current study should be noted at once.

For example in the sensors measurement are given as arbitrary quantities from the analogue output instead of in the calibrated gas concentration units (e.g., ppm). No certified gas mixtures were used, and the alarm threshold was empirically defined as a function of the recorded baseline value and response. Consequently, it is a relative indication of risk instead of compliance to minimum/maximum exposure limits or standards. Second, environmental parameters including temperature and humidity, influential on metal oxide sensor properties, were not systematically varied or compensated (Wang et al., 2010; Majhi et al., 2021). Third, the stability, aging and drift of the MQ-5 sensor over time were not evaluated, but these processes need extended operating time (>month to month), as well as periodic monitoring of performance (Ghafarinia et al., 2023; Hierlemann & Gutierrez-Osuna, 2008). These constraints may suggest several avenues for future research. A natural next step is calibration of the system with known concentration gas mixtures to determine quantitative associations between sensor readings and gas levels and target alarm limits to those to which safety requirements apply.

There may be further studies on the effect of temperature and humidity, on simple compensation methods such as multi-sensor settings, or software corrections. Wireless communication modules (e.g., Wi-Fi or Bluetooth) would allow the system to be monitored remotely and data could be logged, which brings it closer to connected and intelligent sensing paradigms described in the literature (Luo et al., 2023; Ni et al., 2024). Lastly, widening the development to additional sensor types or a small array, accompanied by basic pattern recognition algorithms can also improve selectivity while still maintaining the low-cost and educational character of the prototype. Broadly, reviewing these results in the context of existing research highlights that, while the MQ-5-based system was shown to be simple, its contributions can be aligned with those of gas sensing systems because it exploits

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known chemiresistive principles, engages with behaviours observed previously, and fulfils a practical need for inexpensive early warning devices at the general level of the environment.

6. Conclusion

We proposed the design and implementation of a low-cost gas leakage detection system using a commercially available MQ-5 metal oxide semiconductor gas sensor and an Arduino microcontroller platform. The machine, which combines a buzzer, multi-colour LEDs and an LCD display, is designed to offer audible and visual feedback in various working conditions.

Experimental studies have shown stable initial performance of MQ-5 sensor under clean air (approximately 150–200 a.u.) and immediately and clearly when in contact with flammable gases, including LPG, methane, and gasoline vapours, which the system also has experienced and its outputs with readings between 700–900 a.u. Results in Table 1 suggest that the system recognises normal and hazardous conditions and can generate the alarms in a timely manner whenever gas levels are raised.

The prototype also showed itself robust and repeatable for the tests performed and returned to the old state automatically when gas extraction and a good ventilation were carried out. The vigorous reaction to the gasoline vapour and clear alarm triggers of LPG and fuel gases demonstrate that the MQ-5-based approach is not only simple, but can also be an efficient vehicle for early warning system in homes, laboratories and small workshops. This is in contrast to elaborate and expensive gas analysis systems and the proposed system focuses on accessibility, assembly simplicity, and low cost, all essential characteristics under reality especially under limited resource conditions i.e., commercial detectors not possible or very expensive.

And also, the present study has several of limitations. The system gives comparative indicators of gas presence based on empirical thresholds rather than calibrated concentration values; the impact of temperature, humidity, and long-term sensor drift was not systematically investigated. This reflects numerous avenues for future work, such as calibration with standard gas mixtures, environmental compensation approaches, and long-term stability research. Additionally, additional updates include connecting wireless communication for remote monitoring, implementing simple data logging functions, or extending the design of these sensors to small sensor arrays integrated with simple pattern recognition algorithms. So overall the results demonstrate that a simple combination of an MQ-5 sensor, Arduino control and simple alarm and display elements can be easily integrated into a realistic and low-cost gas leakage detection system. This kind of design not only contributes to enhancing safety in daily settings but also provides a valuable ground for imparting sensor principles, embedded system design, and applied electronics.

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