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DESIGN AND DEVELOPMENT OF AN MQ-2 SENSOR AND ARDUINO UNO GAS LEAK DETECTION SYSTEM WITH AUTOMATIC VENTILATION AND WARNING

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Abstract
Gas leakage can create fire, explosion, and health hazards when it is not detected promptly. This study developed a laboratory-scale gas-leak detection prototype that integrates an MQ-2 metal-oxide sensor, Arduino Uno, 16×2 I2C LCD, audible and visual warnings, a relay, and an automatically activated exhaust fan. Prototype performance was evaluated through distance-based sensor-response tests, alarm-response-time trials, and time-resolved ventilation tests. The average MQ-2 output declined from 721.0 ADC counts at 5 cm to 150.0 ADC counts at 30 cm, indicating a consistent distance-dependent response under the reported test conditions. The warning chain activated in an average of 2.0 s. After fan activation, the average ADC response decreased by 46.7% after 30 s and 79.9% after 60 s relative to the initial reading. These percentages describe changes in relative sensor output, not calibrated gas concentration, because no certified reference-gas or parts-per-million calibration was performed. The prototype demonstrates the feasibility of combining local detection, warning logic, and automatic ventilation in one low-cost platform. It is intended as an educational and supervised proof of concept and should not be treated as a substitute for a certified combustible-gas detector or explosion-protected safety system.
Keywords: Arduino Uno, automatic ventilation, combustible-gas warning, gas-leak detection, MQ-2 sensor, safety prototype.

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INTRODUCTION

Liquefied petroleum gas (LPG) is widely used in households, small businesses, and industrial facilities because it is portable and efficient. A leak, however, can form a flammable atmosphere and can also expose occupants to harmful vapors. Applicable safety guidance emphasizes early detection, ignition control, and adequate ventilation as important risk-reduction measures (National Fire Protection Association, 2024; Occupational Safety and Health Administration, n.d.). Reliance on odor alone is insufficient because detection ability varies among individuals and may be affected by sleep, illness, adaptation, or delayed recognition.

Low-cost metal-oxide semiconductor sensors are frequently selected for embedded gas-monitoring systems because they are simple to interface with microcontrollers and respond to several reducing gases. The MQ-2 is marketed for flammable-gas and smoke detection and provides an analog response that can be read by an Arduino Uno (Zhengzhou Winsen Electronics Technology Co., Ltd., 2021). Nevertheless, metal-oxide sensors are nonlinear and can be influenced by cross-sensitivity, temperature, humidity, aging, baseline drift, and the calibration procedure (Dutta et al., 2023; Krishna et al., 2022; Miquel-Ibarz et al., 2022; Tladi et al., 2023). Raw analog-to-digital converter (ADC) values should therefore be interpreted as relative responses unless a traceable concentration calibration is performed.

Previous Arduino- and Internet of Things-based studies have demonstrated local alarms, remote notifications, and gas-monitoring functions. Inggi and Pangala (2021) developed an Arduino-based LPG detector using an MQ-2 sensor, while Jena et al. (2023) combined embedded sensing with Internet of Things communication for leakage notification. More recent approaches have explored TinyML classification and consequence prediction to improve selectivity and decision support (Dash et al., 2023; Tsoukas et al., 2023). These studies confirm the feasibility of low-cost detection, but many reports emphasize whether an alarm or notification is triggered and provide limited time-resolved evidence regarding the complete local mitigation sequence.

The research gap addressed in this study is the limited integrated characterization of three practical functions within one stand-alone prototype: distance-dependent MQ-2 response, end-to-end warning latency, and the change in sensor output after automatic ventilation begins. The proposed contribution is therefore not a new sensing material or a certified detector. Its applied novelty lies in combining an LCD, buzzer, dual status LEDs, relay-controlled exhaust fan, and programmed warning logic, then reporting quantitative prototype behavior for detection, warning, and ventilation under a single experimental arrangement.

Accordingly, this study aimed to design and implement an Arduino Uno-based MQ-2 gas-leak warning prototype; evaluate the relative sensor response at several source-to-sensor distances; measure the time between gas introduction and alarm activation; and assess the time-resolved decrease in ADC response after exhaust-fan activation. The intended application is a supervised laboratory or educational demonstration in a small indoor setting. Any real-world deployment wo uld require calibrated sensing, verified ventilation design, fail-safe power, durable construction, and compliance with applicable electrical and fire-safety requirements.

METHOD

1. Research Methodology

This study used a research-and-development approach consisting of requirement definition, hardware and software design, prototype assembly, functional verification, and controlled laboratory testing. Three test groups were performed: (1) relative MQ-2 response at six source-to-sensor distances, (2) end-to-end alarm-response time, and (3) change in ADC response after automatic exhaust-fan activation. Because a certified reference-gas system was not available, the measurements are reported as ADC counts rather than parts per million.

2. Software Design

The Arduino Uno was programmed in the Arduino IDE using C/C++-based code. The program initializes the LCD and input/output channels, reads the MQ-2 analog signal, compares the ADC value with the programmed warning threshold, updates the display, and controls the buzzer, LEDs, relay, and exhaust fan. The operating logic uses a continuous monitoring loop so that the system returns to normal status when the relative sensor response falls below the threshold (Banzi & Shiloh, 2022; Margolis et al., 2020).

3. Hardware Components

The prototype components are listed in Table 1. The breadboard and jumper-wire assembly was suitable for laboratory verification but was not intended as a permanent installation.

Table 1. Components Used

No	Component	Quantity
1	Arduino Uno	1
2	MQ-2 Sensor	1
3	16×2 I2C LCD	1
4	1-Channel Relay	1
5	Buzzer	1
6	DC Exhaust Fan	1
7	Red LED	1
8	Green LED	1
9	Breadboard	1

10	Jumper Wires	As needed

4. System Block Diagram

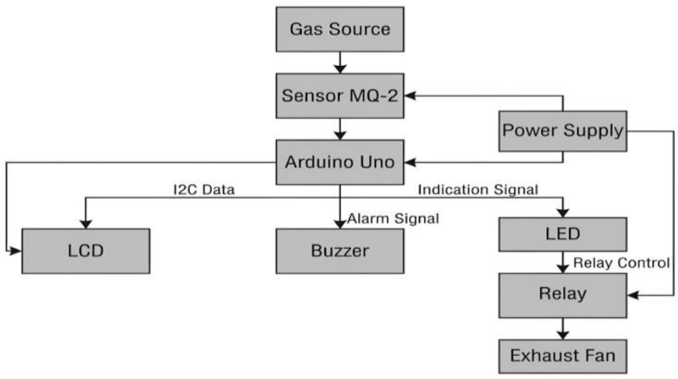

Figure 1. Functional Block Diagram of the Gas-Leak Detection Prototype

5. Experimental Test Configuration

The test configuration is summarized in Figure 2. For the distance test, five ADC readings were recorded at 5, 10, 15, 20, 25, and 30 cm. For the response-time test, five trials recorded the interval between gas introduction and warning activation. For the ventilation test, three repeated ADC readings were recorded before fan activation and at 10 s intervals up to 60 s. The reported distance is a geometric test condition rather than a calibrated detection range because gas release rate, plume dispersion, and ambient airflow were not measured independently.

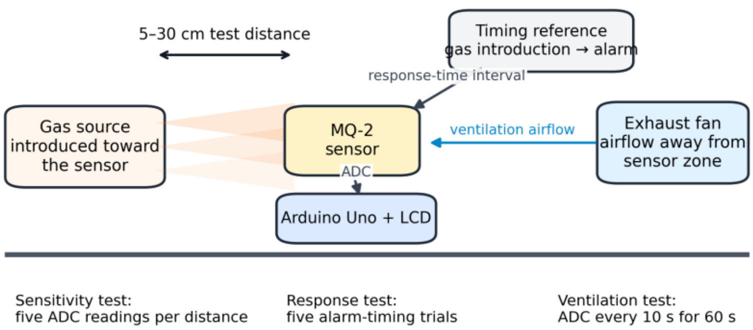

Figure 2. Labelled Experimental Test Configuration (Schematic, Not to Scale)

6. System Workflow (Flowchart)

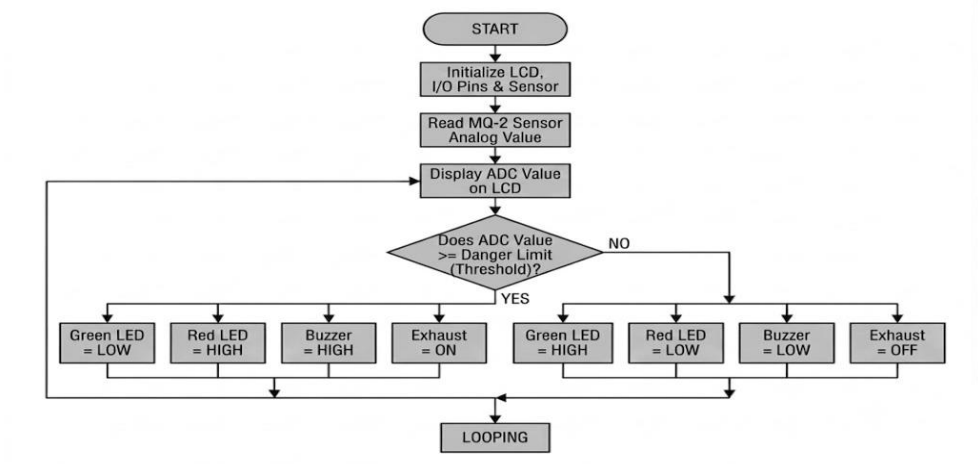

Figure 3. System Operating Logic

a. The system is turned on.
b. The MQ-2 sensor produces a relative analog response to the surrounding gas exposure.
c. The Arduino Uno converts the analog input into an ADC value and applies the programmed control logic.
d. The relative ADC value and system status are displayed on the LCD.
e. If the ADC value remains below the programmed warning threshold:
   1) The green LED turns on.
   2) The buzzer turns off.
   3) The fan turns off.
f. If the ADC value reaches or exceeds the programmed warning threshold:
   1) The red LED turns on.
   2) The buzzer sounds.
   3) The relay activates.
   4) The exhaust fan turns on.
g. The system continuously repeats the sensor-reading and control process.

RESULTS

1. MQ-2 Sensor Sensitivity Test

The sensitivity test exposed the sensor to the same gas source at six nominal distances. Five readings were recorded at each distance, and the mean ADC value was calculated.

Table 2. Sensitivity Test Results

Distance (cm)	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5	Average ADC	Status
5 cm	718	724	721	719	723	721.0	Critical
10 cm	542	548	545	543	547	545.0	Danger
15 cm	428	432	430	427	433	430.0	Danger
20 cm	310	315	312	311	314	312.4	Danger
25 cm	218	222	220	219	221	220.0	Caution
30 cm	148	152	150	149	151	150.0	Safe

a. Analysis

The mean ADC response decreased monotonically as the nominal distance increased, from 721.0 at 5 cm to 150.0 at 30 cm. This pattern shows that the prototype distinguished different exposure conditions in the reported arrangement. It should not be interpreted as an absolute sensitivity curve or a validated 30 cm detection range because the gas release rate, concentration, and plume profile were not independently controlled or calibrated.

Formula for the Average ADC

$$\bar{x} = (x_1 + x_2 + x_3 + x_4 + x_5) / 5$$

Example of a 5 cm distance:

$\bar{x} = (718 + 724 + 721 + 719 + 723) / 5$

$\bar{x} = 3605 / 5 = 721.0$

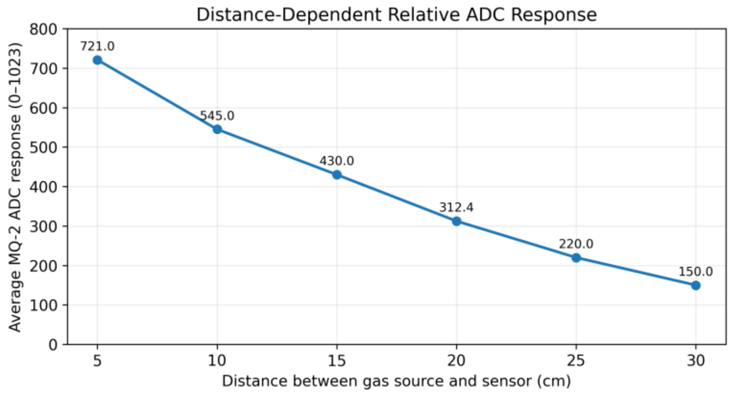

Figure 4. Distance-Dependent Relative MQ-2 ADC Response

2. System Response Time Test

The response-time test recorded the time of gas introduction and the time at which the programmed warning state activated. The timestamps in Table 3 were checked for consistency with the reported two-second intervals.

Table 3. Response Time Test Results

Test	Time Gas Was Applied	Time Alarm Activated	Response Time	ADC Value at Alarm
1	10:00:05	10:00:07	2.0	312
2	10:05:10	10:05:12	2.0	318
3	10:10:15	10:10:17	2.0	305
4	10:10:20	10:10:22	2.0	321
5	10:10:25	10:10:27	2.0	308
Average			2.0 seconds	312.8

a. Analysis

All five trials produced a recorded warning latency of 2.0 s, with ADC values at activation ranging from 305 to 321. The result indicates consistent end-to-end operation of the sensor-reading, threshold, and alarm chain in this prototype. The measurement resolution and manual timing method were not reported in the original experiment; therefore, the value should be interpreted as approximate rather than as a high-precision sensor response specification.

Formula for Average Response Time.

$\bar{t} = (t_1 + t_2 + t_3 + t_4 + t_5) / n$
$\bar{t} = (2.0 + 2.0 + 2.0 + 2.0 + 2.0) / 5$
$\bar{t} = 10.0 / 5 = 2.0$ s

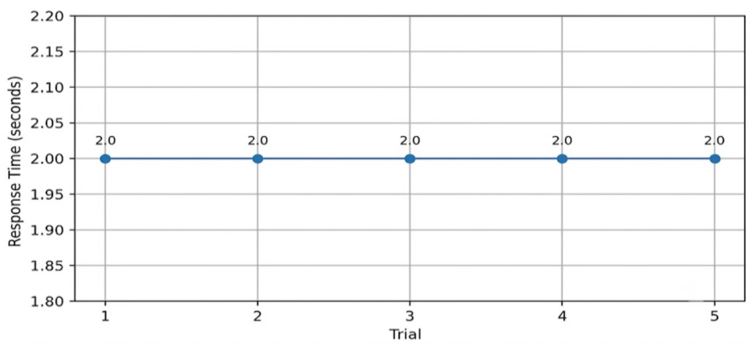

Figure 5. Alarm Response Time Across Five Trials

3. Exhaust Fan Performance Test

The ventilation test recorded the relative MQ-2 ADC response before fan activation and at 10 s intervals for 60 s. Three readings were obtained at each time point.

Table 4. Exhaust Fan Performance Test Results

Time	Experiment 1	Experiment 2	Experiment 3	Average ADC	ADC Decrease (%)

Before Fan ON (0 seconds)	721	718	724	721.0	0%
After 10 Seconds	615	612	618	615.0	14.7%
After 20 Seconds	502	498	506	502.0	30.4%
After 30 Seconds	384	380	388	384.0	46.7%
After 40 Seconds	275	271	279	275.0	61.9%
After 50 Seconds	198	195	201	198.0	72.5%
After 60 Seconds	145	142	148	145.0	79.9%

a. Analysis

After fan activation, the average ADC response decreased progressively from 721.0 to 145.0 over 60 s. The decline is consistent with removal or redistribution of gas in the sensor zone. However, fan-induced airflow can also alter the local plume and sensor temperature; consequently, the percentage decrease represents relative ADC change and does not by itself establish an equivalent percentage reduction in room-average gas concentration.

Formula for the Percentage Decrease in ADC Response

Decrease (%) = ((Initial ADC − ADC_t) / Initial ADC) × 100%

- After 30 seconds:

A 30-second decrease = ((721 − 384) / 721) × 100%

A 30-second ADC decrease = (337 / 721) × 100%

A 30-second ADC decrease = 0.4674 × 100% = 46.7%

- After 60 seconds:

A 60-second decrease = ((721 − 145) / 721) × 100%

A 60-second ADC decrease = (576 / 721) × 100% = 79.9%

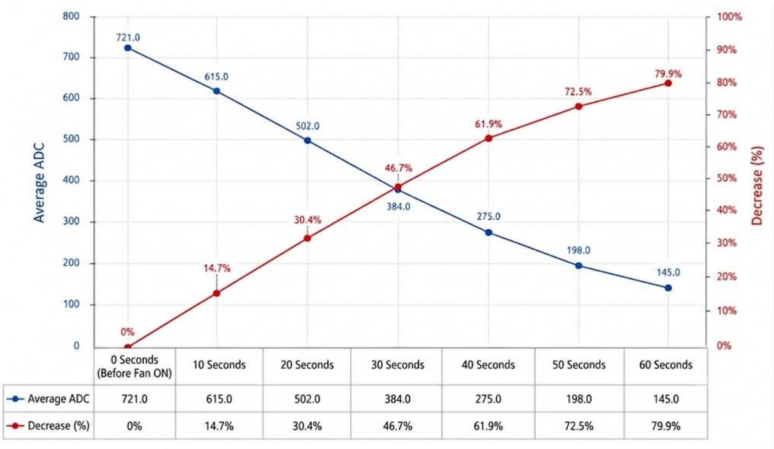

Figure 6. Time-Resolved ADC Response During Automatic Ventilation

DISCUSSION

The distance test produced a clear monotonic change in relative MQ-2 output. This finding is consistent with the general behavior of low-cost metal-oxide sensors, whose resistance changes with exposure to reducing gases. The curve should not be interpreted as linear concentration measurement because metal-oxide response is inherently nonlinear and depends on calibration, gas composition, temperature, humidity, and sensor history (Dutta et al., 2023; Krishna et al., 2022; Miquel-Ibarz et al., 2022). The present result therefore demonstrates discrimination among the tested exposure conditions rather than an absolute measurement in parts per million.

The recorded 2.0 s warning latency indicates that the complete prototype chain - sensor sampling, analog conversion, threshold comparison, and actuator switching - operated consistently across five trials. Direct numerical comparison with earlier Arduino or IoT gas detectors is limited because published prototypes use different sensor types, gas-release procedures, thresholds, sampling intervals, and timing methods (Inggi & Pangala, 2021; Jena et al., 2023). In contrast to studies that primarily emphasize notification connectivity, this experiment explicitly reports end-to-end local warning latency. More precise benchmarking would require electronic event logging and a defined step change in reference-gas concentration.

The fan experiment adds time-resolved evidence to the mitigation function. The ADC response fell by 46.7% after 30 s and 79.9% after 60 s relative to the initial reading. This supports the programmed sequence in which detection automatically initiates local ventilation. Nevertheless, the exhaust fan changes airflow around the sensor, so the observed decline may reflect both gas removal and plume redistribution. A future ventilation study should measure chamber volume, fan flow rate, air changes per hour, multiple spatial sampling points, and calibrated gas concentration before concluding that the same percentage reduction occurs throughout a room.

Several engineering limitations affect interpretation and deployment. The MQ-2 is cross-sensitive to multiple flammable gases and smoke, its response can drift with aging, and its baseline is affected by temperature and humidity. The response is nonlinear, and the sensor requires adequate warm-up and periodic verification (Tladi et al., 2023; Zhengzhou Winsen Electronics Technology Co., Ltd., 2021). Breadboard and jumper-wire connections are vulnerable to loosening, contamination, and voltage drop. Relay contacts may arc or wear when switching inductive loads, while fan airflow can disturb the measurement itself. The current assembly was not evaluated for electromagnetic compatibility, enclosure ingress protection, intrinsic safety, flameproof construction, or operation in a potentially explosive atmosphere.

The practical contribution is a low-cost, stand-alone teaching and supervised demonstration platform that integrates local monitoring, visual and audible warnings, and automatic ventilation without requiring network access. It differs from a commercially certified gas detector because it has no traceable ppm calibration, certified alarm set point, self-test, fault indication, backup power, redundant sensing, approved enclosure, or verified explosion protection. Maintenance would need to include sensor warm-up, periodic calibration or bump testing, cleaning, inspection of wiring and relay contacts, fan-function checks, and replacement of aging components. A power interruption currently disables detection and ventilation; therefore, a regulated backup supply and fail-safe fault alarm are essential before any safety-critical use.

CONCLUSION

An Arduino Uno-based gas-leak warning prototype integrating an MQ-2 sensor, LCD, buzzer, status LEDs, relay, and exhaust fan was successfully assembled and functionally tested. Under the reported laboratory conditions, the mean relative sensor output decreased from 721.0 ADC counts at 5 cm to 150.0 ADC counts at 30 cm, and the warning state activated in an average of 2.0 s. After automatic fan activation, the average ADC response decreased by 46.7% after 30 s and 79.9% after 60 s. These values demonstrate repeatable prototype behavior but do not constitute calibrated gas-concentration measurements or certified ventilation performance. The system is therefore best regarded as an educational proof of concept. Field use would require traceable calibration, environmental compensation, durable and explosion-appropriate hardware, fail-safe power, and validation against applicable gas-detection and ventilation standards.

Recommendations

Future work should calibrate the MQ-2 with certified reference-gas concentrations and report the resulting ppm-response curve, measurement uncertainty, temperature and humidity effects, repeatability, recovery time, false alarms, and long-term drift. The breadboard should be replaced by a verified printed circuit board with an appropriate enclosure, rated relay or solid-state switching device, electrical protection, fault indication, and backup power. Ventilation performance should be tested in a defined chamber using measured fan flow, air-change rate, and multiple sampling locations. Data logging, IoT communication, and smartphone or SMS notification may then be added without weakening local stand-alone alarms. Finally, the prototype should be compared with a certified combustible-gas detector and evaluated by competent safety personnel before any occupied-space trial.

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The authors hope that this work will support further development of carefully calibrated and appropriately certified gas-leak monitoring and mitigation technologies.

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