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Research Paper

Development and Performance-Oriented Design of a Low-Cost Gas and Smoke Detector for Domestic and Small-Scale Industrial Safety

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Abstract

Gas leakages and smoke from early-stage fires are major safety threats in domestic, commercial and small-scale industrial environments. This risk is more severe in low-resource settings where commercial detectors may be unaffordable, difficult to maintain, or dependent on communication infrastructure that is not continuously available. This study presents the design and implementation of a low-cost gas and smoke detector intended for domestic and small-scale industrial safety. The system was developed using an Arduino-class microcontroller, an MQ-series gas/smoke sensor, local visual and audible alarms, a regulated 5 V power supply, and an optional display/telemetry interface. Three design alternatives were compared: cellular GSM alerting, standalone local audio-visual alerting, and IoT cloud-based alerting. The local audio-visual architecture was selected for the core prototype because it provides immediate response, low cost, high maintainability and independence from Wi-Fi or cellular network failures. The detector logic uses analog signal acquisition, voltage conversion, sensor-resistance estimation, digital thresholding and alarm actuation. A threshold of 600 ADC counts, equivalent to approximately 2.93 V on a 10-bit 5 V analog-to-digital converter, was used as the alarm decision level. Power-budget analysis indicated an estimated maximum continuous current demand of about 210 mA, making a 5 V, 1 A adapter sufficient while allowing short-duration battery backup. The prototype is estimated to cost less than USD 25 per unit, indicating potential for affordable deployment in households, workshops and small enterprises. Further work should include certified calibration using known gas concentrations, longer-term drift testing, multi-sensor redundancy and compliance assessment against relevant safety standards.

Keywords: Gas leakage; smoke detection; Arduino; MQ sensor; LPG safety; low-cost detector; domestic safety; embedded systems.

1. Introduction

Accidental leakage of combustible gases and smoke accumulation from incipient fires remain important causes of domestic and workplace accidents. Liquefied petroleum gas (LPG), methane, carbon monoxide and combustion aerosols are especially relevant in kitchens, restaurants, workshops, storage areas and small industrial spaces. Burns and fire-related injuries remain a major public health concern, particularly where prevention systems are weak or inconsistently installed (World Health Organization [WHO], 2023). For flammable-gas safety, detector performance and

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alarm response should be understood against recognized gas-detector and fire-detection requirements (International Electrotechnical Commission [IEC], 2020; International Organization for Standardization [ISO], 2023).

Conventional fire-safety devices have improved life safety in many settings, yet affordability and practical accessibility remain major limitations in low-income households and small enterprises. National fire-alarm guidance emphasizes early warning, proper placement and routine maintenance of smoke alarms, but low adoption can persist where cost, maintenance and user literacy create barriers (National Fire Protection Association [NFPA], 2025). Therefore, an affordable detector that gives simple local warnings can strengthen basic safety without requiring advanced infrastructure.

A practical alternative is a locally fabricated, low-cost and modular detector based on open-source microcontrollers and readily available sensors. Arduino-class boards are suitable for educational and low-cost embedded monitoring because they provide digital inputs/outputs and analog-input capability for sensor acquisition (Arduino, 2026). The objective of this study was therefore to design, implement and evaluate a low-cost gas and smoke detector system that can detect flammable gases and smoke, activate user-friendly audio-visual alarms, and support future real-time alert expansion for domestic and small-scale industrial safety (Nicholaus, 2026).

2. Literature Review

2.1 Gas-sensing technologies

Gas detection in safety systems commonly uses metal oxide semiconductor (MOS), electrochemical, catalytic bead, non-dispersive infrared and other sensing technologies. MOS sensors, especially tin-dioxide-based MQ-series devices, are attractive for low-cost applications because they respond to several reducing gases and are easy to interface with microcontrollers. MQ-2 sensor documentation describes the device as suitable for detecting LPG, propane, methane, hydrogen and smoke, with a simple drive circuit and fast response (Hanwei Electronics Co., Ltd., n.d.; Winsen Electronics Technology Co., Ltd., n.d.).

The major limitation of low-cost MOS sensors is that they are not highly selective. They may respond to several gases at once, and their output can drift with temperature, humidity, sensor ageing and warm-up conditions. For this reason, MOS sensors are useful for low-cost warning systems, but they should be calibrated, periodically checked and treated as screening devices rather than precision certified gas analyzers (IEC, 2020; Seeed Studio, 2023).

2.2 Smoke detection and multi-hazard monitoring

Traditional smoke detectors rely mainly on ionization or photoelectric principles. The ISO 7240-7 smoke-detector standard covers point-type detectors that operate using scattered light, transmitted light or ionization principles and sets requirements, test methods and performance criteria for building fire-detection applications (ISO, 2023). In domestic and workshop settings, hazards may involve both flammable gas leakage and smoke generation; therefore, multi-hazard monitoring can provide broader warning than single-purpose devices.

A combined gas and smoke detector should not replace certified fire-alarm systems where regulation requires them, but it can support early local awareness in low-resource settings. The selected prototype therefore combines a gas/smoke-responsive MQ sensor with visible and audible outputs. This approach is consistent with the project requirement to produce a user-friendly system with audio and visual alarms (Nicholaus, 2026).

2.3 Microcontroller-based detection systems

Microcontroller-based safety systems are suitable for low-cost engineering designs because they allow sensor acquisition, filtering, threshold evaluation and alarm actuation within one programmable platform. The Arduino Uno Rev3 is based on the ATmega328P microcontroller and provides multiple digital pins and analog input channels for sensor interfacing (Arduino, 2026). Arduino documentation also notes that boards such as the Uno use a 10-bit ADC, which maps analog voltages to integer readings from 0 to 1023 (Arduino, 2025).

Remote notification can be implemented with GSM modules or Wi-Fi microcontrollers when communication infrastructure is available. The SIM800 series supports SMS and other cellular functions through AT commands, making it suitable for low-bandwidth alert messages (SIMCom Wireless Solutions, 2021). However, network-based alerting introduces additional power demand, signal dependency, configuration burden and possible transmission delay. For this reason, the core safety action in the present design remains local, while GSM or IoT alerting is treated as an optional extension.

3. Materials and Methods

3.1 Research design

The study followed an engineering design approach consisting of problem identification, component selection, system architecture comparison, circuit design, microcontroller programming, prototype fabrication, calibration planning and controlled testing. The manuscript was developed from the original design project report, which specified the aim of designing and implementing a low-cost gas and smoke detector for domestic and industrial safety (Nicholaus, 2026).

The target application was domestic, small commercial and semi-industrial environments rather than high-risk chemical plants or certified hazardous zones. This distinction is important because certified industrial gas detection normally requires formal compliance testing, defined alarm set-points and detector performance evaluation under recognized standards (IEC, 2020; NFPA, 2025).

3.2 Functional requirements

The detector was designed to satisfy six functional requirements: detection of combustible gases such as LPG and methane; detection of smoke particles from combustion; real-time local warning using visual and audible indicators; continuous monitoring; low power consumption suitable for backup operation; and affordability for low-income users and small businesses. These requirements were adapted from the project objectives and scope presented in the source report (Nicholaus, 2026).

Table 1. Functional requirements of the proposed gas and smoke detector (adapted from Nicholaus, 2026).

Requirement	Design response
Gas detection	MQ-series sensor connected to analog input for combustible gas and smoke-response monitoring.
Smoke detection	Threshold detection of smoke-related sensor response, with provision

	for future dedicated photoelectric smoke module.
Real-time alert	Red LED and piezoelectric buzzer activated when threshold is exceeded; green LED indicates normal state.
Local display	Optional 16 x 2 LCD with I2C interface for status and readings.
Low power	5 V regulated supply, modest current draw and possible battery backup.
Low cost	Use of open-source microcontroller platform and readily available electronic components.

3.3 System architecture and component selection

The prototype consists of an Arduino Nano/Uno class microcontroller, an MQ-series gas/smoke sensor, LED indicators, an active piezoelectric buzzer, an optional 16 x 2 LCD display, a 7805-voltage regulator and a 9 V battery or external 5 V adapter. The MQ sensor was selected because the MQ-2 family is widely used for low-cost detection of LPG, methane, hydrogen, alcohol vapour and smoke in leakage-detection applications (Hanwei Electronics Co., Ltd., n.d.; Seeed Studio, 2023).

The microcontroller continuously samples the analog sensor output and compares the filtered reading with a predefined threshold. Arduino analog-input documentation indicates that a 10-bit ADC produces readings from 0 to 1023, enabling direct voltage-based thresholding for simple warning systems (Arduino, 2025). A GSM or Wi-Fi module can be added in future versions, but the core safety response is local and network-independent to preserve functionality during communication failures (SIMCom Wireless Solutions, 2021).

Table 2. Main hardware components and their functions (adapted from Nicholaus, 2026; Arduino, 2026; Hanwei Electronics Co., Ltd., n.d.).

Component	Function in the system
Arduino Nano/Uno	Acquires analog sensor values, executes decision logic and controls output devices.
MQ-2/MQ-135 sensor	Detects combustible gases and smoke-related reducing gases through resistance change.
Red LED	Indicates danger state when threshold is exceeded.
Green LED	Indicates normal/safe operating condition.
Piezoelectric buzzer	Provides immediate audible alarm to nearby occupants.
16 x 2 LCD with I2C module	Displays system condition and sensor status while minimizing pin usage.
7805 voltage regulators	Converts 9 V input to a regulated 5 V rail for electronics.
GSM/IoT module optional	Provides remote notification if network-based alerting is required.

3.4 Design alternatives

Three alternative configurations were evaluated using functionality, maintainability, cost-effectiveness, reliability and user-friendliness as criteria. The GSM alternative provides remote SMS alerts but requires network signal and airtime. The IoT cloud alternative supports dashboards and continuous logging but depends on stable Wi-Fi and external platforms. The local audio-visual alternative provides direct warning through a buzzer and LEDs, avoiding communication delays and reducing cost (Nicholaus, 2026; SIMCom Wireless Solutions, 2021).

Based on the intended low-resource use case, the local audio-visual approach was selected as the core implementation. This choice is technically justified because an alarm should not depend entirely on external communication infrastructure before alerting nearby occupants. Networked alerts remain useful as secondary notification channels, but the first response should be fast, simple and local (NFPA, 2025).

Table 3. Comparison of design alternatives (adapted from Nicholaus, 2026).

Criterion	GSM alert system	Local audio-visual system	IoT cloud system
Functionality	Remote SMS notification; useful when users are away.	Immediate on-site alarm using buzzer and LEDs.	Remote dashboards and mobile application alerts.
Maintainability	Requires SIM card, airtime and network troubleshooting.	Simple standalone device with minimal routine maintenance.	Requires Wi-Fi credentials, platform configuration and updates.
Cost	Higher due to GSM hardware and service costs.	Very low due to basic off-the-shelf components.	Moderate due to wireless hardware and software setup.
Reliability	Affected by network signal and SMS delays.	Independent of external network infrastructure.	Affected by internet, router and cloud-service failures.
User-friendliness	Simple SMS, but more complex setup.	Clear LED and buzzer signals; no technical literacy required.	Modern interface but requires smartphone and internet.

3.5 Circuit interfacing

The electrical circuit uses a regulated 5 V rail to supply the microcontroller, sensor, display and indicators. The MQ-series sensor analog output is connected to the microcontroller ADC pin. The buzzer and LED indicators are connected to digital output pins. Each LED is protected using a 220-ohm series resistor. An I2C LCD may be connected using SDA and SCL pins to reduce digital pin usage. The pin assignment follows the design logic of the original project report and the Arduino pin availability described in official documentation (Arduino, 2026; Nicholaus, 2026).

Table 4. Example pin assignment for the prototype (adapted from Nicholaus, 2026).

Microcontroller pin	Linked component	Operational role	Normal state	Alarm state
A0	MQ-series sensor	Gas/smoke analog input	Active sampling	Active sampling
D2	Piezoelectric buzzer	Audible alarm	LOW	HIGH/PWM
D3	Red LED	Visual danger indicator	LOW	HIGH

D4	Green LED	Visual normal indicator	HIGH	LOW
A4/A5	I2C LCD optional	Display data transfer	Active if installed	Active if installed

3.6 Sensor signal conversion and alarm logic

The MQ sensor is treated as a variable-resistance element in a voltage-divider circuit. This is consistent with MQ sensor documentation, which describes changes in sensor resistance as gas concentration changes (Hanwei Electronics Co., Ltd., n.d.; Winsen Electronics Technology Co., Ltd., n.d.). The output voltage is given by Equation (1):

$$Vout = Vcc \times RL / (Rs + RL) \quad (1)$$

where Vcc is the supply voltage, RL is the load resistance and Rs is the gas-sensitive resistance. The microcontroller converts the analog signal into a digital value using a 10-bit ADC (Arduino, 2025):

$$ADC = 1023 \times Vout / Vcc \quad (2)$$

and therefore:

$$Vout = ADC \times Vcc / 1023 \quad (3)$$

The sensor resistance can then be estimated using:

$$Rs = RL \times (Vcc - Vout) / Vout \quad (4)$$

To reduce transient noise, the firmware can apply a moving-average filter over n samples:

$$Afiltered = (A1 + A2 + ... + An) / n \quad (5)$$

In the prototype logic, a digital threshold of 600 ADC counts was adopted. With a 5 V ADC reference, this corresponds to Vout = 600 x 5/1023 = 2.93 V. When Afiltered is greater than or equal to the threshold, the red LED and buzzer are activated and the green LED is switched off. When the reading remains below the threshold, the green LED stays on while the warning devices remain off. Threshold selection should be refined through controlled calibration before field deployment (IEC, 2020; Nicholaus, 2026).

3.7 Testing and validation protocol

Testing was planned using controlled indoor exposure cycles. Clean air was first used to establish the baseline sensor reading. The detector was then exposed to controlled smoke and combustible-gas test conditions in a supervised laboratory setting, and environmental disturbances such as humidity and dust were considered as possible causes of false alarms. The source report specifies a minimum of thirty exposure cycles to assess operational reliability, response time, GSM latency where applicable, saturation level and recovery time (Nicholaus, 2026).

For a publication-ready version, tests should be performed with calibrated reference instruments and documented concentrations. This is necessary because gas detectors require controlled performance assessment, and informal smoke or gas exposure is not sufficient for certified calibration or regulatory claims (IEC, 2020; ISO, 2023).

4. Results and Discussion

4.1 Selected design configuration

The comparison of design alternatives showed that the standalone local audio-visual detector is the most appropriate core design for the target context. It has the lowest estimated cost, requires the least maintenance, and does not depend on external cellular or Wi-Fi infrastructure. This is important for households and small businesses where internet service, mobile airtime or technical support may be inconsistent. Remote alerting remains valuable, but it should be added as a secondary layer rather than replacing immediate local alarm actuation (NFPA, 2025; SIMCom Wireless Solutions, 2021).

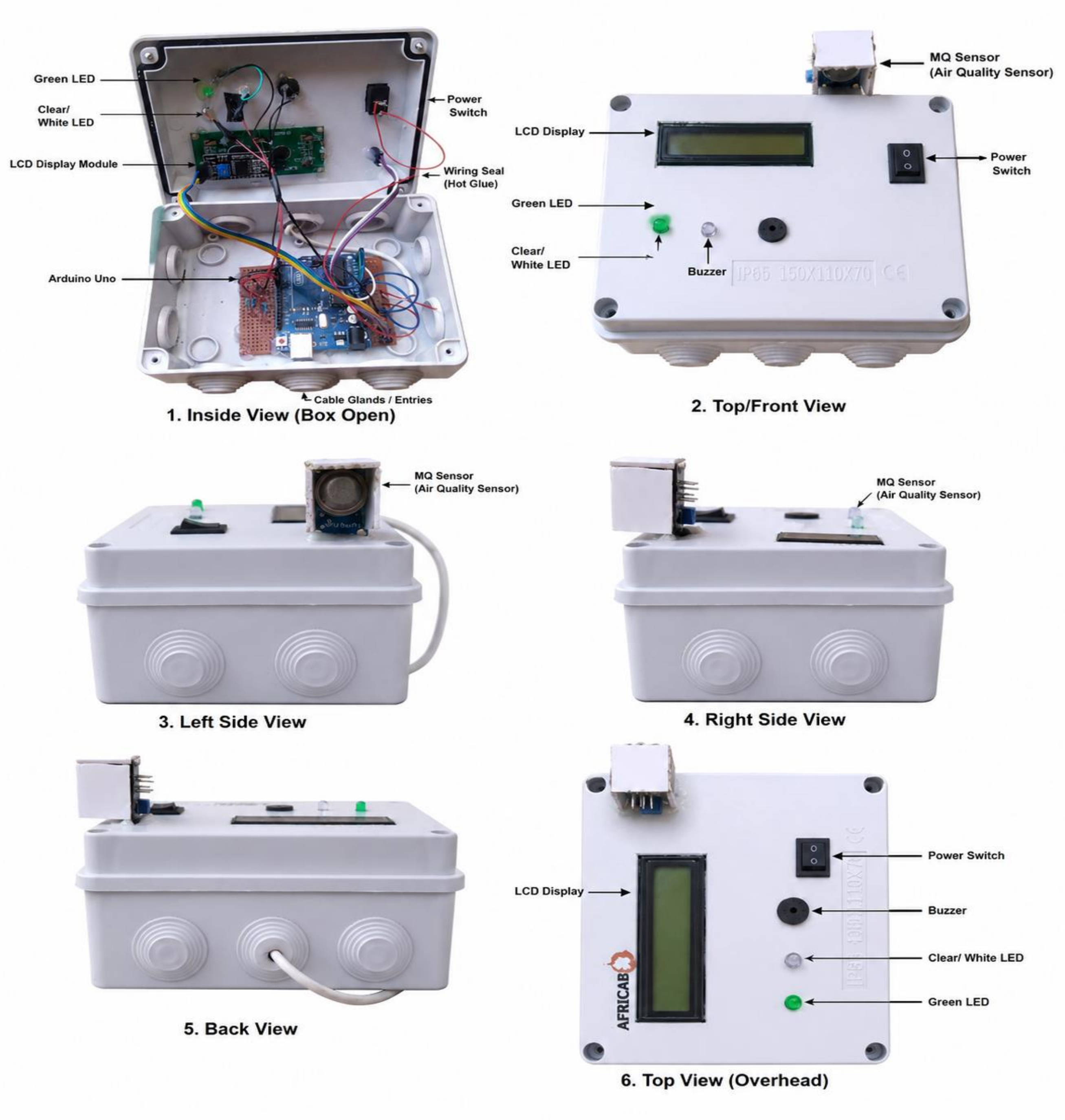

Figure 1: Gas and Smoke Detector

4.2 Threshold and signal-processing results

The selected threshold of 600 ADC counts corresponds to approximately 2.93 V for a 5 V, 10-bit ADC. Clean-air baseline readings are expected to remain lower than this threshold, while exposure to combustible gases or smoke should increase the sensor output sufficiently to activate the alarm. A moving-average filter is proposed to reduce short-duration electrical noise and transient disturbances. However, because MOS sensors are cross-sensitive, a fixed threshold should be treated as a prototype value until validated with known gas and smoke concentrations (Arduino, 2025; Hanwei Electronics Co., Ltd., n.d.; IEC, 2020).

4.3 Power-budget analysis

The total maximum current demand was estimated by summing the current required by the microcontroller, sensor heater, buzzer, LCD and LED indicators. The estimated worst-case continuous current was about 210 mA. Therefore, a standard 5 V, 1 A adapter provides a large current margin for stable operation. Battery backup is possible, but operating time will depend strongly on the sensor heater current and display backlight consumption (Arduino, 2026; Hanwei Electronics Co., Ltd., n.d.).

Table 5. Estimated worst-case current consumption (adapted from Nicholaus, 2026).

Component	Estimated current
Arduino Nano/Uno microcontroller	20 mA
MQ-series sensor heater and module	50 mA steady state; up to 150 mA transient preheat
Piezoelectric buzzer	10 mA
16 x 2 LCD with I2C backlight	15 mA
LED indicators and resistors	15 mA combined
Estimated maximum total	Approximately 210 mA

4.4 Cost and accessibility

The prototype is estimated to cost less than USD 25 per unit when assembled from commonly available components. This cost level makes the system suitable for educational institutions, domestic users, workshops and small enterprises. The open-source microcontroller platform also improves repairability because the circuit and firmware can be modified locally. Nevertheless, very low cost should not be confused with certified safety performance; before commercial use, the detector should be validated against relevant gas- and smoke-detection standards (IEC, 2020; ISO, 2023).

4.5 Risk assessment

The main technical risks include inaccurate detection, false positives, false negatives, sensor drift, limited detection range and power instability. These risks can be reduced by calibration, sensor redundancy, stable power regulation, environmental compensation and periodic maintenance. User-related risks include poor installation and alarm neglect; therefore, simple instructions and routine testing are essential (NFPA, 2025; Nicholaus, 2026).

Table 6. Key risks and mitigation measures (adapted from Nicholaus, 2026).

Risk	Likely effect	Mitigation
Sensor drift	Reduced accuracy over time	Periodic recalibration and diagnostic reminders.
False alarms	Loss of user confidence	Filtering, threshold tuning and environmental compensation.
False negatives	Missed hazardous condition	Add sensor redundancy and test with known concentrations.
Power instability	Erratic readings or system failure	Stable adapter, voltage regulator and smoothing capacitors.
Poor installation	Reduced detection effectiveness	Clear placement instructions and user training.
Network failure if GSM/IoT is added	Remote alert not delivered	Maintain local buzzer/LED alarm as the primary safety response.

4.6 Scientific contribution

The contribution of this study is the development of a low-cost, locally maintainable and network-independent gas and smoke detector architecture for households and small-scale industrial users. The work demonstrates how low-cost embedded systems can be applied to safety engineering where commercial systems are financially inaccessible. The article also identifies the additional validation required before the prototype can be described as a certified detector, including calibrated concentration testing, long-term drift measurement and compliance assessment (IEC, 2020; ISO, 2023; Nicholaus, 2026).

5. Conclusion

This study designed and implemented a low-cost gas and smoke detector for domestic and small-scale industrial safety. The selected system uses an Arduino-class microcontroller, MQ-series sensor, LED indicators, piezoelectric buzzer, regulated power supply and optional display or remote communication interface. The local audio-visual architecture was selected as the core design because it offers low cost, simple maintenance and independence from external communication infrastructure. The prototype logic uses analog sensing, voltage conversion, moving-average filtering and threshold comparison to activate the alarm. Based on a threshold of 600 ADC counts, the corresponding voltage is approximately 2.93 V for a 5 V ADC reference. The estimated maximum current demand is about 210 mA, making a 5 V, 1 A adapter adequate for prototype operation. The system is promising for affordable safety awareness, but publication and deployment claims should be supported by calibrated response-time, recovery-time, false-alarm and long-term reliability data (Arduino, 2025; IEC, 2020; Nicholaus, 2026).

6. Recommendations and Future Work

Future development should include certified calibration using known LPG, methane, carbon monoxide and smoke concentrations; testing under different temperature and humidity conditions; integration of a dedicated photoelectric smoke sensor; addition of sensor redundancy to reduce false negatives; long-term drift testing; battery-life optimization; and comparison with commercial detectors. A complete journal submission should also include numerical performance results with mean response time, standard deviation, recovery time, false-alarm rate, sensor baseline drift and calibration curves (IEC, 2020; ISO, 2023; NFPA, 2025).

For community deployment, the system should be accompanied by user training on installation, routine testing, cleaning and alarm response. Where GSM or IoT modules are added, local alerts should remain active even if the communication module fails. These improvements would make the detector more robust, safer and more suitable for practical domestic and small-enterprise use (SIMCom Wireless Solutions, 2021; WHO, 2023).

Limitations

The current manuscript is based on a design project report and therefore contains mainly design calculations, prototype logic and qualitative implementation outcomes. Detailed numerical experimental results such as mean response time, standard deviation, false-alarm rate, recovery time and calibration curves must be inserted after controlled laboratory testing. The prototype should not be presented as a certified industrial gas or smoke detector until it has been evaluated against appropriate performance standards (IEC, 2020; ISO, 2023; Nicholaus, 2026).

Declarations

Ethics approval: Not applicable because the study involved prototype development and did not involve human participants or animal subjects.

Funding: The author state that no external funding was received.

Conflict of interest: The authors should declare whether they have any competing interests.

Data availability: Prototype design calculations and testing protocols are available from the corresponding author upon reasonable request. Numerical testing datasets should be attached as supplementary material when available.

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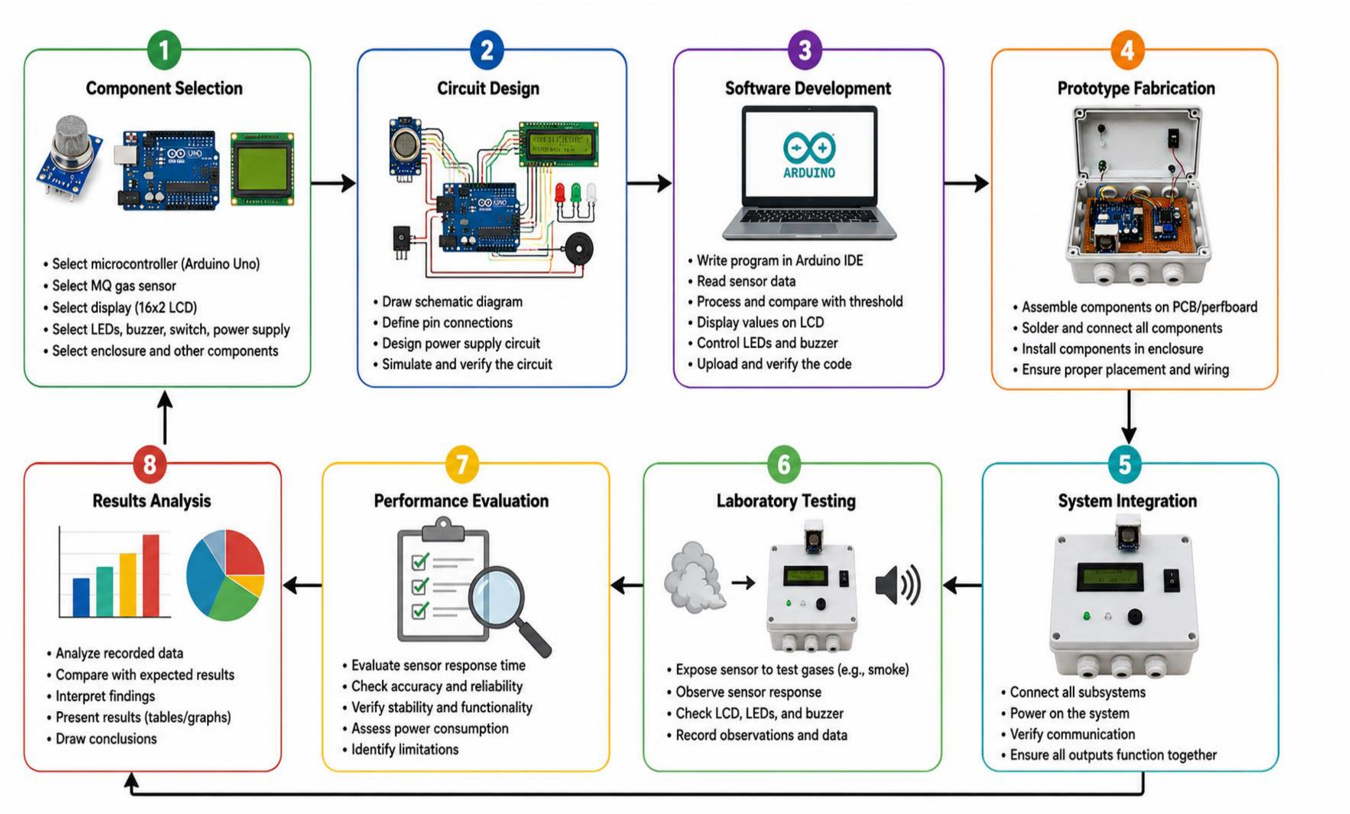
Appendices

Appendix one: program of Arduino

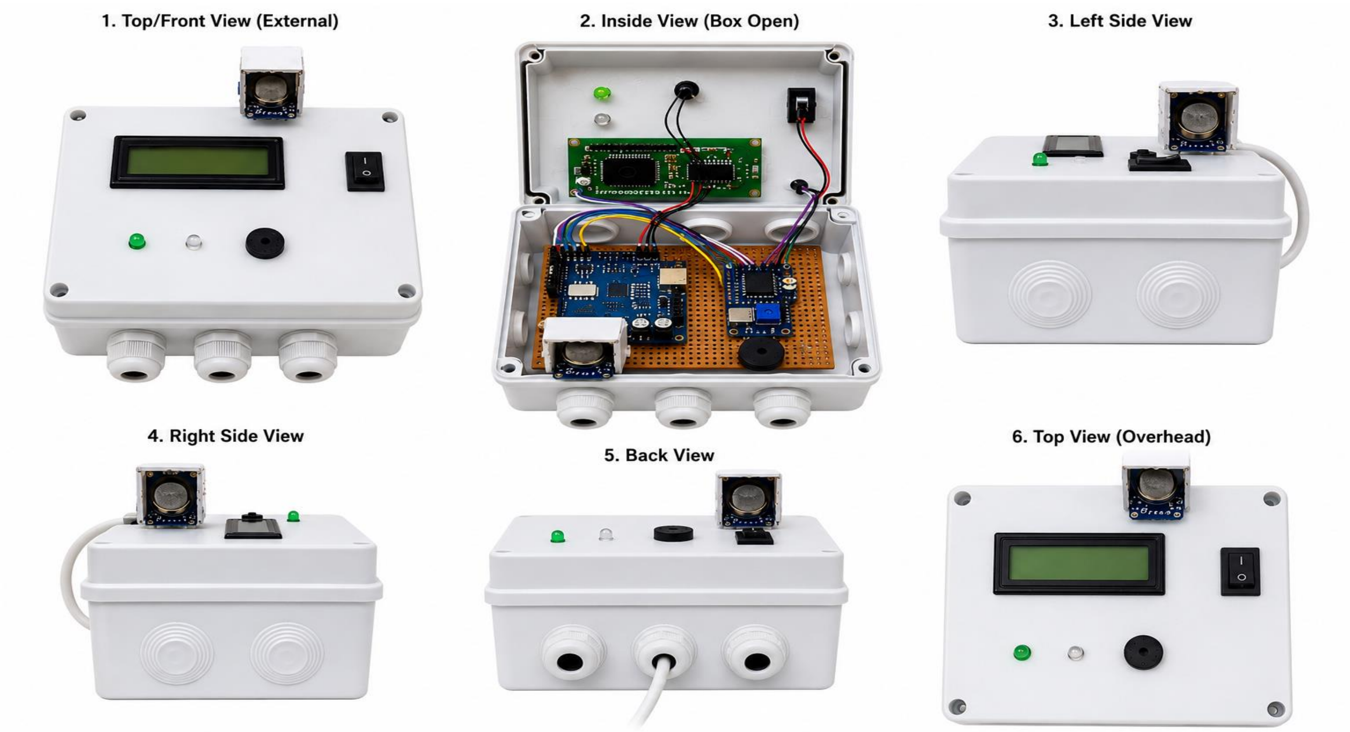
```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27, 16, 2);
// Pin connections
const int mqSensor = A0;
const int greenLED = 9;
const int whiteLED = 10;
const int buzzer = 8;
// Set gas threshold
const int gasThreshold = 400;
int gasValue = 0;
void setup() {
  pinMode(mqSensor, INPUT);
  pinMode(greenLED, OUTPUT);
```

```
  pinMode(whiteLED, OUTPUT);
  pinMode(buzzer, OUTPUT);
  lcd.init();
  lcd.backlight();
  lcd.setCursor(0, 0);
  lcd.print("Air Quality");
  lcd.setCursor(0, 1);
  lcd.print("Monitor Ready");
  delay(2000);
  lcd.clear();
}
void loop() {
  gasValue = analogRead(mqSensor);
  lcd.setCursor(0, 0);
  lcd.print("Gas Value:     ");
  lcd.setCursor(11, 0);
  lcd.print(gasValue);
  if (gasValue < gasThreshold) {
    digitalWrite(greenLED, HIGH);
    digitalWrite(whiteLED, LOW);
    digitalWrite(buzzer, LOW);
    lcd.setCursor(0, 1);
    lcd.print("Status: SAFE   ");
  }
  else {
    digitalWrite(greenLED, LOW);
    digitalWrite(whiteLED, HIGH);
    digitalWrite(buzzer, HIGH);
    lcd.setCursor(0, 1);
    lcd.print("Status: DANGER ");
  }
  delay(500);
}
```

Appendix Two: Study Flow Diagram



Appendix three: Images



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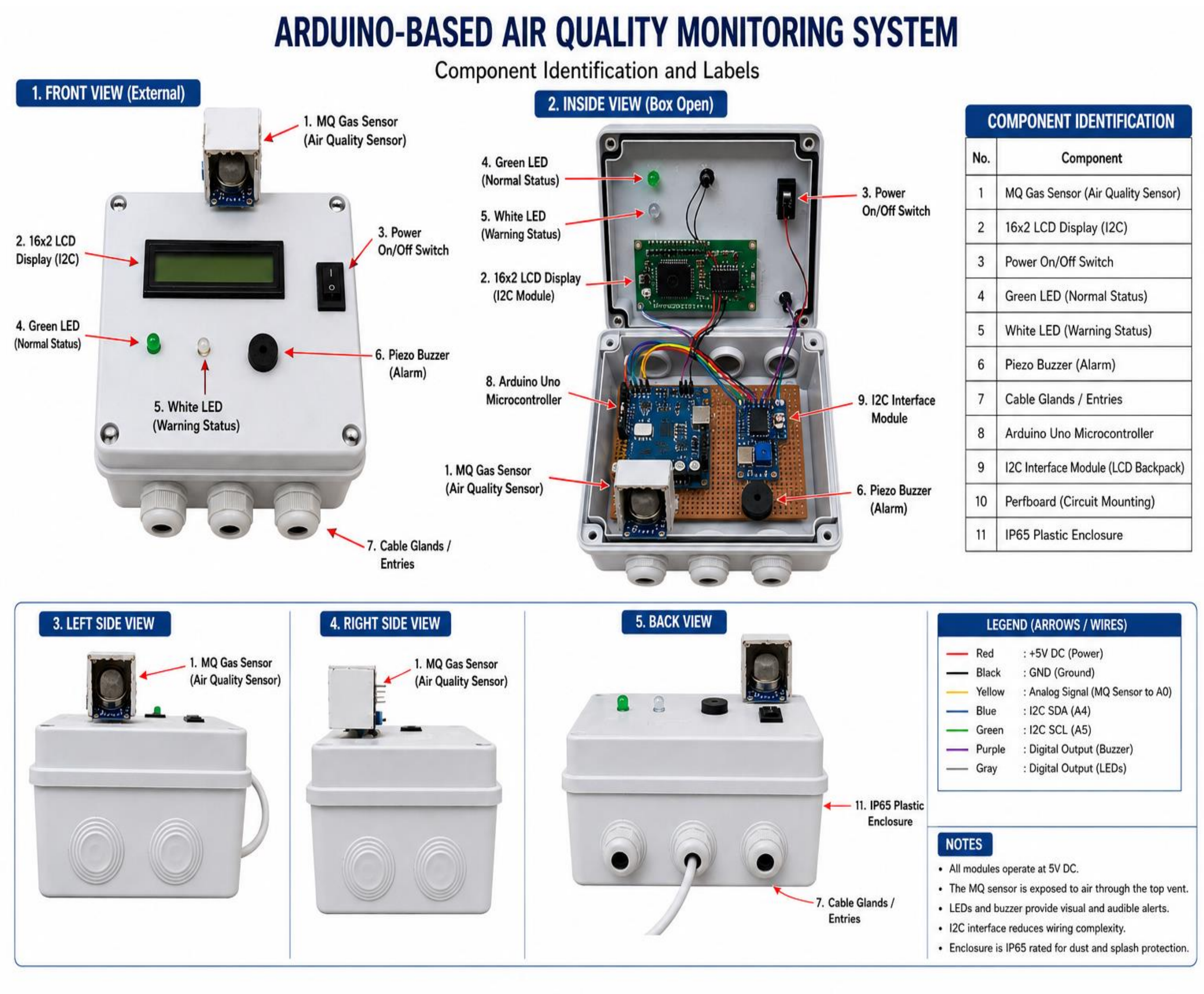
Appendix Four: Arduino Based Quality Monitoring System



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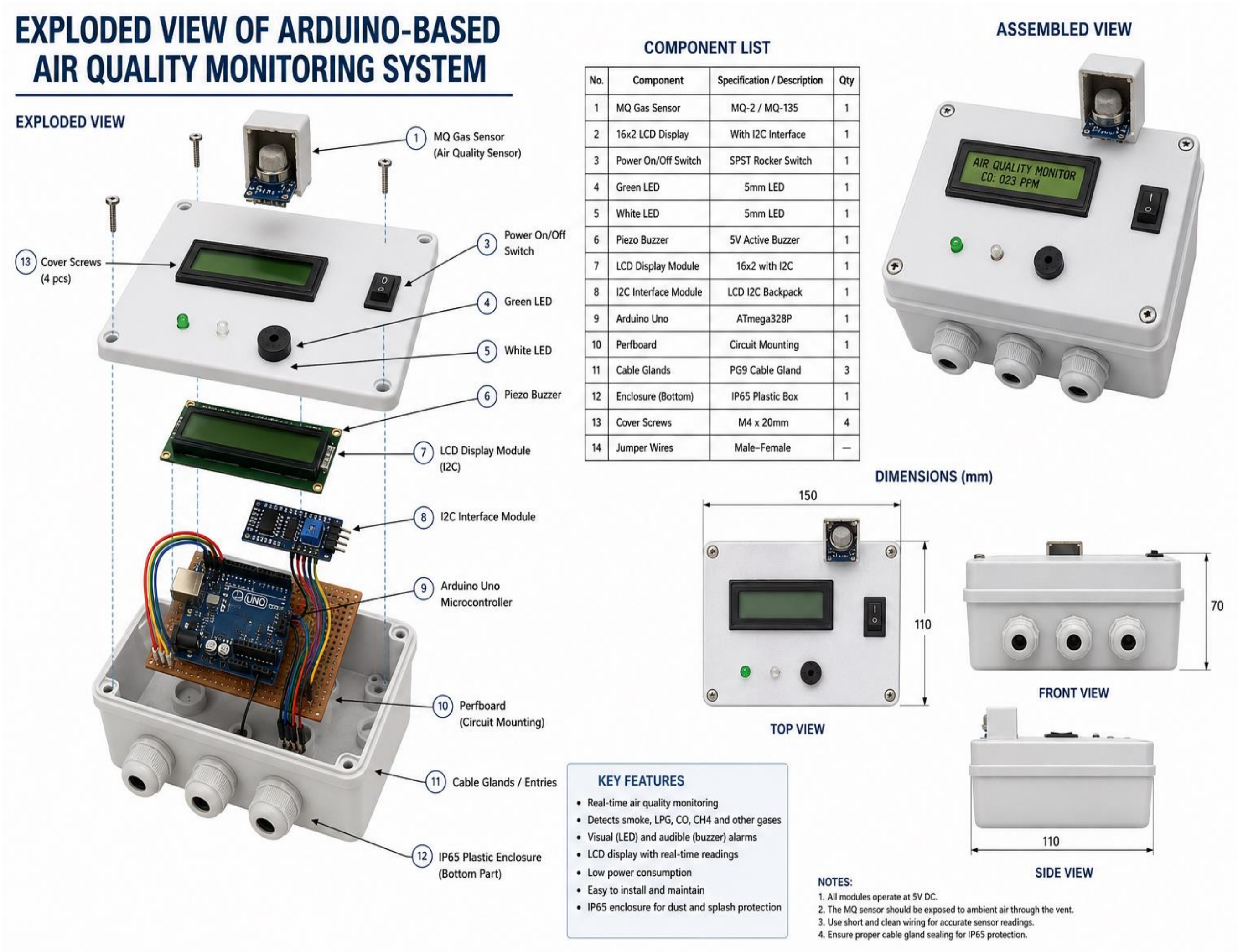
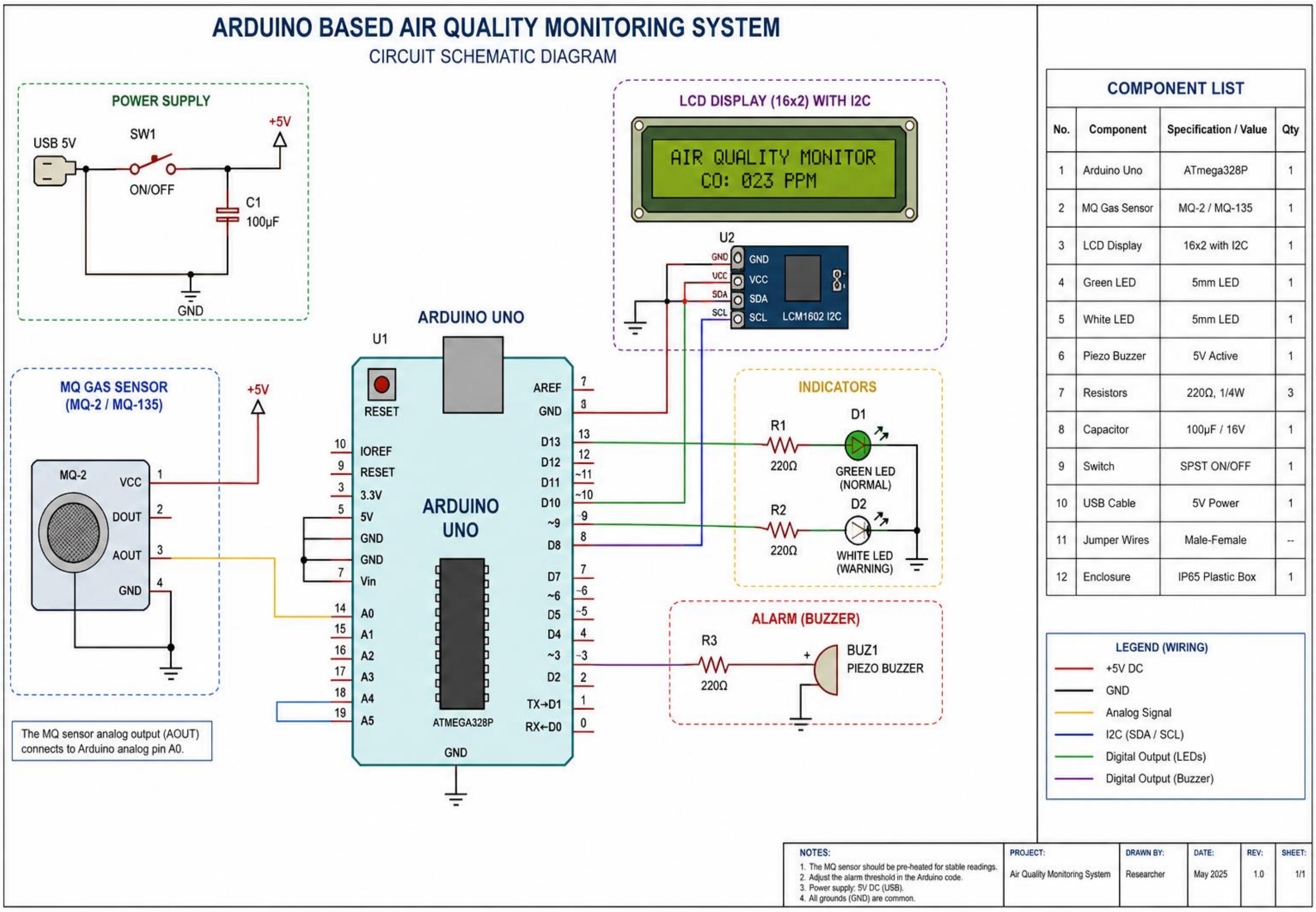
Appendix Five: Exploded-View Engineering Illustrations of The Device



Appendix Six: Circuit Schematic in Proteus or Fritzing Style



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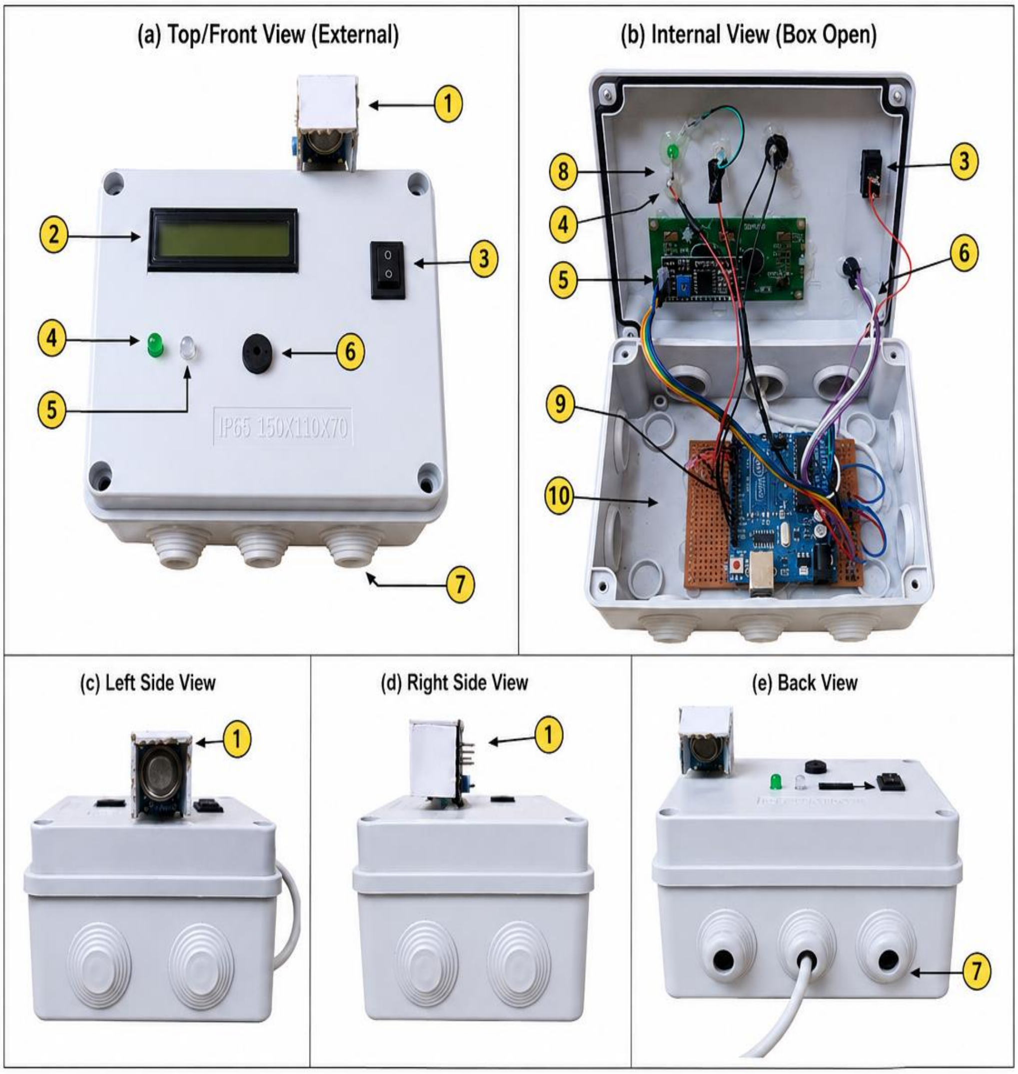
Appendix Seven: Arduino-based air quality prototype diagram



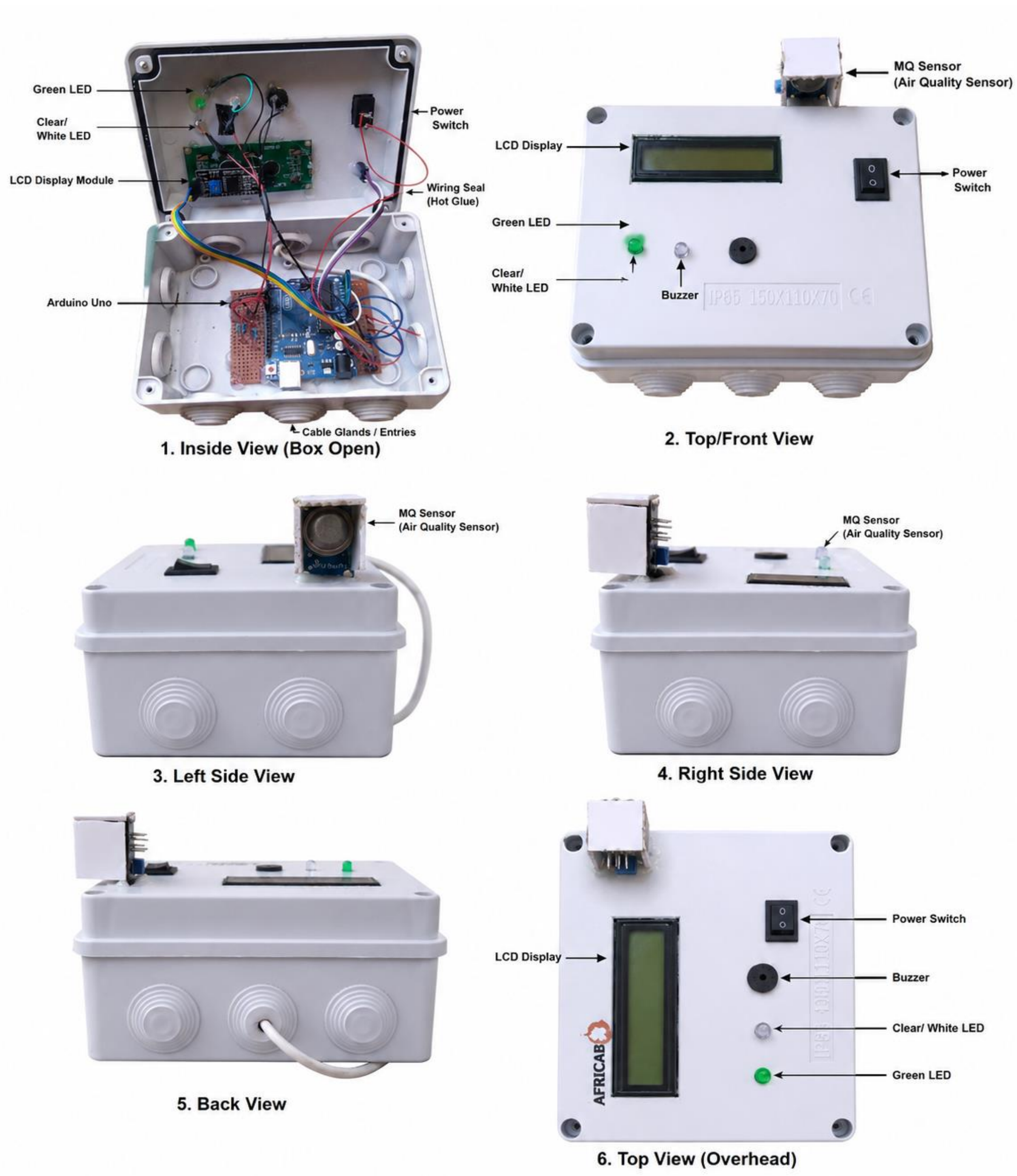
Component List

No.	Component
1	MQ Gas Sensor (Air Quality Sensor)
2	16×2 LCD Display (I2C)
3	Power On/Off Switch
4	Green LED (Normal Status)
5	White LED (Warning Status)
6	Piezo Buzzer (Alarm)
7	Cable Glands / Entries
8	LCD Display Module (I2C)
9	Arduino Uno Microcontroller
10	Perfboard (Circuit Mounting)

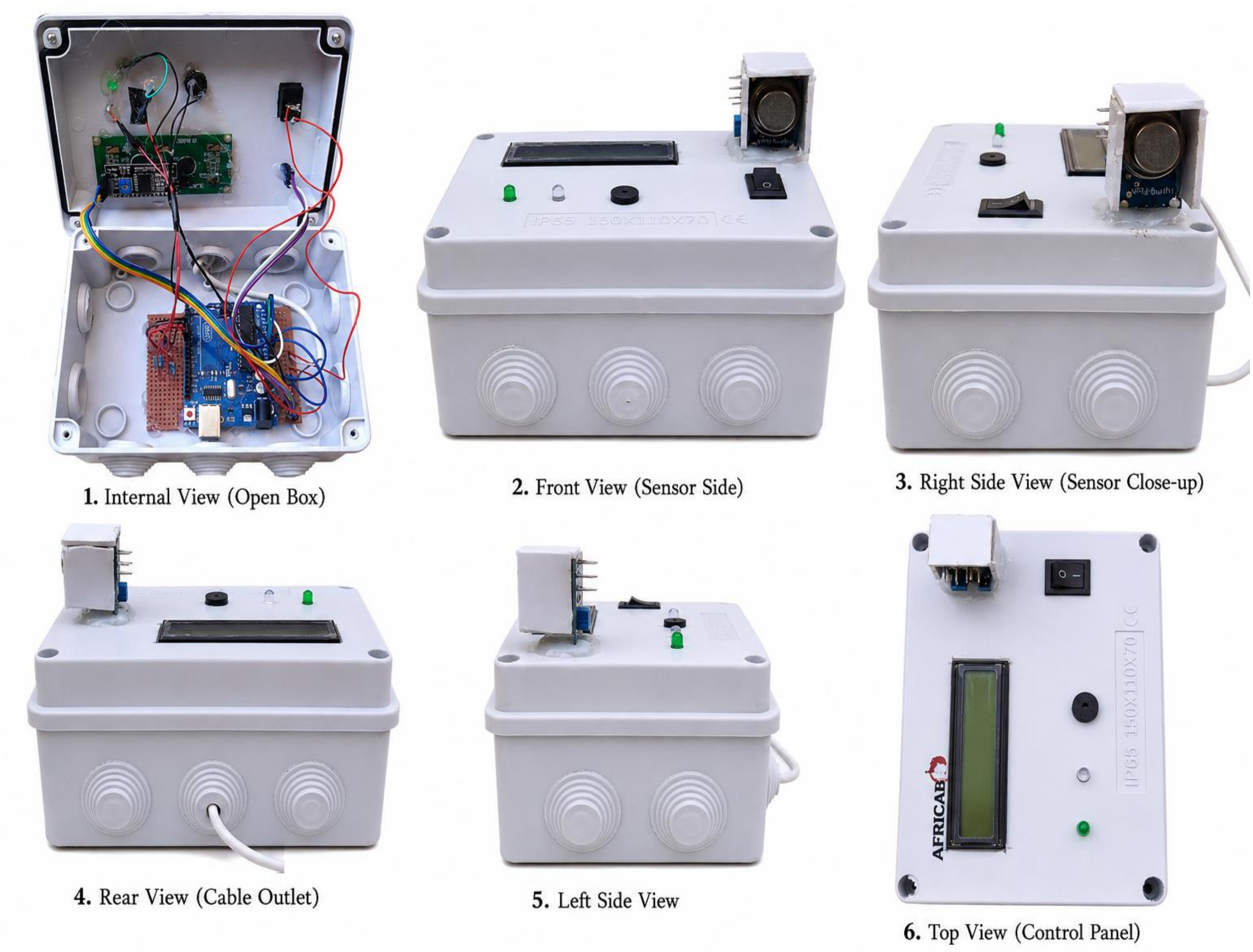
5 V DC
GND
Signal (Analog)
I2C (SDA / SCL)
Digital Output

Figure 1. Arduino-based air quality monitoring system. **(a)** Top/front view of the prototype (external), **(b)** internal hardware configuration, **(c)** left side view, **(d)** right side view, and **(e)** back view showing cable gland entries. The numbered callouts correspond to the list of components.

Appendix Eight: Air quality device technical diagram



Appendix Nine: DIY electronic enclosure product diagram



1. Internal View (Open Box)
2. Front View (Sensor Side)
3. Right Side View (Sensor Close-up)
4. Rear View (Cable Outlet)
5. Left Side View
6. Top View (Control Panel)

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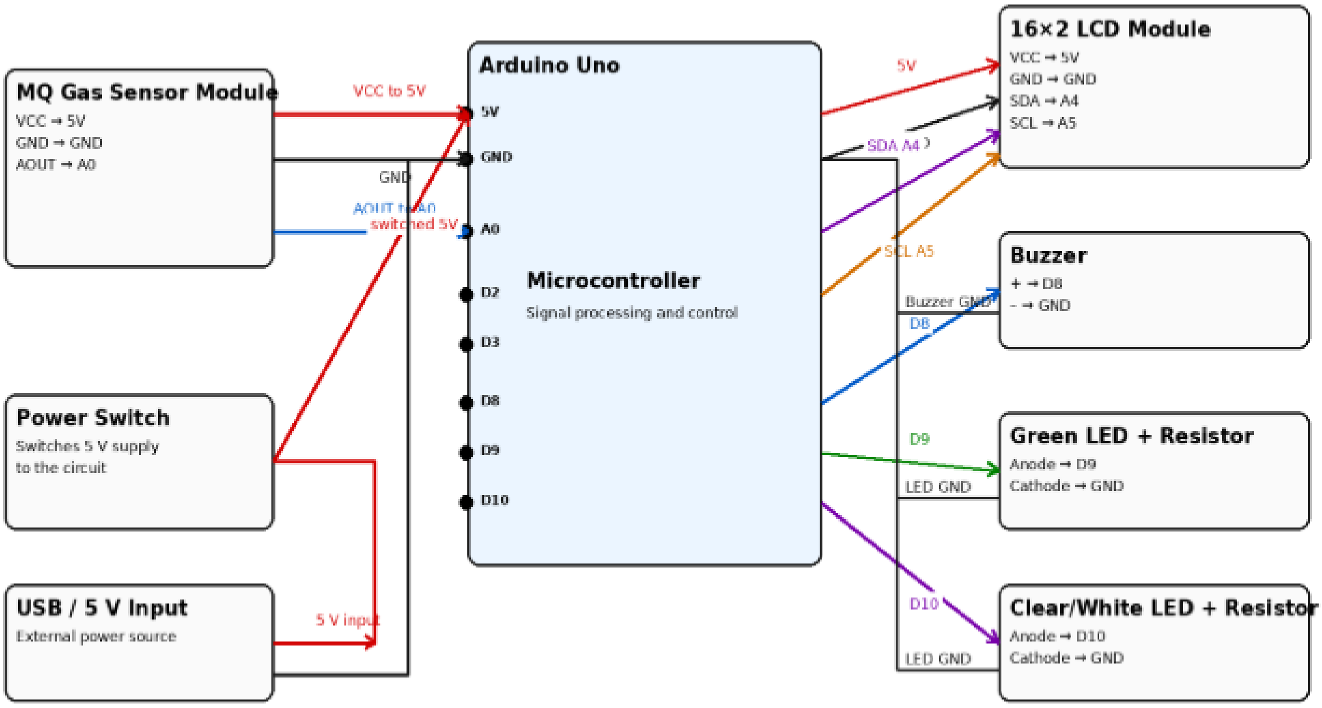
Appendix Ten: 2D Wiring Diagram of the Arduino – Based Air Quality Monitoring Circuit



Appendix Eleven: Block Diagram of Arduino Based Air Quality Monitoring System