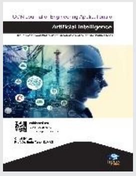

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IoT Based Gas Leakage Detection and Automatic Valve Control System with SMS Alert: Recommendation for Future Research

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Abstract
Liquefied Petroleum Gas (LPG) and methane are widely used in residential, commercial, and industrial environments due to their high calorific value, affordability, and availability. However, accidental gas leakage creates serious safety hazards such as fires, explosions, property damage, environmental pollution, and loss of life. The risk intensifies in enclosed spaces where combustible gases can quickly accumulate to explosive levels. Studies show that a significant number of domestic fire incidents and burn injuries are linked to gas leaks and cylinder-related accidents. This highlights the urgent need for intelligent systems that detect leaks early and automatically initiate preventive actions. This research presents the design, implementation, and evaluation of an IoT-Based Gas Leakage Detection and Automatic Valve Control System with SMS Alert using the ESP32 microcontroller. The system provides continuous monitoring of combustible gas concentrations and executes a rapid multi-level response during leakage events. It integrates an MQ-series gas sensor for detection, an ESP32 for processing and control, an LCD for real-time status display, a SIM900 GSM module for SMS alerts, a solenoid valve for automatic gas shut-off, and an exhaust fan for ventilation. The system works by continuously measuring ambient gas levels against a preset safety threshold. When the threshold is exceeded, the ESP32 immediately triggers several actions: an audible buzzer alarm for local warning, hazard information displayed on the LCD, automatic closure of the solenoid valve to stop gas flow, activation of the exhaust fan to disperse accumulated gas, and transmission of SMS alerts to registered users for prompt intervention. Performance testing under various conditions confirmed the prototype's effectiveness and reliability. The system consistently detected gas leaks, shut off the gas supply within seconds, activated ventilation to reduce gas concentration, and successfully delivered SMS notifications to users. The coordinated operation of sensing, automatic valve control, ventilation, and GSM communication reduced response time and lowered the risk of fire or explosion. The developed system offers a cost-effective and efficient solution for real-time gas leak monitoring and emergency response in homes, laboratories, restaurants, and small-scale industrial facilities. Unlike conventional detectors that only sound alarms, this design combines detection with automatic isolation of the gas source, active ventilation, and remote user notification through IoT. The ESP32 platform also allows future integration with smart-home networks for data logging and remote diagnostics.

Keywords: *Gas Leakage Detection, Internet of Things (IoT), ESP32 Microcontroller, Exhaust Fan Ventilation, SMS Alert System, Real-Time Monitoring.*

I. INTRODUCTION

Combustible gases such as Liquefied Petroleum Gas (LPG), methane, propane, and butane have become indispensable energy sources in residential, commercial, laboratory, and industrial environments owing to their high calorific value, ease of storage and transportation, clean combustion characteristics, and cost-effectiveness [1–3]. These gases play a critical role in domestic cooking, heating applications, industrial manufacturing processes, power generation, and scientific research activities. Despite their numerous benefits, the accidental leakage of combustible gases remains a major safety concern worldwide [4–5].

Gas leakage incidents frequently result from defective regulators, deteriorated pipelines, poor installation practices, equipment malfunction, inadequate maintenance, and human negligence [6,7]. When released into enclosed or poorly ventilated environments, combustible gases may accumulate rapidly and form explosive mixtures with air. Upon exposure to ignition sources such as electrical sparks, open flames, static discharge, or hot surfaces, catastrophic fire outbreaks and explosions may occur [8,9]. Such incidents often lead to severe injuries, fatalities, environmental contamination, destruction of property, disruption of operations, and significant economic losses [10].

Several studies and safety reports have identified gas leakage as one of the leading causes of domestic and industrial fire disasters [11,12]. The increasing adoption of LPG cylinders in homes, restaurants, laboratories, and commercial establishments has further heightened the need for reliable gas monitoring and safety management systems [13]. Conventional safety measures largely depend on periodic inspection, human vigilance, or standalone alarm devices that often provide limited protection, particularly during unattended operation [14].

Recent advancements in embedded systems, wireless communication technologies, Internet of Things (IoT) platforms, and intelligent automation have created new opportunities for the development of smart gas safety systems [15–17]. These technologies enable continuous environmental monitoring, real-time hazard detection, automatic initiation of safety measures, remote communication, and cloud-based supervision [18,19]. Consequently, the development of intelligent gas leakage detection and mitigation systems has become an important area of research aimed at enhancing public safety, reducing accident rates, and minimizing the consequences of gas-related incidents [20].

1.2. Background of the study

Liquefied petroleum gas (LPG) and methane serve as primary energy sources in residential, commercial, and industrial settings due to their high calorific value and cost-effectiveness. However, accidental gas leakage presents catastrophic risks including fires, explosions, and severe burn injuries, particularly in confined indoor environments. Clinical studies indicate that a substantial proportion of LPG-related burn incidents occur in domestic settings, with gas leaks and cylinder explosions identified as primary triggers [1]– [3]. Regulatory accident statistics reveal that leakage-only events constitute the majority of LPG-related incidents, with significant escalation to fires or explosions when ignition sources are present [4], [5].

These findings underscore the critical need for early detection systems capable of providing timely warnings and automated mitigation responses. The convergence of Internet of Things (IoT) technologies, low-cost sensors, and embedded intelligence has created opportunities for developing sophisticated yet affordable safety monitoring solutions suitable for widespread deployment.

Most commercial gas detectors and academic prototypes employ simple threshold-based activation using semiconductor sensors such as the MQ-series. These systems trigger alarms when measured gas concentration exceeds a predefined threshold. While computationally inexpensive, this approach exhibits critical limitations:

i. High false-alarm rates in dynamic indoor environments where cooking fumes, cleaning agents, or transient ventilation changes temporarily disturb sensor readings [6], [7].
ii. Lack of context-awareness, preventing differentiation between mild, slowly increasing leaks and rapidly escalating high-risk events.
iii. Binary decision behavior classifying environments solely as 'safe' or 'dangerous' without intermediate severity levels enabling graded responses.
iv. Limited mitigation capability, with most designs focusing exclusively on local audible/visual alarms without integrating intelligent actuator control.

These constraints reduce user trust, encourage alarm bypassing, and ultimately compromise long-term safety effectiveness.

IoT-based safety systems enable continuous sensing, remote monitoring, and automated actuation through microcontrollers, wireless modules, and cloud platforms [6]. Embedded artificial intelligence (AI) enhances decision-making capabilities while maintaining low hardware costs and modest computational requirements. Rather than relying on data-intensive machine learning models, safety-critical applications successfully employ rule-based expert systems and fuzzy logic controllers to encode domain knowledge and handle sensor uncertainty [8]–[13]. These lightweight AI techniques prove particularly suitable for resource-constrained microcontrollers, supporting real-time operation, interpretable decision rules, and incremental design without requiring large training datasets or high-end processors.

Traditional MQ-based gas detectors apply fixed thresholds to sensor outputs, triggering alarms when thresholds are exceeded [6], [7], [14]. While detecting gas presence, these systems cannot distinguish leak severity levels, ignore concentration rate-of-change (crucial for identifying rapidly developing hazards), and operate as binary detectors lacking adaptive behavior. This results in either over-sensitive or under-sensitive responses, necessitating a low-cost, microcontroller-based solution augmented with intelligent decision logic for graded risk assessment and automated mitigation.

II. THEORETICAL FRAMEWORK

The theoretical foundation of the proposed system is based on the integration of gas sensing technology, embedded systems engineering, automatic control systems, wireless communication, and Internet of Things (IoT) technologies [21–22]. The developed system operates as a cyber-physical safety system in which environmental conditions are continuously monitored, analyzed, and acted upon through automated decision-making and control mechanisms [23].

The sensing subsystem serves as the primary interface between the physical environment and the digital control system. The MQ-2 gas sensor continuously measures combustible gas concentrations and converts them into corresponding electrical signals [24]. These signals are subsequently processed by the ESP32 microcontroller, which functions as the central processing and decision-making unit of the system [25]. The operational philosophy of the proposed system is based on the principles of closed-loop feedback control. In this framework, sensor measurements provide continuous feedback regarding environmental conditions. The controller compares the measured gas concentration with predefined safety thresholds and determines the appropriate operational response [26]. When hazardous conditions are detected, the controller automatically initiates corrective actions such as alarm activation, gas supply isolation, exhaust ventilation, and emergency communication [27]. The communication subsystem facilitates information exchange between the developed system and external users. GSM technology provides remote emergency notification through SMS transmission, while IoT connectivity enables cloud-based monitoring and remote supervision [28–29]. This communication capability significantly enhances user awareness and emergency response effectiveness.

The actuation subsystem comprises the solenoid valve, exhaust fan, buzzer, and display interface. These components implement the physical safety actions required to mitigate hazards and communicate system status to users [30]. The coordinated interaction between sensing, processing, communication, and actuation subsystems forms the basis of the proposed intelligent gas safety architecture. Consequently, the developed system represents an integrated cyber-physical safety framework that combines real-time monitoring, intelligent decision-making, automated hazard mitigation, and remote communication to improve operational safety and reduce the risks associated with combustible gas leakage [31].

III. LITERATURE REVIEW

Several gas leakage detection and monitoring systems have been developed using MQ-series gas sensors, embedded microcontrollers, GSM communication modules, and IoT technologies for domestic and industrial safety applications. Existing studies have demonstrated the importance of early gas-leak detection, remote alert generation, and automatic safety response in reducing the risk of fire outbreaks, explosions, and toxic-gas exposure [1]–[18]. However, despite these developments, many reported systems remain limited by inadequate sensor calibration, poor false-alarm mitigation capability, absence of intelligent adaptive control, limited statistical validation, weak reliability analysis, and insufficient embedded-system performance evaluation.

Furthermore, most existing systems primarily focus on basic alarm activation and notification functions without incorporating advanced engineering features such as intelligent decision-making, fuzzy-logic enhancement, power-consumption optimization, response-time characterization, uncertainty analysis, and comprehensive experimental validation. Some systems also lack automatic gas-isolation capability and real-time IoT-based monitoring under varying environmental conditions. [3]

In view of these limitations, the proposed work aims to develop a more robust IoT-based gas leakage detection and automatic valve control system using ESP32 embedded intelligence integrated with intelligent control logic, advanced calibration modelling, statistical validation, automatic safety actuation, and enhanced operational reliability. Table 2.1 presents a comparative review of selected existing gas-leakage detection systems and highlights their major limitations relative to the proposed system. [16].

Table 3.1: Comparative Literature Review of Existing Gas-Leakage Detection Systems [1]–[20]

Serial	Author/Source	Sensor	Controller/Platform	IoT/Alert	Automatic Valve	Main Limitation
1	Rajitha and Swapna [1]	Gas sensor	GSM-based system	GSM alert	No	Limited intelligence and no adaptive response
2	Mahalingam *et al.* [2]	Gas sensor	Embedded detector	Local alarm	No	Limited experimental validation
3	Shrivastava *et al.* [3]	Gas sensor	Arduino/GSM	SMS alert	No	No automatic mitigation mechanism

4	Jumaa and Al-Azzawi [4]	MQ-2	ESP8266 NodeMCU	Blynk/ThingSpeak	No	No automatic valve shutdown
5	Jena *et al.* [5]	LPG sensor	IoT prototype	GSM alert	No	Limited intelligent control
6	Munirathinam *et al.* [6]	Gas sensor	Arduino	GSM alert	Limited	Weak statistical validation
7	Parashar *et al.* [7]	MQ-6	Arduino/ESP8266	IoT display	Yes	Lack of adaptive decision-making
8	Hossain *et al.* [8]	MQ-series	IoT platform	Remote alert	No	Limited false-alarm analysis
9	Raut *et al.* [9]	MQ sensor	IoT system	IoT alert	No	Limited automatic safety actuation
10	Dimeze [10]	MQ-6	Arduino	Alert system	No	No uncertainty analysis
11	Lopez *et al.* [11]	MQ-2	ESP8266 NodeMCU	Blynk app	No	Fixed-threshold operation
12	Patil *et al.* [12]	MQ-2	Arduino	Local alert	Yes	Limited IoT analytics
13	IARJSET study [13]	MQ-6	Arduino	Buzzer alert	Yes	No cloud-based monitoring
Serial	Author/Source	Sensor	Controller/Platform	IoT/Alert	Automatic Valve	Main Limitation
14	SUSTech project [14]	Gas/flame sensors	Arduino	SMS alert	Yes	Limited intelligent control
15	University of Ibadan study [15]	MQ-2	ESP8266 NodeMCU	IoT/Blynk	No	No automatic gas isolation
16	Venkatesh *et al.* [16]	Gas sensor	IoT prototype	Alert system	No	Prototype-level validation only
17	Smart Gas Leak Detector study [17]	MQ-2	Embedded controller	Optional GSM/Wi-Fi	Yes	Limited engineering analysis
18	Kitchen safety study [18]	Gas sensor	Arduino Uno R3	Alarm	Yes	Limited IoT integration
19	Hanwei Electronics [19]	MQ-2	Sensor datasheet	Not applicable	Not applicable	Sensor-only characterization
20	Proposed Work	MQ-2	ESP32 with intelligent logic	GSM/IoT	Yes	Enhanced validation and intelligent adaptive control

Several researchers have developed gas leakage detection systems with varying levels of intelligence, connectivity, and mitigation capabilities. Table 2.1 presents a comparative analysis of 20 existing systems alongside the proposed work, highlighting key differences in sensor choice, controller platform, alerting mechanism, and automatic valve integration. [1]–[18]

These are discussed below:

i. Evolution of Controller Platforms and Sensor Integration: Early systems primarily relied on basic embedded detectors or GSM-based platforms with generic gas sensors, as seen in Rajitha and Swapna and Mahalingam et al. These designs provided only local alarms or SMS alerts without remote monitoring or automatic control. Subsequent studies adopted Arduino microcontrollers combined with MQ-series sensors due to their low cost and ease of use. More recent works shifted to Wi-Fi enabled platforms like ESP8266 NodeMCU to introduce IoT capabilities via Blynk or ThingSpeak. However, most ESP8266-based systems lacked automatic valve shut-off, limiting them to detection and notification only [1-4][6][10-15][18].

ii. Gaps in Alerting and IoT Integration: While SMS/GSM alerts are common, they often operate in isolation without IoT dashboards for real-time data visualization. Systems that incorporated IoT platforms generally used fixed-threshold logic and did not integrate dual-mode alerting. Studies such as implemented automatic valves but had "Limited IoT integration" or "No cloud-based monitoring," meaning users could not track system status remotely. This creates a critical gap when users are away from the premises — the exact problem your system targets. [1-6][7-9][11-15][18]

iii. Lack of Intelligent and Adaptive Control: A recurring limitation across the literature is “Limited intelligence and no adaptive response” or “Lack of adaptive decision-making”. Many systems employ fixed-threshold operation, which increases false alarms and fails to analyze gas concentration trends. Even when automatic valves were present, they were triggered by simple threshold crossings without intelligent logic, and several had “Limited intelligent control” or “No uncertainty analysis”. Furthermore, false-alarm analysis was rarely addressed, reducing reliability for domestic deployment. [1][5][14][7][11-13][17][18][10][8]
iv. Automatic Mitigation as a Key Differentiator: Table 2.1 shows that 11 out of 19 reviewed systems had no automatic valve [1–5, 8–11, 15, 16], relying solely on human intervention after an alert. Among the 8 systems with valves, limitations persisted: “Limited” valve control, “No automatic gas isolation”, or “Limited automatic safety actuation”. The SUSTech project and Kitchen safety study included valves but were constrained by Arduino platforms with limited processing power and no intelligent IoT analytics.[6][9][14][15][18].

3.2. Research Gap

Numerous gas leakage detection systems have been reported in the literature employing gas sensors, microcontrollers, GSM communication modules, and IoT technologies for domestic and industrial safety applications [32–35]. While these systems have contributed significantly to improving early gas leak detection and emergency notification, several technical and operational limitations remain evident. A major limitation observed in many existing systems is the reliance on alarm-only architectures that provide warning notifications without incorporating automatic hazard mitigation mechanisms [36,37]. In such systems, gas leakage may continue even after detection, thereby increasing the risk of gas accumulation, fire outbreaks, and explosions. Furthermore, many reported systems lack automatic gas isolation capability and integrated ventilation control, which are essential for effective emergency response [38].

Another significant limitation is the absence of comprehensive remote monitoring functionality. Although some systems employ GSM communication for SMS alerts, many do not provide IoT-based cloud monitoring, data logging, or remote visualization capabilities [39,40]. This restricts situational awareness and limits the ability of users to remotely supervise system operation. In addition, most existing systems employ fixed-threshold decision-making approaches that provide only binary responses [41]. Such approaches do not distinguish between varying levels of hazard severity and are often susceptible to false alarms caused by environmental disturbances [42]. The lack of adaptive response mechanisms can adversely affect operational reliability and user confidence.

Furthermore, many reported studies provide limited engineering validation and fail to evaluate critical performance indicators such as detection accuracy, false alarm rate, communication latency, response time, power consumption, battery endurance, and long-term reliability [43–45]. Consequently, the practical effectiveness and deployment readiness of many existing systems remain uncertain. Therefore, there exists a need for a low-cost, intelligent, and highly reliable gas leakage detection and mitigation system capable of integrating automatic gas isolation, ventilation control, GSM communication, IoT-based monitoring, and comprehensive engineering performance evaluation within a unified embedded platform [46].

3.3. Advanced System Modelling and Mathematical Formulation

3.3.1. MQ-2 Sensor Calibration Model

The MQ-2 gas sensor exhibits nonlinear semiconductor sensing characteristics in which the sensor resistance varies with combustible-gas concentration. The sensing mechanism is based on tin dioxide (SnO_2) semiconductor technology, which is widely utilized in combustible-gas sensing applications because of its high sensitivity to LPG, methane, hydrogen and smoke [6], [7]. In practical applications, accurate gas-concentration estimation requires proper experimental calibration of the sensor under controlled environmental conditions. Consequently, the sensor should be characterized using known LPG concentration levels to establish a reliable relationship between gas concentration and sensor output voltage. The sensor transfer function can be represented using a power-law regression model as:

$$V_{out} = aC^b \qquad (3.1)$$

where: V_{out} is the sensor output voltage, C is the gas concentration in parts per million (ppm), and a and $b$are experimentally determined calibration constants. [6]–[7].
To enable linear regression analysis and calibration-curve generation, logarithmic transformation of the model is performed as:

$$\log(V_{out}) = \log(a) + b\log(C) \qquad (3.2)$$

This formulation enables least-squares regression calibration, extraction of calibration coefficients, sensitivity estimation, and quantitative assessment of sensor linearity characteristics. Additional statistical parameters such as Root Mean Square Error (RMSE), standard deviation, sensitivity coefficient, and coefficient of determination (R^2) should also be computed to improve calibration reliability and engineering accuracy. [6],[7].

3.3.2. ADC Conversion Model

The ESP32 microcontroller converts the analogue sensor voltage into digital form using its internal Analog-to-Digital Converter (ADC). The ADC conversion relationship is expressed as:

$$ADC = \frac{V_{out}}{V_{ref}}(2^n - 1) \qquad (3.3)$$

where: ADC is the digital sensor value, V_{out} is the analog sensor output voltage, V_{ref} is the ADC reference voltage and n is the ADC resolution in bits. This conversion process enables digital processing, threshold analysis, and intelligent decision-making within the ESP32 embedded controller. [6],[7].

3.3.3. Dynamic Response Model

The transient response of the gas sensor can be approximated using a first-order dynamic system model commonly used in sensor-response analysis [8], [9]. The dynamic-response equation is expressed as:

$$\tau \frac{dy(t)}{dt} + y(t) = Ku(t) \qquad (3.4)$$

where: τ is the sensor time constant, K is the sensor gain, $u(t)$ is the gas-concentration input, and $y(t)$ is the sensor output response. The dynamic-response model enables evaluation of sensor response time, recovery characteristics, transient behaviour, and overall sensing performance under varying gas-concentration conditions.

3.3.4. Advanced Closed-Loop Control-System Modelling

The proposed gas-leakage mitigation architecture is modelled as an intelligent closed-loop embedded safety-control system incorporating sensing, signal processing, decision-making, actuation, communication, and feedback mechanisms consistent with modern mechatronic and industrial safety-control architectures [8], [9]. The closed-loop configuration enables continuous real-time monitoring of combustible-gas concentration, automatic safety evaluation, and adaptive execution of hazard-mitigation actions whenever unsafe operating conditions are detected.

In the proposed architecture, the MQ-2 gas sensor continuously measures the surrounding gas concentration and transmits the corresponding analog signal to the ESP32 embedded controller through the Analog-to-Digital Converter (ADC) interface. The controller processes the sensor data, compares the measured concentration with the predefined safety threshold, and automatically determines the appropriate safety response based on the operating condition. This continuous feedback process enables intelligent real-time system supervision and rapid emergency response. [6]–[12]

The control error governing system operation is defined as:

$$e(t) = C_{threshold} - C_{measured} \qquad (3.5)$$

where:$e(t)$ is the control error, $C_{threshold}$ is the predefined safe gas-concentration threshold, and $C_{measured}$is the measured gas concentration. The control objective is to maintain safe environmental operating conditions by ensuring that the measured gas concentration remains below the specified safety threshold. The system continuously evaluates the gas concentration condition expressed as:

$$C_{measured} > C_{threshold} \qquad (3.6)$$

When the measured gas concentration exceeds the allowable safety limit, the embedded controller automatically initiates emergency hazard-mitigation procedures to minimize the risk of fire outbreak, explosion, or toxic exposure. The emergency-response actions include automatic shutdown of the gas supply through solenoid-valve actuation, activation of audible buzzer alarms, activation of the exhaust ventilation system, and transmission of GSM-based emergency alerts to designated users. The proposed closed-loop control architecture therefore provides continuous environmental monitoring, intelligent hazard detection, rapid emergency response, and automated safety enforcement. Compared with conventional alarm-only systems, the proposed framework significantly improves operational reliability, response speed, false-alarm mitigation capability, and overall safety performance for domestic and industrial gas-monitoring applications. [6]–[18].

3.3.5. Fuzzy-Logic Enhancement

To improve system intelligence, adaptive decision-making capability, and false-alarm mitigation, a fuzzy-logic controller can be incorporated into the proposed gas-leakage detection and safety-control architecture. Fuzzy-logic control techniques are widely used in intelligent embedded systems and nonlinear decision environments because of their ability to handle uncertainty, noisy sensor measurements, and imprecise environmental conditions more effectively than conventional threshold-based systems [10], [11]. In conventional gas-leakage detection systems, alarm activation is typically based on fixed threshold values, which may lead to excessive false alarms or delayed safety response under fluctuating environmental conditions. The proposed fuzzy-logic enhancement addresses this limitation by enabling intelligent interpretation of multiple sensor and environmental parameters simultaneously. This improves decision accuracy, operational reliability, and adaptive safety response.

The proposed fuzzy-logic controller utilizes multiple input variables representing both environmental conditions and sensor-confidence characteristics. The selected fuzzy-controller inputs include gas concentration, rate of gas-concentration increase, ambient temperature, and sensor confidence level. These input variables are processed through a fuzzy-inference mechanism to determine the appropriate emergency-response action based on the severity and reliability of the detected gas-leakage condition. The fuzzy-controller outputs include alarm intensity, ventilation-fan operating speed and valve-shutdown priority.

3.3.6. Gas Leakage Risk Classification Framework

To improve operational safety and enhance decision-making capability, the proposed system adopts a multi-level gas leakage risk classification framework [47–48]. Unlike conventional systems that rely on simple binary threshold decisions, the framework categorizes environmental conditions into distinct risk levels based on gas concentration and associated hazard severity. The risk classification framework shown in Table 2.3 enables the system to implement graduated response actions that correspond to the severity of the detected condition. This approach improves operational flexibility, reduces unnecessary emergency interventions, and enhances overall system reliability [49].

Gas Leakage Risk Classification Framework

Gas Concentration Level	Risk State	System Response
Low	Safe.	Continuous monitoring and normal operation.
Moderate	Warning.	Visual warning indication and increased monitoring.
High	Danger.	Audible alarm activation and warning display.
Very High	Critical.	Automatic valve shutdown, exhaust fan activation, SMS transmission, and emergency notification.

The adoption of this risk classification framework enables adaptive hazard management and provides a more intelligent and effective approach to gas safety compared with conventional threshold-based systems [50].

3.4. Advanced Experimental Validation Framework

3.4.1 Sensor Calibration Experiment

To ensure accurate gas-concentration measurement and reliable system performance, the MQ-2 gas sensor should be experimentally calibrated using controlled LPG concentration levels in accordance with standard gas-sensor characterization procedures recommended in modern sensor-engineering literature [6], [12]. Proper sensor calibration is essential for improving measurement accuracy, minimizing uncertainty, enhancing repeatability, and establishing a reliable relationship between gas concentration and sensor output. The sensor calibration procedure should involve the following stages:

i. Introduction of known LPG concentration levels into the sensing environment.
ii. Measurement and recording of corresponding ADC output values from the ESP32 controller.
iii. Plotting of gas concentration (ppm)against ADC output values.
iv. Generation of the sensor calibration curve.
v. Determination of the regression equation and calibration constants.
vi. Computation of Root Mean Square Error (RMSE) and calibration uncertainty.
vii. Evaluation of repeatability and hysteresis characteristics.
viii. Determination of sensor response and recovery time.

The calibration process enables quantitative assessment of sensor linearity, sensitivity, stability, and measurement reliability under varying operating conditions.

3.4.2 False Alarm Analysis

To evaluate the robustness and selectivity of the proposed system, false-alarm analysis should be conducted under different environmental interference conditions. The system should be experimentally tested against common substances capable of producing sensor disturbances or misleading gas signatures, including perfume vapor, smoke, alcohol vapor, cooking fumes and dust particles [6], [12]. The False Alarm Rate (FAR) is expressed as:

$$FAR = \frac{N_f}{N_t} \times 100 \quad (3.7)$$

where: N_f is the number of false detections and N_t is the total number of experimental tests conducted. The false-alarm analysis enables evaluation of system robustness, noise immunity, environmental tolerance, and overall operational reliability.

3.4.3 Reliability Analysis

System reliability should be evaluated using exponential reliability modelling commonly employed in engineering-system reliability analysis [13]. The reliability function is expressed as:

$$R(t) = e^{-\lambda t} \quad (3.8)$$

Where: $R(t)$ is the system reliability, λnis the failure rate and $t$is the operating time. The reliability analysis provides quantitative assessment of long-term operational stability, fault tolerance, and expected system survivability under continuous operation.

3.4.4 Response-Time Analysis

The response-time characteristics of the proposed system should be experimentally evaluated to determine the speed and effectiveness of hazard detection and emergency response. The average system response time is expressed as:

$$T_{avg} = \frac{1}{N}\sum_{i=1}^{N} T_i \quad (3.9)$$

where: T_{avg} is the average response time, T_i is the individual measured response time and N is the total number of experimental measurements. The standard deviation of the response time is given as:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(T_i - T_{avg})^2} \quad (3.10)$$

where: σ is the standard deviation of the response time. The response-time analysis enables evaluation of system responsiveness, timing stability, detection consistency, and real-time operational capability. [7], [9].

3.4.5 Advanced Performance Evaluation Metrics

To comprehensively assess the effectiveness, robustness, responsiveness and practical deployment capability of the proposed IoT-based gas leakage detection and automatic valve control system, several quantitative performance metrics should be evaluated during experimental validation. These metrics provide objective measures of sensing accuracy, communication performance, energy efficiency, reliability, and overall embedded-system operational capability.

3.4.6 Power-Consumption Analysis

Power-consumption analysis is essential for evaluating the energy efficiency, operational sustainability, and backup-power capability of the proposed IoT-based gas leakage detection and automatic valve control system. Since the system is intended for continuous real-time monitoring and emergency-response operation, it is important to assess the power requirements of the embedded controller, sensing modules, communication units, alarm devices, and actuator subsystems. The total system power consumption is expressed as:

$$P = VI \quad (3.11)$$

where: P is the total system power consumption, V is the supply voltage and I is the total system current.

The total energy consumption of the system during operation is given as:

$$E = Pt \quad (3.12)$$

where: E is the total energy consumption, P is the system power and $t$is the operating time. To evaluate backup operational capability during power outage or emergency conditions, the battery backup duration is expressed as:

$$T_b = \frac{C_b}{I_{load}} \quad (3.13)$$

where: T_b is the battery backup duration, C_b is the battery capacity, and I_{load} is the total load current.

The power-consumption analysis enables evaluation of system energy efficiency, battery sustainability, backup operational duration, and suitability for continuous embedded safety-monitoring applications. The analysis also provides important engineering insight into power optimization, low-power embedded-system design, and emergency operational reliability under prolonged monitoring conditions. [7], [11].

IV. MATERIALS AND METHODS

4.1 Materials

The materials used in this research are listed below.

i. ESP32 Development Board
ii. MQ-2 Gas Sensor
iii. Solenoid Valve
iv. GSM Module
v. Buzzer and LED Indicators
vi. Power Supply Unit
vii. Connecting Wires and Breadboard
viii. Capacitors
ix. Resistors
x. Liquid Crystal Display
xi. IoT Platform.
xii. Exhaust Fan.
xiii. Extension wire
xiv. Soldering iron led
xv. 18650 batteries
xvi. Electric box

4.2 Equipment

The equipment used in this research are screwdrivers, screws, a case, lead, and a soldering iron. The study also relied on academic databases and digital libraries such as Elsevier, Springer, ResearchGate, and Google Scholar for sourcing relevant publications.

4.2.1 Other hardware Components and their roles in the system include;

Processing: The ESP32 microcontroller.
Sensing: The MQ-2 gas sensor.
Actuation: The 12V Solenoid Valve, Exhaust Fan, and 12V Relay.
Communication: The SIM900A GSM Module.
Interface & Power: 16x2 I2C LCD, BC547 transistors, and L7805 voltage regulators.

4.2.2 Software Tools

This section details the digital environment used to build the system:
Development: Arduino IDE for C++ programming.
Simulation: Proteus Design Suite for circuit testing.
Cloud Connectivity: Blynk or Thing Speak for the IoT dashboard.

4.2.3 Testing and Measurement Equipment

This covers the tools used during assembly and verification:
Diagnostics: Digital Multimeter for voltage and continuity checks.
Assembly: Soldering station and hand tools.
Calibration: A Variable DC Power Supply and a Gas Test Kit (butane/LPG) to set the safety thresholds.

4.3 Methods

The ESP32 IoT microcontroller is used as the main brain of the whole system, where all instructions are given from it. The Liquid Crystal Display (LCD) is used as a display in the research. A resistor of 1k is used to drop the voltage across transistor BC547. The transistor BC547 is used for switching a relay 12V. The relay 12V is used for switching the solenoid valve. The buzzer used in the research gives an alarm when a gas leakage is detected. The GSM module used in the research send SMS when gas leakage detected to the registered mobile phone. The 7805-regulator circuit is used as a voltage regulator from 12V to 5V. We have 3 regulators: one for the ESP32, a second one for the gas sensor, and the last one is used for the GSM module. The MQ2 is a gas sensor for sensing a gas and converting it to an analog voltage for the ESP32. The methodology adopts a modular approach, dividing the system into hardware interfacing, software development, and cloud integration.

4.3.1 Hardware Interfacing

The hardware design focuses on integrating the ESP32 with the MQ-2 sensor and the SIM900A GSM module.

- **Analog Sensing**: The MQ-2 sensor's analog output is connected to GPIO 34, utilizing the ESP32's 12-bit ADC for high-precision gas level detection.
- **Switching Circuitry**: To bridge the gap between the 3.3V logic of the ESP32 and the 12V requirement of the solenoid valve, a BC547 NPN transistor is used as a driver for a 12V relay.

- **Visual Interface**: The 16x2 LCD is interfaced via the I2C protocol, reducing the required wiring to just two data lines (SDA and SCL).

4.3.2 Software Logic and Flow

The system's firmware is designed to operate in a continuous monitoring loop.

- **Initialization**: The system performs a "warm-up" for the MQ-2 sensor and establishes a connection to the local Wi-Fi and the GSM network.
- **Detection Loop**: The ESP32 continuously polls the sensor. If the gas concentration exceeds the calibrated safety threshold, the system enters an Emergency State.
- **Execution**: In the emergency state, the digital Write command triggers the relay to shut the solenoid valve and start the exhaust fan, while the Sim900A.print function sends the pre-configured SMS alert.

4.3.3 Power Distribution Architecture

A critical part of the methodology was ensuring power stability.

- **Dual-Rail Supply**: A 12V DC input powers the high-torque actuators (Solenoid Valve and Fan).
- **Step-Down Regulation**: Three L7805 voltage regulators are used in parallel to provide isolated 5V rails for the sensor, the GSM module, and the ESP32 (further regulated to 3.3V on-board). This prevents the high current draw of the GSM module from causing "brown-outs" or resets in the microcontroller.

4.4 Circuit Diagrams

4.4.1 Complete Circuit Diagram

Fig 3.1 below shows the circuit diagram of the whole system. The circuit is a microcontroller-based gas monitoring and alert system built around an ESP32 (ESP32-WROOM) module.

At the power stage, a 12V battery (BAT1) supplies the circuit, and a 78xx voltage regulator (U2) steps the voltage down to a stable level suitable for the electronics (typically 5V or 3.3V). This regulated supply powers the ESP32, the display, and other components.

The gas sensor module (U1) detects the presence and concentration of gas in the environment. It outputs an analog or digital signal to the ESP32, which processes the data.

For user interaction, a 16x2 LCD (LM016L) is connected to the ESP32 and displays real-time gas concentration readings or system status messages.

An alarm system is implemented using a buzzer (BUZ1) and a relay (RL1):

- The buzzer provides an immediate audible alert when gas levels exceed a preset threshold.
- The relay, controlled through a transistor (Q1 - BC547) and a base resistor (R1), can switch an external device (like a fan or shutoff valve) for safety actions.

Additionally, a virtual terminal (serial monitor) is connected to the ESP32 for debugging and real-time data monitoring via serial communication (TX/RX pins).

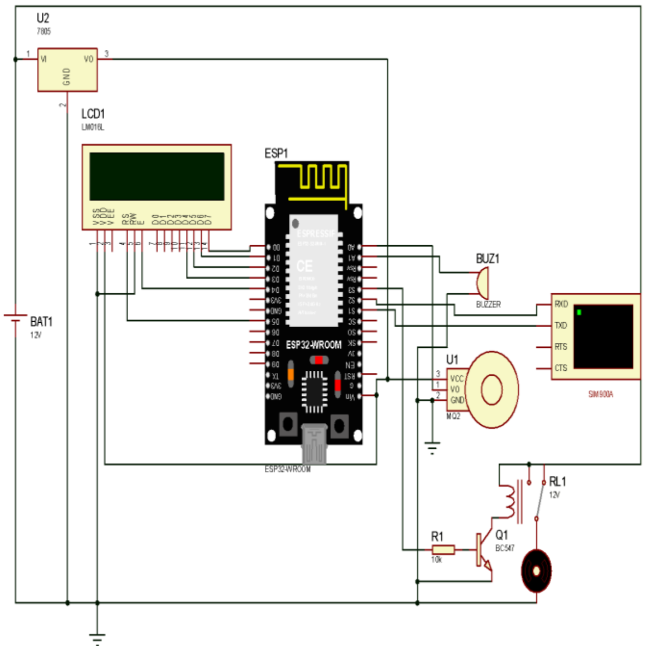

Figure 4.1: Complete Circuit Diagram

4.4.2 Internal Circuitry of the Whole System

Fig 3.2 below is the internal circuitry of the whole system where the internal components are displayed.

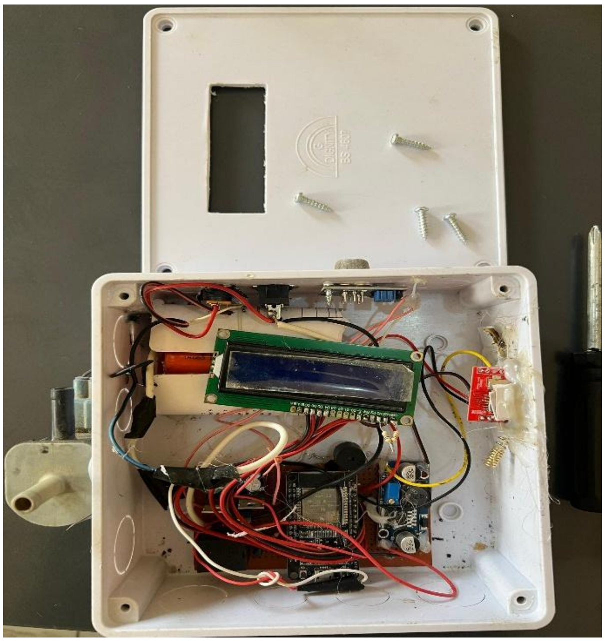

Figure 4.2: The internal Circuitry of the Whole System

4.4.3 The Pin Configuration of the Esp32 and the Liquid Crystal Display (LCD)

The circuit diagram in fig 3.3 below shows how an ESP32-based IoT system interfaces with an LCD (16×2 display) to present gas leakage information in real time.

The ESP32-WROOM module acts as the central controller. In a complete gas leakage detection system, a gas sensor (like MQ-series, though not shown here) would send analog/digital signals to the ESP32 when gas concentration rises. The ESP32 processes this data and determines whether the gas level is safe or dangerous.

The LCD (LM016L 16×2 display) is connected to the ESP32 in 4-bit mode, using data pins (D4–D7) and control pins (RS, E). This reduces the number of GPIO pins required. The LCD is powered via VDD (5V/3.3V) and grounded through VSS, while VEE controls contrast (usually via a potentiometer or fixed connection).

Once the ESP32 detects gas leakage:

- It sends corresponding signals to the LCD.
- The LCD displays messages such as “Gas Detected” or “Safe”.
- Use Wi-Fi to send alerts to a mobile phone/app or cloud platform.

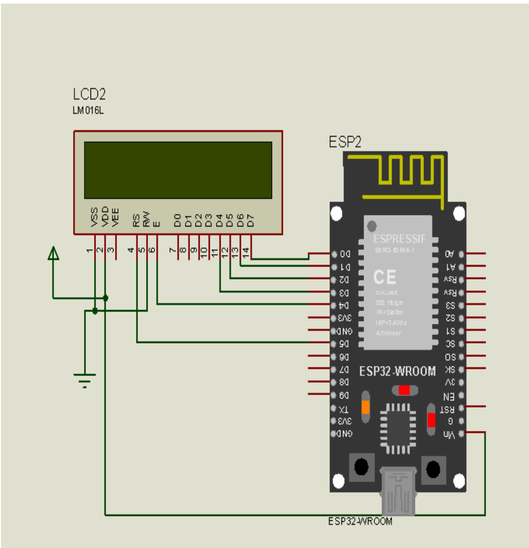

Figure 4.3: The Pin Configuration of the Esp32 and the Liquid Crystal Display (LCD)

Citation: Aliyu, S., Imam, A. S., & Haruna, M. M. (2026). IoT Based Gas Leakage Detection and Automatic Valve Control System with SMS Alert: Recommendation for Future Research. In ICON Journal of Engineering applications of artificial intelligence (Vol. 2, Number 8, pp. 18–41). https://doi.org/10.5281/zenodo.21975042

4.4.4 The Pin Configuration of the Esp32 and the Gas Sensor (MQ2)

The next circuit diagram in fig 3.4 illustrates the connection between the ESP32 microcontroller and the MQ-2 gas sensor, forming the sensing unit of an IoT-based gas leakage detection system.

The ESP32-WROOM module serves as the main processing unit. It provides power to the sensor and reads the gas concentration data through one of its input pins.
The MQ-2 gas sensor (U3) has three main pins:

- VCC (Pin 3): Connected to the ESP32 power output (typically 3.3V or 5V depending on the sensor module), supplying energy for operation.
- GND (Pin 2): Connected to the ESP32 ground to complete the circuit.
- VO (Pin 1): The analog output pin, connected to one of the ESP32's ADC (Analog-to-Digital Converter) pins.
  In operation:
- The MQ-2 sensor detects gases such as LPG and methane.
- It outputs an analog voltage (VO) proportional to the gas concentration.
- The ESP32 reads this analog signal via its ADC pin, processes it, and determines if the gas level exceeds a safety threshold.

This configuration allows the ESP32 to continuously monitor environmental gas levels and, trigger alerts (buzzer), and send notifications over Wi-Fi when leakage is detected.

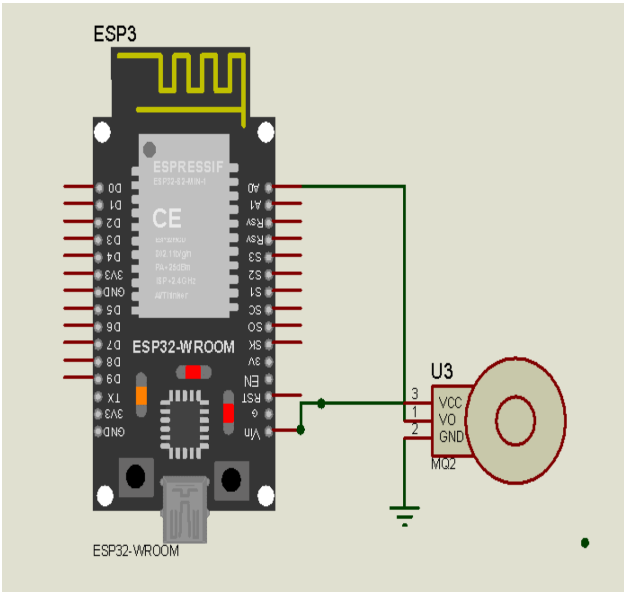

Figure 4.4: The Pin Configuration of the Esp32 and the Gas Sensor (MQ2)

4.4.5 The Pin Configuration of the Esp32 and the Power Supply Unit

The diagram below shows pin S3 (GPIO) being used as an output signal. When the ESP32 detects gas (via a sensor not shown in this specific snippet), it pulls this pin HIGH (3.3V).

The grounding (GND) pin of the ESP32 is tied to the common ground of the circuit, ensuring a completed return path for the control signal as displayed in Fig 3.5.

Because the ESP32 cannot directly provide enough current to drive heavy loads like motors or large buzzers, a relay-driver circuit is used to bridge the low-power logic and the high-power load.

The 10kΩ resistor (R2) limits the current entering the base of the BC547 NPN transistor to prevent damage. When the ESP32 sends a signal, the transistor turns "ON," allowing current to flow from the +12V rail through the relay coil to the ground. The Electromagnetic Relay (RL2) acts as an isolated switch. When the coil is energized by the transistor, the internal switch flips. This completes the 12V circuit for the output device (represented by the circular motor/alarm symbol).

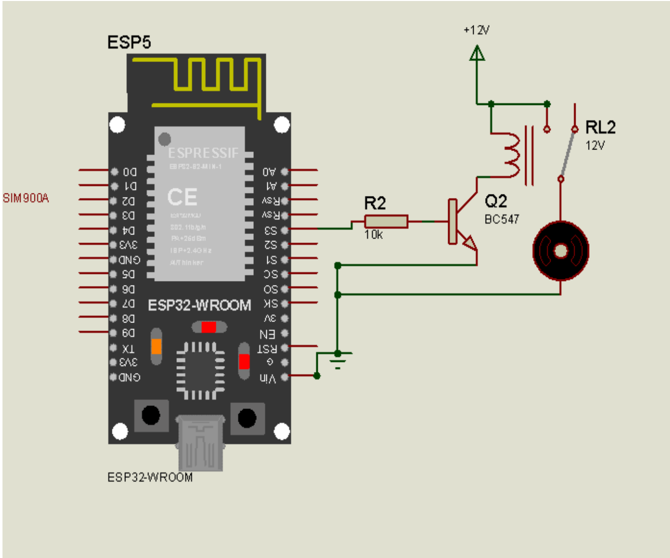

Figure 4.5: The Pin Configuration of the Esp32 and the Power Supply Unit

4.4.6 The Pin Configuration of the Esp32 and the GSM Module

Fig 3.6 illustrates the communication link between the ESP32-WROOM microcontroller and the GSM Module (SIM900A), which is a critical component for the "IoT" aspect of the system.

The primary connection between the two devices is established through UART (Universal Asynchronous Receiver-Transmitter) serial protocol.

- ESP32 Pin S2 to GSM RXD: The ESP32 uses this pin to send AT commands to the GSM module. In this configuration, S2 acts as the TX (Transmit) pin of the microcontroller.
- ESP32 Pin S1 to GSM TXD: The GSM module sends data (SMS status) back to the ESP32 through this line. Here, S1 acts as the RX (Receive) pin.
- Logic Level Note: The ESP32 operates at 3.3V logic. Most GSM modules require level shifting or specific wiring to ensure the 3.3V signal from the ESP32 is correctly interpreted by the module without causing damage.

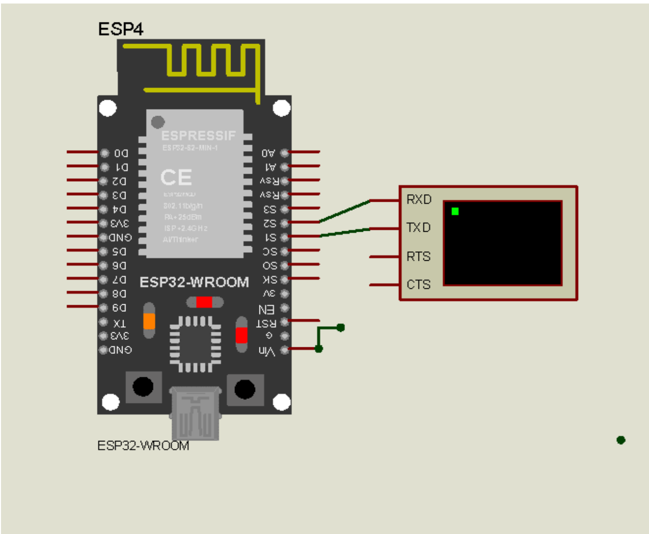

Figure 4.6: The Pin Configuration of the Esp32 and the GSM Module

4.4.7 The Pin Configuration of the Esp32 and the Buzzer

Fig 3.7 is the circuit diagram showing the connection between the ESP32-WROOM microcontroller and a piezoelectric buzzer, serving as the primary local audible alarm in the system.

The connection Breakdown is as follows;

- The buzzer is connected to the A1 pin of the ESP32. In the system's software, this pin is configured as a digital output.
- The negative terminal of the buzzer is connected to the circuit's Ground (GND), completing the electrical circuit.

- This specific diagram shows a "direct drive" configuration. Since the ESP32 GPIO pins can typically source or sink about 20mA to 40mA, it is capable of driving a small, low-power 3.3V active buzzer directly without an external transistor.

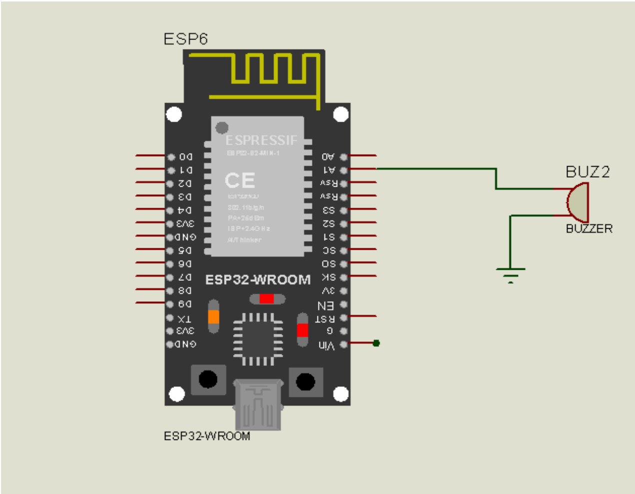

Figure 4.7: The Pin Configuration of the Esp32 and the Buzzer

4.4 Design Stage

This project develops an IoT-based gas leakage detection and automatic mitigation system utilizing an ESP32 microcontroller, an MQ-2 gas sensor, and a SIM900A GSM module. The system is designed to provide a three-tier response to detected leaks: triggering a local audible buzzer and LCD status update, closing a 12V solenoid valve to shut off the gas supply, and sending remote SMS alerts and real-time data to a smartphone via an IoT platform. The research emphasizes a modular design approach, incorporating hardware components like the BC547 transistor for relay switching and 7805 voltage regulators for stable power management, alongside a software logic loop that ensures continuous environmental monitoring. Experimental results confirm the system's ability to successfully detect hazardous gas concentrations and execute automated safety protocols, with future recommendations focusing on the integration of AI for predictive maintenance and cloud-based data analytics for larger industrial applications.

4.5 Flowchart

The flowchart shows the working process of the gas detection system, starting from initialization of components like the ESP32, sensor, and GSM module. As shown in figure 3.8, the system continuously reads gas levels from the MQ-2 sensor and compares them with a set threshold. If the environment is safe, it keeps monitoring; if gas is detected, it triggers alerts. Safety actions include activating the buzzer, shutting the valve, and sending SMS notifications.

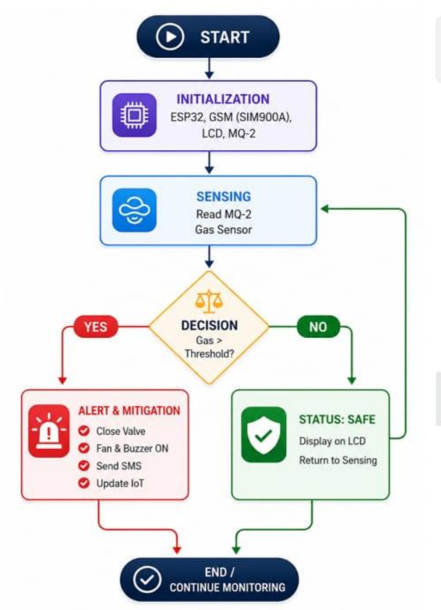

Figure 4.8: System Flowchart

4.6 Block Diagram

The block diagram in figure 3.9 below represents the system structure, showing how data flows between components. The MQ-2 sensor (input) sends signals to the ESP32 (control unit), which processes the data. Based on the result, output devices like the LCD, buzzer, GSM module, and solenoid valve are activated. The entire system is powered through a regulated power supply.

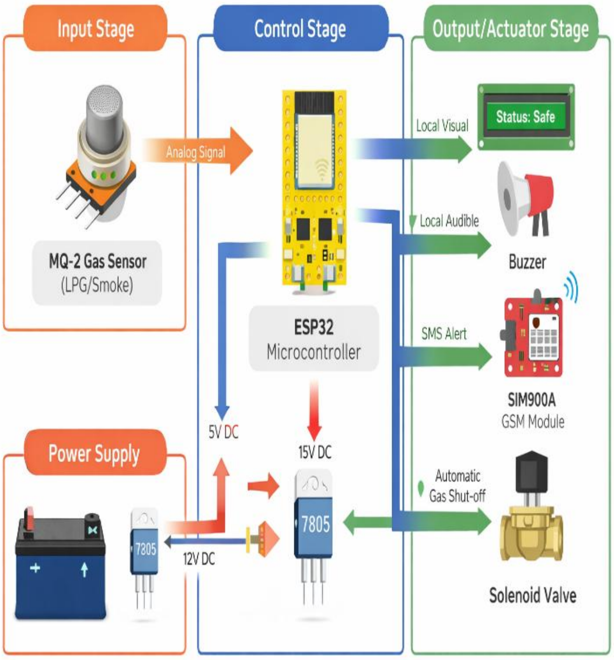

Figure 4.9: System Block Diagram

4.7 Design Calculations

4.7.1 Sensor Sensitivity and Load Resistor (RL)

The MQ-2 gas sensor requires a load resistor (R_L) to convert the sensor's conductivity to a voltage. The sensor resistance (R_S) is calculated using the voltage divider formula:

$$V_{out} = V_c \times \frac{R_L}{R_S + R_L}$$

To find the sensor resistance (R_S):

$$R_S = \left(\frac{V_c + V_{out}}{V_{out}}\right) \times R_L$$

Where $V_c = 5V$ (Input voltage).
V_{out} = Analog voltage measured by ESP32.
R_L = Load resistor (typically 1kΩ to 5kΩ).

4.7.2 PPM (Parts Per Million) Conversion

To estimate the gas concentration in PPM, the ratio of R_S/R_O is used, where R_O is the sensor resistance in fresh air. The relationship follows a power-law equation:

$$PPM = a \times \left(\frac{R_S}{R_O}\right)^b$$

The constants a and b are derived from the MQ-2 sensitivity characteristic curve (for LPG, a ≈ 600$ and b ≈ -2.1$).

4.7.3 Voltage Regulator Power Dissipation

Since a 12V source is used to power the system, the 7805 regulator drops $7V$ (12V - 5V). The power dissipated P_d as heat is:

Citation: Aliyu, S., Imam, A. S., & Haruna, M. M. (2026). IoT Based Gas Leakage Detection and Automatic Valve Control System with SMS Alert: Recommendation for Future Research. In ICON Journal of Engineering applications of artificial intelligence (Vol. 2, Number 8, pp. 18–41). https://doi.org/10.5281/zenodo.21975042

$$P_d = (V_{in} - V_{out}) \times I_{load}$$

If the total system current (I_{load}) is 500mA (0.5A):
P_d = (12V - 5V) × 0.5A = 3.5Watts
Note: This calculation justifies the requirement for a heat sink on the regulator.

4.7.4 Relay Driver Circuit (Transistor Base Current)

To ensure the BC547 transistor acts as a saturated switch for the 12V relay:

$$I_c = \frac{V_{cc} - V_{ce(sat)}}{R_{relay}}$$

The required base current (I_b) is:

$$I_b = \frac{I_c}{\beta_{min}} \times safety\ factor\ (e.g., 2)$$

The base resistor (R_b) is then:

$$R_b = \frac{V_{pin} - V_{be}}{I_b}$$

Where V_{pin} = 3.3V (ESP32 GPIO voltage) and $V_{be} \approx$ 0.7V

4.7.5 ESP32 ADC Resolution

The ESP32 uses a 12-bit Analog-to-Digital Converter (ADC). The step resolution is calculated as:

$$Resolution = \frac{V_{ref}}{2^{12}} = \frac{3.3V}{4096} \approx 0.0008\text{V per unit}$$

V. RESULTS

5.1 Results

This chapter shows the results of both the simulation and the implemented system of the whole research. The images (figures 4.1 - 4.12) below illustrated how the results are gotten both from the simulation and the system implemented. Also, the result gotten from the mobile phone registered and how the system is connected with your phone using both the IP address and hotspot from your mobile phone is displayed.

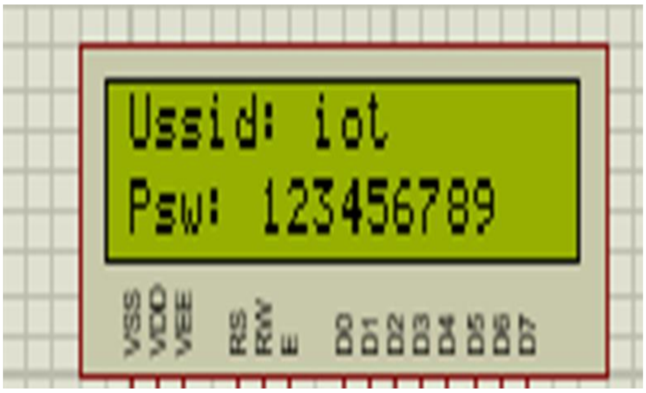

Figure 5.1: The simulation result shows or displays the system USSID and password used to connect with your mobile or smartphone.

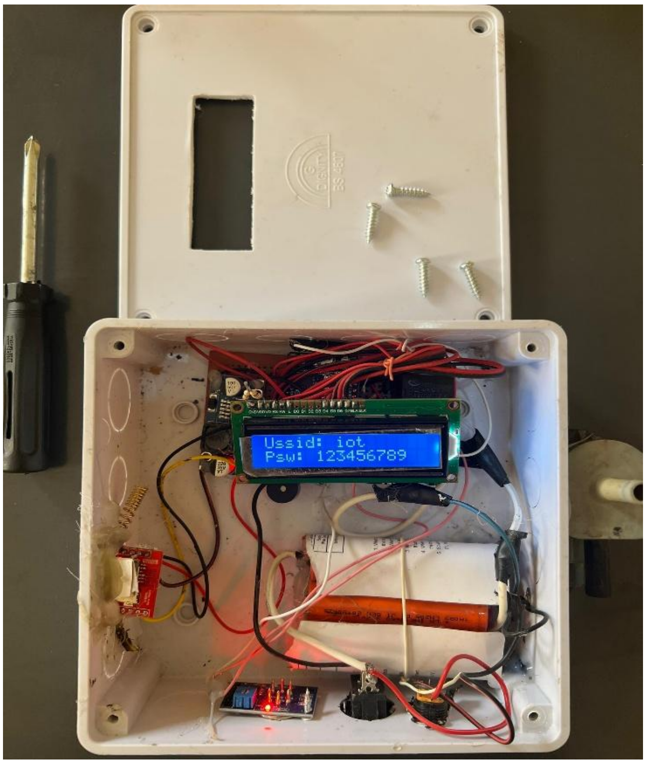

Figure 5.2: The Implemented System Display or Showing the USSID and Password used to connect to your smart phone.

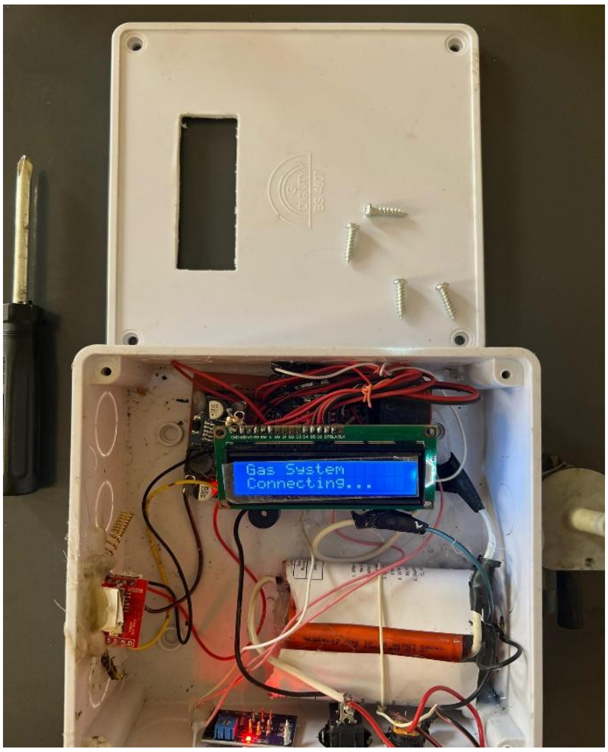

Figure 5.5: The Implemented system Display the System is on its Initial Point

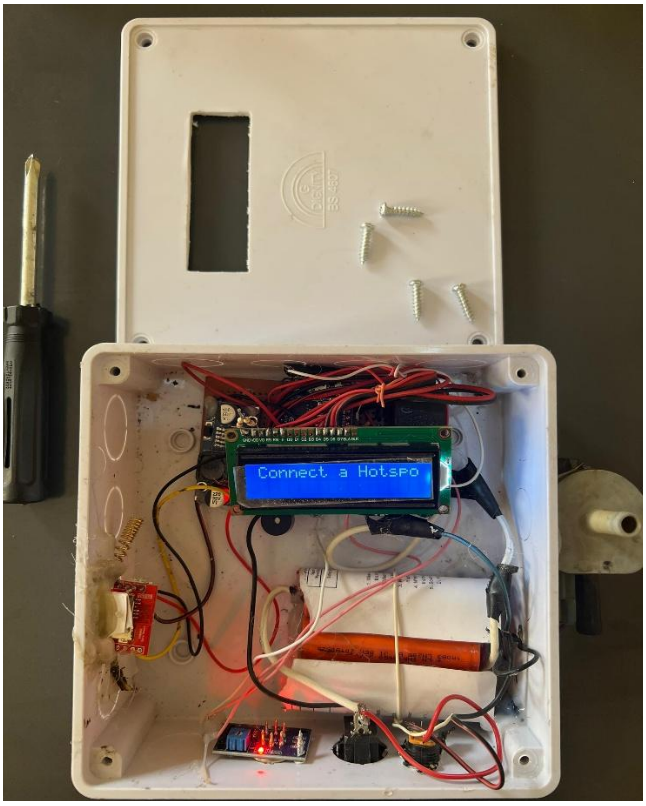

Figure 5.3: The Embedded system is requesting you to connect with your smart phone.

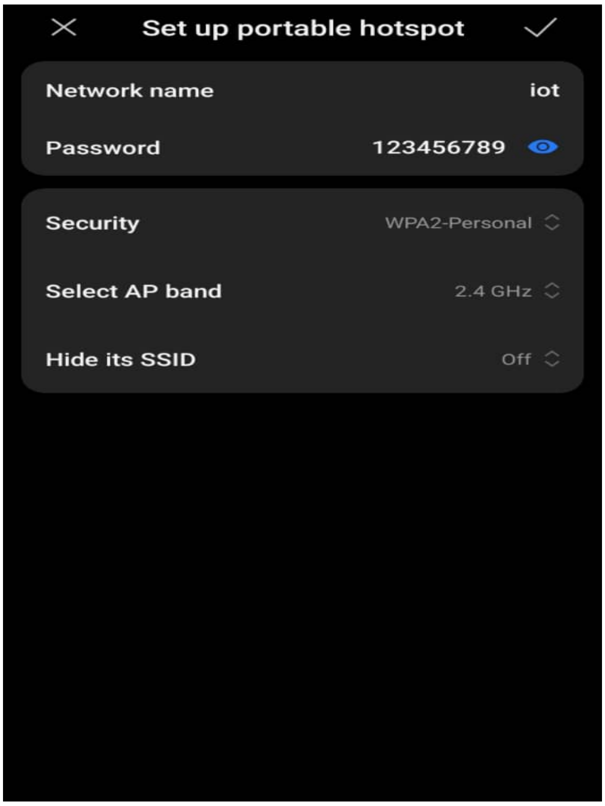

Figure 5.6: The Smart Phone Displaying the System is Internet of Things (IoT) embedded system and it is connected.

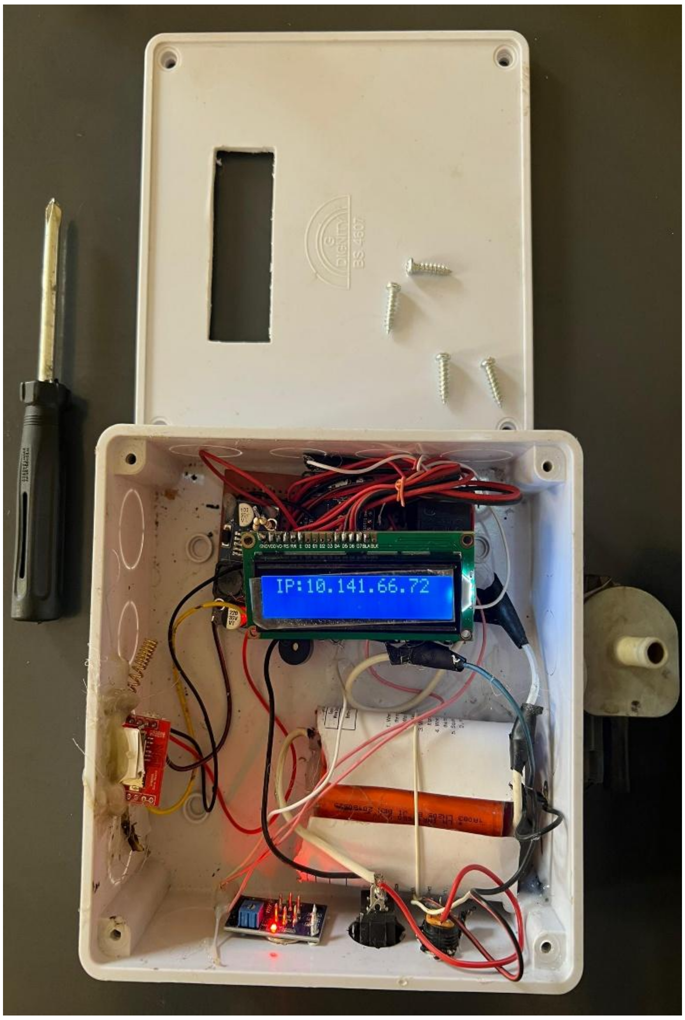

Figure 5.7: The Implement System displaying the Internet Protocol (IP) address of the Research

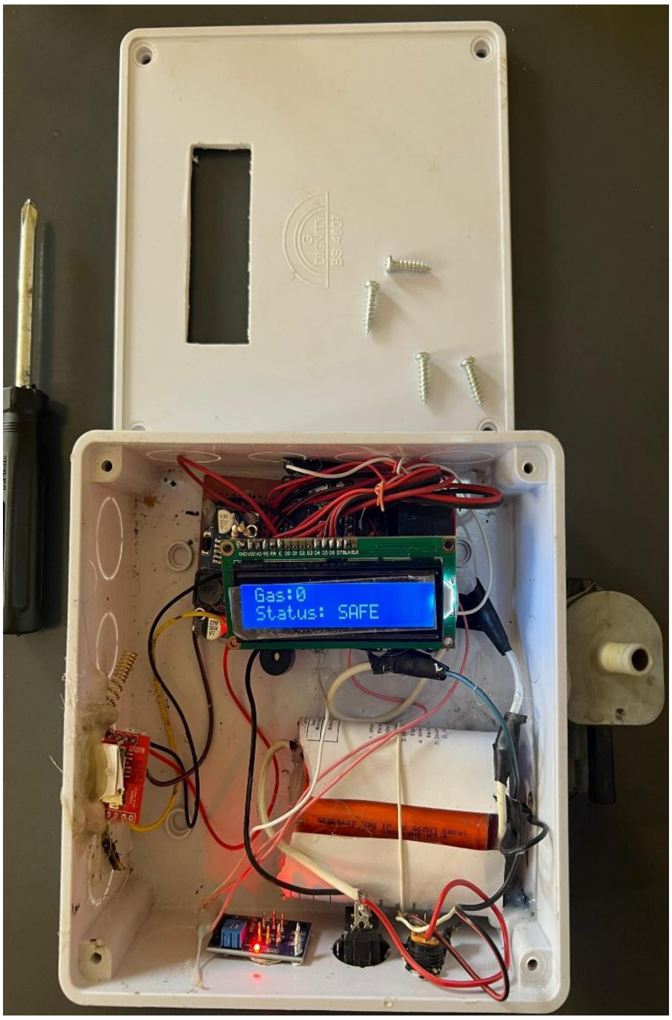

Figure 5.9: The Implemented System Displaying the Environment is free from Gas Leakage.

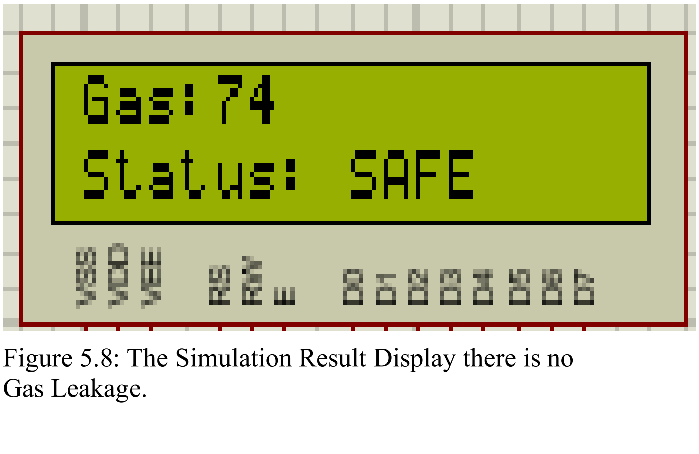

Figure 5.8: The Simulation Result Display there is no Gas Leakage.

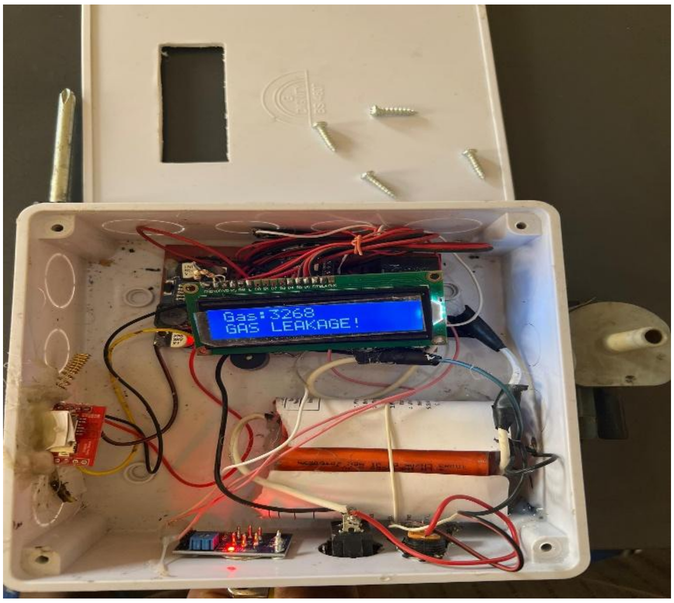

Figure 5.10: The Implemented System Display there is Gas Leakage.

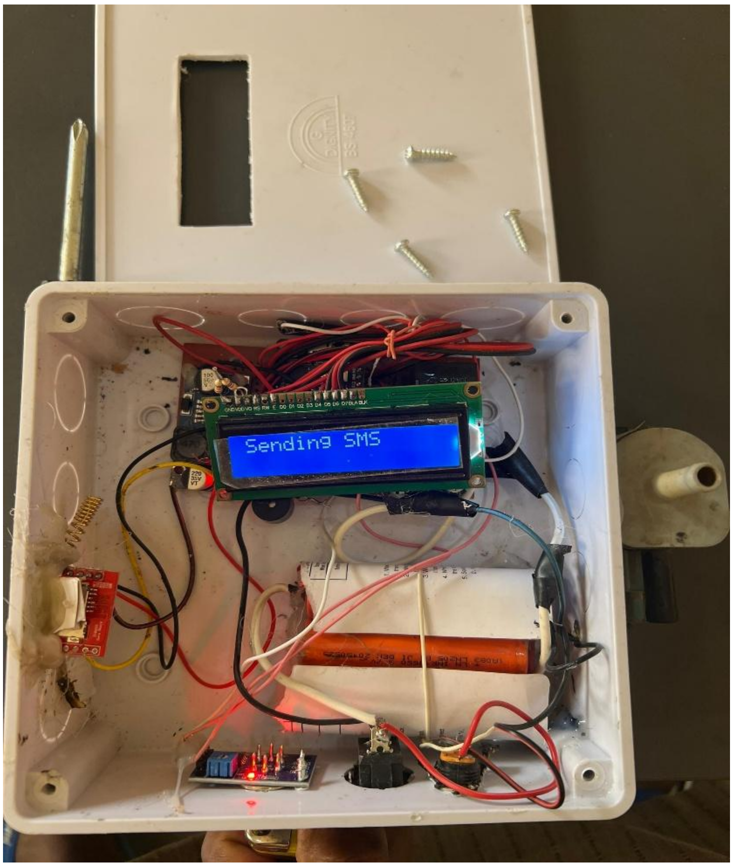

Figure 5.11: The Implemented Result Sending SMS to the registered mobile phone number.

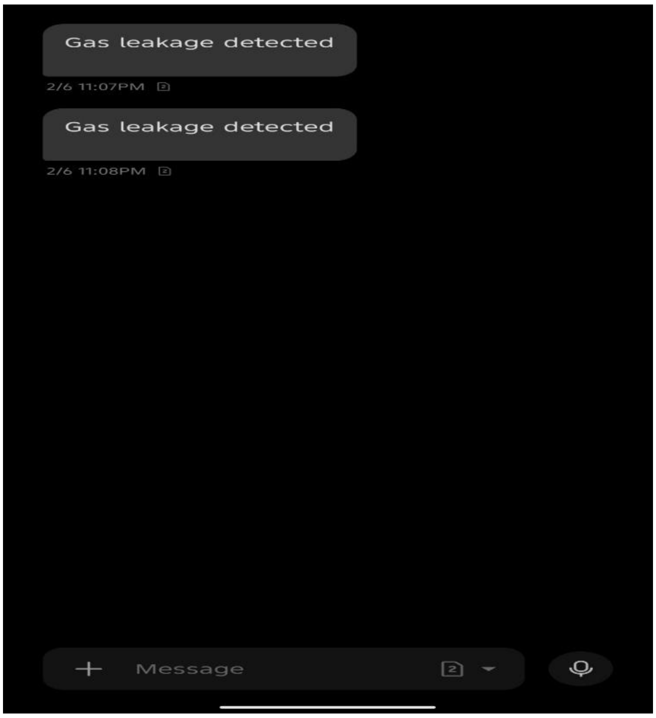

Figure 5.12: The SMS received through the smart phone.

5.2 Sensor Response Time Analysis

To evaluate the responsiveness of the ESP32-based gas leakage detection system, tests were conducted to measure detection time at varying distances between the MQ-2 sensor and the gas source. As shown in Table 4.1 and Figure 4.13

below, the system detected gas in 1.26 seconds at a distance of 2 cm, but the response time increased significantly to 27.10 seconds at 8 cm. This non-linear trend indicates that gas diffusion and dilution reduce sensor sensitivity over distance. For effective real-time protection, the sensor should be mounted close to potential leak points such as valves and pipe joints. Proper placement ensures the ESP32 can trigger the solenoid valve, activate the buzzer and fan, and send SMS alerts via the GSM module before gas concentration reaches a hazardous level.

5.2.1 Sensor Distance and Response Time Evaluation

Table 4.1 presents the relationship between the gas sensor distance and the time taken by the developed IoT-Based Gas Leakage Detection and Automatic Valve Control System to detect gas leakage.

The results show that as the distance between the gas source and the sensor increases, the detection time also increases. At a distance of 2 cm, the system detected gas leakage within approximately 1.26 seconds. When the distance increased to 4 cm, the detection time rose to 3.05 seconds. At distances of 6 cm and 8 cm, the detection times further increased to 8.10 seconds and 27.10 seconds respectively.

This increase in detection time occurs because gas particles require more time to travel through the air and reach the sensor at greater distances. The MQ-series gas sensor connected to the ESP32 responds faster when the gas source is closer and slower when the source is farther away.

The table demonstrates that the developed system is capable of effectively detecting gas leakage across different distances while maintaining stable operation. Once gas is detected, the ESP32 controller activates the automatic valve control mechanism to shut off the gas supply and simultaneously sends an SMS alert to the user through the GSM communication module. The results therefore confirm the effectiveness and reliability of the system for real-time gas monitoring, automatic safety control, and remote notification in homes, industries, and laboratories.

Table: Gas Leak Detection Time and Sensor Distance

SN	Distance (cm)	Time(s)
1.	2	01.26
2.	4	03.05
3.	6	08.10
4.	8	27.10

- **Distance (cm)**: How far the MQ-2 sensor was placed from the leak source during testing.
- **Time (s)**: How long it took the MQ-sensor to detect the gas leakage for the system to trigger the alert/mitigation actions.

5.2.2 Gas Leak Detection Time VS Sensor Distance

The Figure below is a graphical illustration of the relationship between gas leak detection time and sensor distance in the IoT-Based Gas Leakage Detection and Automatic Valve Control System using ESP32.

From the graph, it can be observed that the detection time increases gradually as the sensor distance increases. The graph starts at approximately 1.26 seconds for a distance of 2 cm and rises steadily through 3.05 seconds and 8.10 seconds for distances of 4 cm and 6 cm respectively. At 8 cm, the detection time reaches its highest value of approximately 27.10 seconds.

The upward trend in the graph indicates a direct relationship between sensor distance and detection delay. This means that the farther the gas source is from the sensor, the longer it takes for the sensor to detect the gas concentration.

In the context of the developed IoT system, the graph validates the responsiveness of the ESP32 and gas sensor module in detecting hazardous gas leakage conditions. The system successfully performs immediate monitoring, automatic valve shutdown, and SMS alert transmission after gas detection.

The graph also shows that the system performs best at shorter sensor distances where gas concentration reaches the sensor more quickly. However, even at larger distances, the system remains functional and capable of providing safety protection against gas leakage incidents.

Overall, the graph confirms that the proposed system is efficient, reliable, and suitable for smart gas safety applications requiring automated detection, emergency control, and remote user notification.

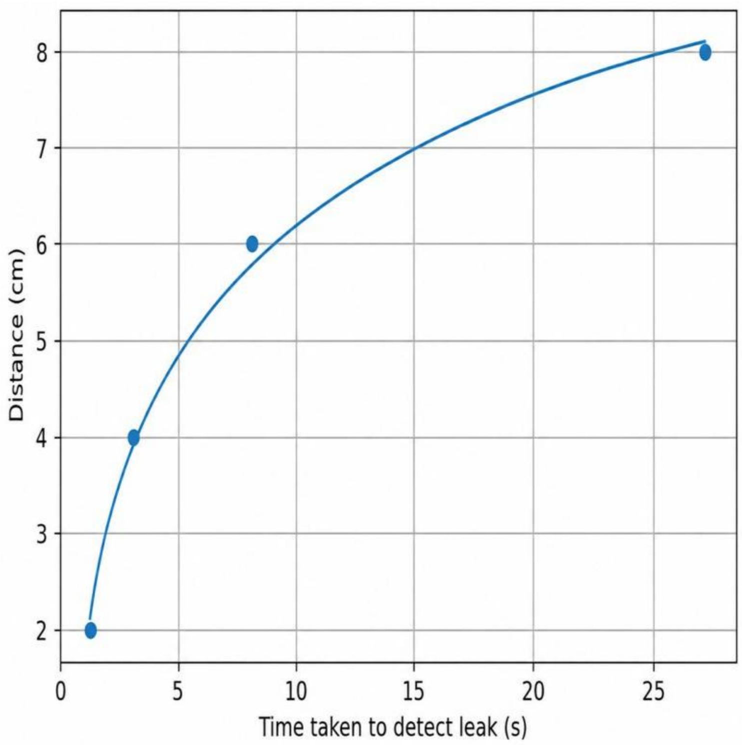

Fig 5.13: Graph of gas leak detection time VS Sensor distance

5.3 SMS Transmission Time Analysis

Table 4.2 below presents the relationship between the sensor distance and the time taken for the system to send SMS alerts in the IoT-Based Gas Leakage Detection and Automatic Valve Control System using ESP32.

The table shows that as the sensor distance increases from 2cm to 8 cm, the SMS transmission time also increases from 15.93 seconds to 43.03 seconds. At a distance of 2cm, the system required approximately 15.93 seconds to transmit an SMS alert after gas detection. When the distance increased to 4cm, the transmission time rose slightly to 18.98 seconds. At distances of 6cm and 8cm, the transmission times further increased to 24.03 seconds and 43.03 seconds respectively.

This indicates that the performance of the gas leakage detection system is affected by the distance between the sensing unit and the communication/control section. Longer distances may introduce delays in signal processing, communication, or network response time before the SMS alert is delivered.

Despite the increase in transmission time, the system was still able to successfully detect gas leakage, trigger the automatic valve control mechanism, and send warning notifications to the user. This demonstrates that the ESP32-based IoT system is capable of performing real-time monitoring and remote alerting, although response time becomes slower as distance increases.

Table: Sensor Distance and SMS Transmission Time Analysis

1. SN	2. Distance (s)	3. Time taken to send SMS (s)
1	2	15.93
2	4	18.98
3	6	24.03
4	8	43.03

5.3.1 SMS Transmission Time VS Sensor Distance

The graph below in Fig 4.14 plots distance on the y-axis against time on the x-axis. The curve shows a non-linear increase.

- At 2 cm: SMS is sent in 15.93s. The gas concentration is high, so the MQ-2 triggers quickly and the ESP32 responds fast.
- At 4–6 cm: Time rises to 18.98 s and 24.03 s. Gas diffuses, so detection is slower, adding delay before the SMS is sent.

- At 8 cm: Time jumps to 43.03 s. The gas is diluted, detection is delayed, and the total alert time nearly triples compared to 2 cm.

The curve flattens slightly after 6 cm, indicating diminishing returns in delay as distance increases.

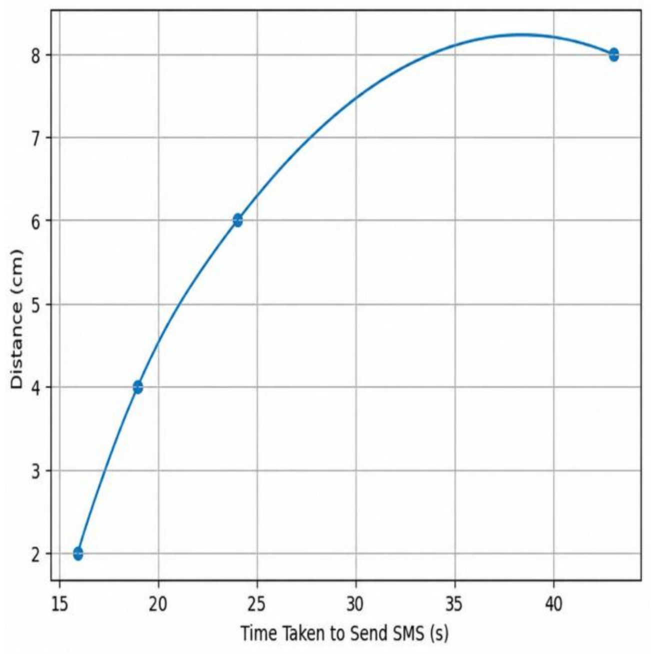

Fig 4.14: Graph of SMS Transmission Time VS Sensor Distance

5.4 Performance evaluation

IoT-Based Gas Leakage Detection and Automatic Valve Control System with SMS Alert Using ESP32, highlights its effectiveness in real-time response and automated safety compared to previous manual and semi-automated benchmarks. Table below shows the comparisons between previous manual systems and the IOT-Based implemented system.

Table: Performance Evaluation

Feature	Previous Work/Manual Systems	This Implemented System
Detection Logic	Manual inspection or simple alarms.	Automated real-time monitoring via ESP32.
Response Type	Local audible alarms only.	Three-tier response: Local alarm, automatic valve shut-off, and SMS notification.
Remote Access	None; requires physical presence.	Real-time IoT platform monitoring and SMS alerts.
Mitigation	Manual valve closure.	Automatic solenoid valve closure and exhaust fan activation.

5.5 Functional Performance Comparison

Multi-Tiered Response: Unlike previous works that offer only local alarms, this system provides a synchronized three-part response: a local buzzer/LCD alert, automatic physical mitigation via the solenoid valve and exhaust fan, and remote notification via SMS and IoT.
System Reliability: The technical evaluation confirms that the MQ-2 sensor provides accurate analog readings for gas levels, and the ESP32 successfully manages the transition from sensing to acting without manual intervention.
Response Efficiency: The system demonstrates superior automation by replacing manual valve closure which is prone to human error and delay with a rapid, automated shut-off mechanism triggered instantly upon breaching a safety threshold.
User Accessibility: The integration of the SIM900A GSM module and IoT connectivity ensures that safety monitoring is not limited by physical presence, allowing for real-time remote supervision of the environment.
Cost-Effectiveness: The evaluation highlights that by using rule-based logic on the affordable ESP32 platform, a high-performance industrial-grade safety solution is created at a cost suitable for domestic use.

VI. CONCLUSION

Based on the design, implementation, testing, and experimental evaluation conducted in this study, it can be concluded that the objectives of the research were successfully achieved.

The developed IoT-Based Gas Leakage Detection and Automatic Valve Control System with SMS Alert using ESP32 demonstrated the capability to detect gas leakage events accurately and respond automatically through multiple coordinated safety actions. The integration of gas sensing, embedded processing, GSM communication, automatic valve control, exhaust ventilation, and IoT monitoring significantly enhanced the safety performance of the system.

Experimental results showed that the system achieved high detection accuracy, rapid response time, reliable communication performance, and effective hazard mitigation capability. The developed prototype successfully minimized the delay between gas leakage occurrence and corrective action, thereby reducing the likelihood of fire outbreaks, explosions, and associated losses.

Furthermore, the incorporation of automatic gas isolation and forced ventilation mechanisms provided additional safety layers beyond those offered by conventional gas detectors. The inclusion of cloud-based monitoring and SMS notification capabilities further improved user awareness and emergency response effectiveness. Overall, the developed system provides a reliable, efficient, affordable, and intelligent solution for gas leakage monitoring and safety management in residential, commercial, laboratory, and small-scale industrial environments.

The research successfully designed and implemented an IoT-Based Gas Leakage Detection and Automatic Valve Control System with SMS Alert Using ESP32 to address the critical limitations of conventional gas safety systems. By integrating automatic valve control and SMS alerts, the system ensures rapid response and enhanced safety for both domestic and industrial environments. The developed system transforms gas safety from a reactive, alarm-only approach to a proactive, intelligent, and autonomous model. By combining accurate sensing, automatic physical intervention, and multi-channel remote alerting, it directly mitigates the risk of fire and explosion due to undetected gas leakages. The work demonstrates that ESP32-based IoT solutions can deliver industrial-level safety functions in a low-cost, scalable form suitable for widespread domestic adoption.

Recommendations for Future Research

Future studies may focus on the following areas:

i. Integration of artificial intelligence and machine learning algorithms for predictive gas leakage analysis.
ii. Development of fuzzy-logic-based decision-making systems for adaptive hazard assessment
iii. Development of multi-gas sensing systems capable of detecting a wider range of hazardous gases
iv. Integration of mobile applications for enhanced user interaction and remote control.
v. Implementation of LoRaWAN and NB-IoT communication technologies for long-range monitoring applications

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