Intelligent LPG Leakage Detection and Automated Emergency Response

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***Abstract*—Liquefied Petroleum Gas (LPG) leaks in residential kitchens pose serious risks, including fire accidents, explosions, property damage, and loss of life. Conventional gas leak detectors typically provide only local alarm notifications and lack automated hazard mitigation or remote emergency reporting capabilities. This paper proposes an AI-driven smart LPG leak detection and emergency response system that integrates edge computing with cloud-based monitoring. The system continuously monitors gas concentration using an MQ-2 sensor connected to a Raspberry Pi 4B and employs a rate-of-change analysis to distinguish actual gas leaks from normal environmental fluctuations. When a hazardous leak is detected, the system automatically shuts off the gas supply, activates ventilation, and transmits real-time alerts and sensor data to cloud platforms for remote monitoring. An adaptive communication strategy minimizes bandwidth consumption during normal operation while enabling high-frequency data transmission during emergencies. Experimental evaluation demonstrates rapid hazard detection, automatic physical response, and low-latency cloud notifications, highlighting the effectiveness of the proposed cyber-physical solution in improving residential kitchen safety.**

***Index Terms*—Internet of Things (IoT), LPG Leakage Prevention, Edge AI, Automated Regulator Valve, Raspberry Pi, Rate-of-Change Algorithm.**

I. INTRODUCTION

A. Background & Motivation

Liquefied Petroleum Gas (LPG) comprising volatile hydro-carbon mixtures of propane (C_3H_8) and butane (C_4H_{10}) is widely utilized globally for residential cooking, space heating, and commercial catering applications. Despite its clean combustion characteristics and energy efficiency, LPG possesses a high volumetric energy density and extreme flammability. When unburned LPG leaks into an enclosed, unventilated in-door space, it forms a highly explosive stoichiometric mixture with ambient oxygen once the gas concentration crosses its Lower Explosive Limit (LEL) of approximately 1.8% to 2.1% by volume (18, 000–21, 000 PPM).

Because LPG is heavier than air (with a relative vapor density of ≈ 1.55 to 2.0), escaped vapors do not readily dissipate through elevated ventilation openings. Instead, they pool near floor levels, accumulating unnoticed in cabinets, corners, and low-lying spaces. Under such conditions, minor electrical arcs such as those produced by a refrigerator com-pressor relay, a light switch, or a static discharge are sufficient to trigger explosive combustion.

Beyond immediate fire risks, dense LPG accumulation leads to displacement of atmospheric oxygen, creating severe asphyxiation risks for sleeping or in-capacitated occupants. Establishing a truly effective domestic gas safety ecosystem requires moving beyond passive audible alerts to deploy an intelligent, cyber-physical platform capable of physical source isolation, active vapor evacuation, and direct emergency responder dispatch.

B. Problem Statement

Standard commercial gas leakage detection units suffer from several fundamental architectural limitations that impede their effectiveness during real-world domestic emergencies:

1) Limited Local Warning Mechanism:

Most commercially available gas leak detectors, such as MQ-2 and MQ-5 based systems, generate only audible alerts through an onboard buzzer when gas concentration exceeds a predefined threshold. Although effective in the presence of nearby occupants, these alarms offer limited protection if residents are asleep, have hearing impairments, or are not at home.

2) No Automated Leak Mitigation:
Conventional detectors are designed only to identify gas leaks and issue warnings. They do not include mechanisms to automatically shut off the LPG supply or activate ventilation systems, allowing the leaked gas to continue accumulating and increasing the likelihood of hazardous situations.

3) Fixed Threshold Detection:
Many existing systems rely on predefined gas concentration thresholds (e.g., above 400 PPM) to trigger alarms. Such static threshold-based detection can produce false alarms due to smoke, cooking vapors, humidity variations, or household chemicals, while also being less effective at identifying gradual gas leaks before they become dangerous.

4) Lack of Remote Emergency Communication:
Traditional standalone gas detectors generally operate without internet connectivity. As a result, they cannot automatically transmit alerts, location details, or cylinder identification information to emergency services, gas suppliers, or designated contacts during critical incidents.

C. Research Objectives

To address these technical gaps, this research designs, implements, and experimentally validates an integrated edge-AI safety architecture.

The specific objectives are:

- To build a high-precision continuous analog gas acquisition channel utilizing an MCP3008 ADC IC connected to a Raspberry Pi 4B edge node over hardware SPI.
- To formulate an edge Rate-of-Change ($\Delta PPM/\Delta t$) slope evaluation algorithm capable of temporal trend prediction and false-positive filtering.
- To engineer a closed-loop physical actuation framework incorporating a high-torque MG996R servo motor for 90-degree regulator switch shutoff and relay-driven active ventilation.
- To deploy a scalable, multi-role cloud platform featuring adaptive data logging (15-min heartbeat vs. 1-s emergency mode), unique Cylinder ID tracking, and real-time agency geolocation mapping.

II. LITERATURE REVIEW & INCIDENT CONTEXT

Domestic gas leakages represent complex emergency scenarios where technical detector limitations collide with hu-man behavioral vulnerabilities. Evaluating existing research requires analyzing historical safety systems, recent IoT indoor alarm frameworks, and real-world human behavior during crisis events.

A. Real-World Incident Analysis & Human Limitations

A tragic real-world example highlighting this limitation occurred in **Mysuru, Karnataka, in May 2024**, where an LPG leak inside a residence led to the deaths of an entire family of four. According to police reports, the family had gone to sleep after dinner while LPG continued leaking inside the closed house throughout the night. The accumulated gas displaced oxygen, resulting in fatal asphyxiation before anyone could detect the leak or take corrective action. The incident demonstrates that conventional gas detectors or reliance on human perception alone may be inadequate during late-night hours, when occupants are asleep and unable to respond promptly to an emergency.

Similarly, in Faridabad, Haryana (October 2024), a residential LPG leak caused a powerful explosion at approximately 2:15 a.m. while family members were asleep. The blast led to the collapse of the house, killing four people and injuring others. Investigators reported that leaked gas had accumulated inside the room before being ignited, emphasizing the consequences of delayed leak detection and the absence of automatic gas isolation mechanisms.

1) Asphyxiation and Rapid Incapacitation:
In poorly ventilated indoor environments, continuous LPG leakage can gradually displace oxygen, creating an oxygen-deficient atmosphere that may cause dizziness, disorientation, impaired judgment, and, in severe cases, loss of consciousness. These effects can significantly delay or prevent occupants from reaching the gas regulator or taking appropriate emergency action, thereby increasing the likelihood of serious injury or fatality.

2) Panic-Induced Safety Risks:
During emergency situations, occupants often react under stress and may attempt to close the gas regulator hastily. Such panic-driven actions can delay effective leak control and increase the likelihood of unsafe practices, such as operating electrical switches or using ignition sources in the presence of accumulated gas. These actions can significantly elevate the risk of fire or explosion.

3) Continuous Fuel Supply in Piped Gas Systems:
Unlike LPG cylinders, which contain a limited quantity of fuel, Piped Natural Gas (PNG) systems receive a continuous supply of gas from municipal distribution networks. If a leak remains undetected or the supply valve is not automatically isolated, gas may continue to accumulate within the enclosed environment, increasing the probability of hazardous conditions over time.

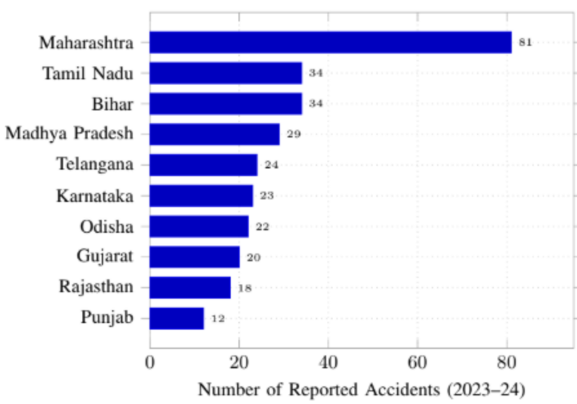

Fig. 1. State-wise distribution of reported LPG accident complaints during 2023–24, highlighting high-incidence regions requiring automated mitigation.

B. Review of Existing Automated Solutions & Related Work

Academic literature has explored various IoT-enabled gas and fire detection prototypes over recent years. Early implementations utilized basic microcontrollers (e.g., Arduino ATmega328P or ESP8266) paired with GSM modules to send automated SMS text messages to property owners upon leak detection. While SMS alerts improve remote awareness, sending a text message to a user who is miles away or stuck in traffic does nothing to halt the immediate physical buildup of gas in their kitchen.

More recently, Chen et al. [1] proposed a distributed indoor fire alarm system using LoRa wireless sensor networks. While their work effectively addresses wide-area building telemetry and long-range multi-node communication, it operates as a passive monitoring network relying on static parameter thresholds and human administrative intervention. It lacks autonomous physical source isolation and fails to calculate real-time gas rate-of-change dynamics.

TABLE I Comparative Matrix: Conventional Safety Paradigms vs. Proposed Edge-AI & Cloud System

Feature / Criteria	Basic Buzzer Alarms	Standard GSM Alarms	Manual Hose/Pipe Pull	Proposed Edge-AI System
Data Telemetry	Binary (On/Off)	Binary (On/Off)	None (Human Sense of Smell)	Continuous Analytical Analog (PPM)
Execution Speed	Instant (Local Alarm)	Delayed (Network Depen-dent)	Slow / Variable (Panic Driven)	Edge Action under 200 ms
Physical Hazard Isolation	None	Rare / Exhaust Fan Only	Manual Valve Shutoff / Hose Pull	Automatic Servo Regula-tor Isolation
Remote Incident Reporting	None	Basic SMS Message	None	Real-Time Agency Map & Unique ID
Dependence on Human Presence	High (Requires Listener)	Low (Remote Alert)	Total (Requires Physical Human)	Zero (100% Autonomous Edge AI)
Early Trend Prediction	No (Static Threshold)	No (Static Threshold)	No	Yes ($\Delta PPM/\Delta t$ Rate-of-Change)

Furthermore, most micro-controller-based detectors rely on simple binary limit logic (e.g., checking if $PPM > 400$). Static limits cannot analyze the derivative of concentration over time ($\Delta PPM/\Delta t$), rendering them incapable of distinguishing between a brief transient cooking spike and an accelerating major hose breach.

C. Comparative Evaluation

To overcome the deficiencies of passive alarms, basic GSM alerts, distributed LoRa telemetry, and risky manual interventions, this paper proposes an autonomous edge-AI cyber-physical platform. Table I presents a comprehensive comparison matrix evaluating four safety approaches across key operational parameters.

D. Key Technical Contributions

The proposed platform resolves the identified literature gaps through three main innovations:

- Autonomous Sub-Second Physical Isolation: Eliminates risky human intervention by deploying an edge-controlled MG996R servo motor that rotates the physical regulator lever 90 degrees within 200 ms of leak verification.
- Decoupled Edge Computing Architecture: Decouples local physical safety triggers from cloud networking, ensuring local valve shutoff and fan activation operate flawlessly even if Wi-Fi or cloud connections are severed.
- Actionable Enterprise Dispatch: Integrates unique Cylinder IDs (HP12345678) mapped to cloud GIS end-points, providing gas utility agencies with live emergency location maps for rapid technician dispatches.

III. HARDWARE SYSTEM ARCHITECTURE

The physical layer of the platform is designed as an edge-computed cyber-physical node capable of high-speed sensor sampling, local risk calculation, mechanical actuation, and asynchronous cloud synchronization.

A. Core Edge Processing Node

Unlike standard microcontrollers restricted to single-threaded, sequential loop execution, the proposed architecture uses a Raspberry Pi 4B (Quad-Core ARM Cortex-A72 @ 1.5 GHz, 2 GB LPDDR4) as the central edge processor. Running a full POSIX-compliant Linux OS allows POSIX multithreading:

1) Thread 1 (High-Priority Hardware Loop): Dedicated to continuous 100 Hz SPI polling of the gas sensor, real-time calculation of the Rate-of-Change slope ($\Delta PPM/\Delta t$), and sub-second GPIO execution for local actuators.
2) Thread 2 (Asynchronous Network Worker): Manages HTTPS/MQTT socket connections, JSON payload construction, and adaptive cloud data mirroring to Fire-base/Blynk.

This multithreaded separation ensures that local safety triggers operate deterministically, completely unaffected by network latency or internet outages.

B. Analog Data Conversion via SPI Protocol

Because the Raspberry Pi lacks internal Analog-to-Digital Converters (ADCs), reading exact continuous gas concentration levels (PPM) from the analog output (A_O) of the MQ-2 sensor requires an intermediate discretization stage. An 8-channel, 10-bit MCP3008 ADC IC bridges the MQ-2 sensor and the Pi over the Serial Peripheral Interface (SPI) bus.

The SPI interface operates using four dedicated pins: Master Out Slave In (MOSI, GPIO 10), Master in Slave Out (MISO, GPIO 9), Serial Clock (SCLK, GPIO 11), and Chip Enable (CE0, GPIO 8). The raw 10-bit ADC output integer ($D_{out} \in [0, 1023]$) is converted to input voltage (V_{in}) and calibrated parts-per-million (PPM) using Equation 1:

$$V_{in} = \frac{D_{out} \times V_{REF}}{1023}, \quad V_{REF} = 3.3\text{ V} \tag{1}$$

C. Automated Safety Actuators

Upon critical hazard verification, three hardware counter-measures trigger simultaneously:

Reference	Year	Existing Approach	Limitations
[2]	2022	MQ-2 based LPG leakage detection with buzzer alarm	Provides only local alerts; no automatic gas shutoff, cloud monitoring, or remote notifications.
[3]	2023	IoT-enabled gas leakage monitoring using Wi-Fi	Supports remote monitoring but lacks autonomous hazard mitigation and intelligent decision-making.
[4]	2024	Gas leakage detection with cloud dashboard	Offers cloud visualization but does not include physical intervention such as regulator shutoff or active ventilation.

[5]	2025	Smart LPG safety system with mobile alerts	Provides notifications to users but cannot identify cylinder information, perform adaptive logging, or assist emergency agencies.
Proposed System	2026	Edge-based LPG leakage detection using Raspberry Pi 4B, MQ-2 sensor, MCP3008 ADC, Rate-of-Change ($\Delta PPM/\Delta t$) hazard evaluation, servo-based regulator shut-off, relay-controlled exhaust fan, adaptive cloud logging, Cylinder ID tracking, geolocation mapping, and real-time dashboards.	Addresses the limitations of previous systems by combining intelligent edge processing, automatic physical hazard mitigation, cloud-based monitoring, adaptive data logging, and emergency response support.

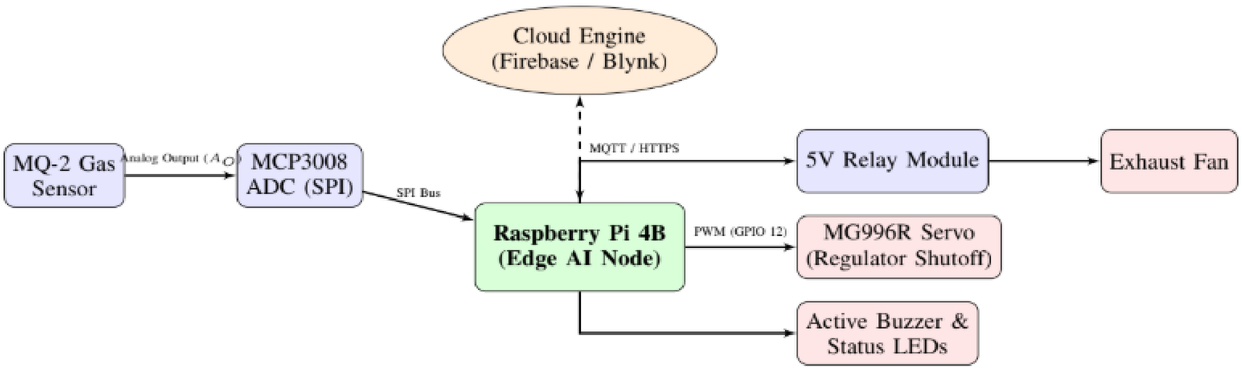

Fig. 2. System Hardware Architecture Block Diagram illustrating edge processing, SPI sensor acquisition, actuators, and cloud pipelines.

TABLE II Physical Hardware Component Specifications & Parameters

Component	Model / IC	Key Operating Parameter	System Function
Edge Processor	Raspberry Pi 4B	Quad-Core 1.5 GHz, 2GB LPDDR4	Master Edge AI Controller
Gas Sensor	MQ-2 Module	100-10,000 PPM (Butane/LPG)	Continuous Fume Sensing
ADC Converter	MCP3008 IC	10-Bit Resolution, 8-Ch SPI	Analog Signal Discretization
Servo Actuator	MG996R	11 kg · cm Torque @ 4.8V	90° Regulator Valve Isolation
Active Ventilation	5V DC Fan	Relay Switched, 35 CFM Fume Flow	Active Vapor Evacuation
Power Supply	Dual Isolated	5V/3A Type-C & Ext 5V/3A DC	System Power & Voltage Isolation

- High-Torque Servo Regulator Isolation:

An MG996R metal-gear servo motor (11 kg · cm torque @ 4.8 V) is mechanically coupled to the 90-degree residential LPG cylinder regulator switch. Driven by a 50 Hz Pulse Width Modulation (PWM) signal on GPIO 12, the motor rotates 90 degrees within 200 ms of leak detection, shutting off the gas supply.

- Active Forced Ventilation:

A 5, V DC, high-CFM exhaust fan is controlled through an optocoupler-isolated, single-channel 5, V relay module connected to GPIO 22 of the Raspberry Pi. Upon detection of elevated gas concentrations, the relay is actuated to activate the exhaust fan, facilitating the rapid evacuation of accumulated LPG fumes from the monitored environment.

- Audible & Visual Alarms:

A 5 V active piezo buzzer (GPIO 27) sounds local alarms alongside dual status indicator LEDs (Green for Safe Mode on GPIO 18, Red for Hazard Mode on GPIO 23).

D. Power Management & Electrical Isolation

High-torque inductive loads like the MG996R servo motor draw momentary current surges (1.0 A to 2.5 A) during initial rotation. Drawing power directly from the Raspberry Pi's 5 V GPIO bus causes brownouts, system freezing, or SD card corruption.

To ensure electrical stability, an isolated dual power architecture is configured:

1) A dedicated USB Type-C power supply (5 V/3 A) powers the Raspberry Pi core and low-power ICs.
2) An external 5 V/3 A DC power adapter feeds the MG996R servo motor directly.
3) Common Ground Reference: The negative ground terminal of the external servo power supply is tied directly to a Raspberry Pi Ground pin (Physical Pin 30), establishing a shared signal reference without routing motor current surges through Pi PCB traces.

TABLE III Compact Hardware Interfacing Pinout Summary

Component	Pin Name	Interface / Destination	RP1 Pin
MCP3008 ADC	VDD / VREF	3.3V Power Rail	Pin 1
	AGND / DGND	System Ground Reference	Pin 6
	SCLK / DOUT / DIN	SPI Bus (GPIO 11 / 9 / 10)	Pins 23 / 21 / 19
	CS	Chip Select (GPIO 8 / CE0)	Pin 24
MQ-2 Sensor	VCC / GND	5V Power / Ground	Pins 2 / 6
	Analog Out (A_0)	MCP3008 Channel 0	CH0 (IC Pin 1)
MG996R Servo	Red / Brown	External 5V Power / Common GND	Ext / Pin 30
	Yellow (Signal)	PWM Control (GPIO 12)	Pin 32
5V Relay Fan	VCC / GND / IN	5V / Ground / Trigger (GPIO 22)	Pins 4 / 4 / 15
Active Siren	VCC / GND / I/O	5V / Ground / Alert (GPIO 27)	Pins 4 / 25 / 13

IV. IOT CLOUD INFRASTRUCTURE & DATA PIPELINES

A. Cloud Database Architecture

The system integrates Google Firebase Realtime Database and Blynk IoT Cloud to maintain continuous data mirrors. Firebase stores persistent JSON telemetry logs, while Blynk handles instant mobile push alerts and visual gauge dashboards for homeowners and utility agencies.

B. Adaptive Bandwidth-Saving Logging Protocol

To prevent database bloat across thousands of deployed cylinders while preserving high-resolution hazard trends, an adaptive dual-mode logging strategy is deployed:

- Heartbeat Mode (Gas PPM ≤ 400): Edge node logs a single heartbeat entry to the cloud every 15 minutes (96 entries/day), verifying system uptime without wasting storage.
- Emergency Mode (Gas PPM > 400): Instantly shifts to high-speed 1-second continuous logging to capture detailed spike graphs during an emergency event.

C. JSON Payload Schema

Listing 1 details the standardized JSON data payload trans-mitted via MQTT/HTTPS endpoints during cloud updates.


```
{
  "cylinderID": "HP12345678",
  "customerName": "ABC",
  "location": "Charholi, Pune",
  "gasLevelPPM": 760,
  "aiRiskStatus": "CRITICAL",
  "regulatorState": "SHUT_OFF",
  "loggingMode": "HIGH_RES_EMERGENCY",
  "timestamp": "2026-07-22T18:45:00Z"
}
```


Listing 1. Standardized JSON Cloud Payload Schema

D. Network Security Protocols

Communications utilize Transport Layer Security (TLS 1.3) encryption over HTTPS/MQTT sockets. Cloud access requires token-based authentication (API Private Keys and Firebase Admin SDK tokens), securing data payloads against unauthorized access or malicious valve overrides.

V. AI LOGIC & PREDICTIVE HAZARD ENGINE

A. Rate-of-Change (ΔPPM/Δt) Algorithm

Rather than relying solely on fixed limit checks, the edge AI engine continuously measures the temporal slope of gas concentration ($\Delta PPM/\Delta t$) using Equation 2:

$$\frac{\Delta \mathrm{PPM}}{\Delta t} = \frac{\mathrm{PPM}_t - \mathrm{PPM}_{t-\Delta t}}{\Delta t} \quad (2)$$

By tracking slope steepness, the system catches sudden gas spikes (such as butane released during lighter testing) instantly while ignoring minor ambient sensor drift.

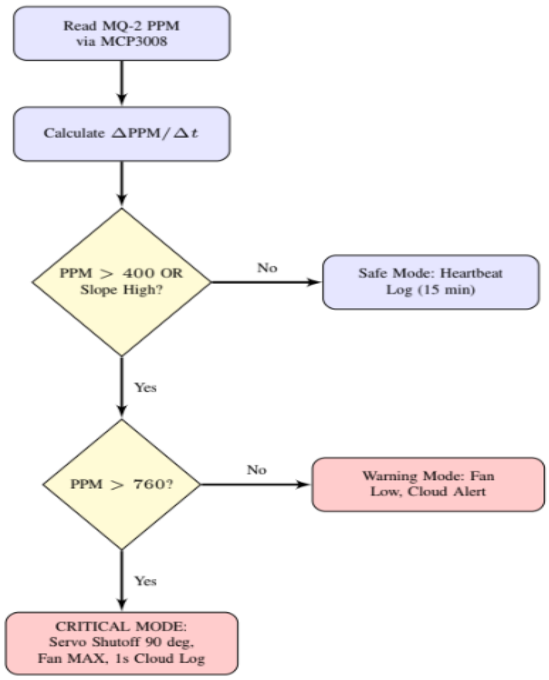

Fig. 3. Decision Flowchart of Edge Rate-of-Change Algorithm and Actuation.

B. Multi-Stage Decision Matrix

The decision engine classifies hazard levels into three states based on gas concentration and temporal slope, executing proportional countermeasures as detailed in Table IV.

VI. MULTI-ROLE WEB PLATFORM & MITIGATION

A. Gas Agency Administrative Portal

The enterprise portal allows gas providers to oversee thou-sands of deployed smart cylinders in real time. Features include:

- Live GIS Map Mapping: Displays interactive customer locations with color-coded status pins (Green for Safe, Red for Leaks).

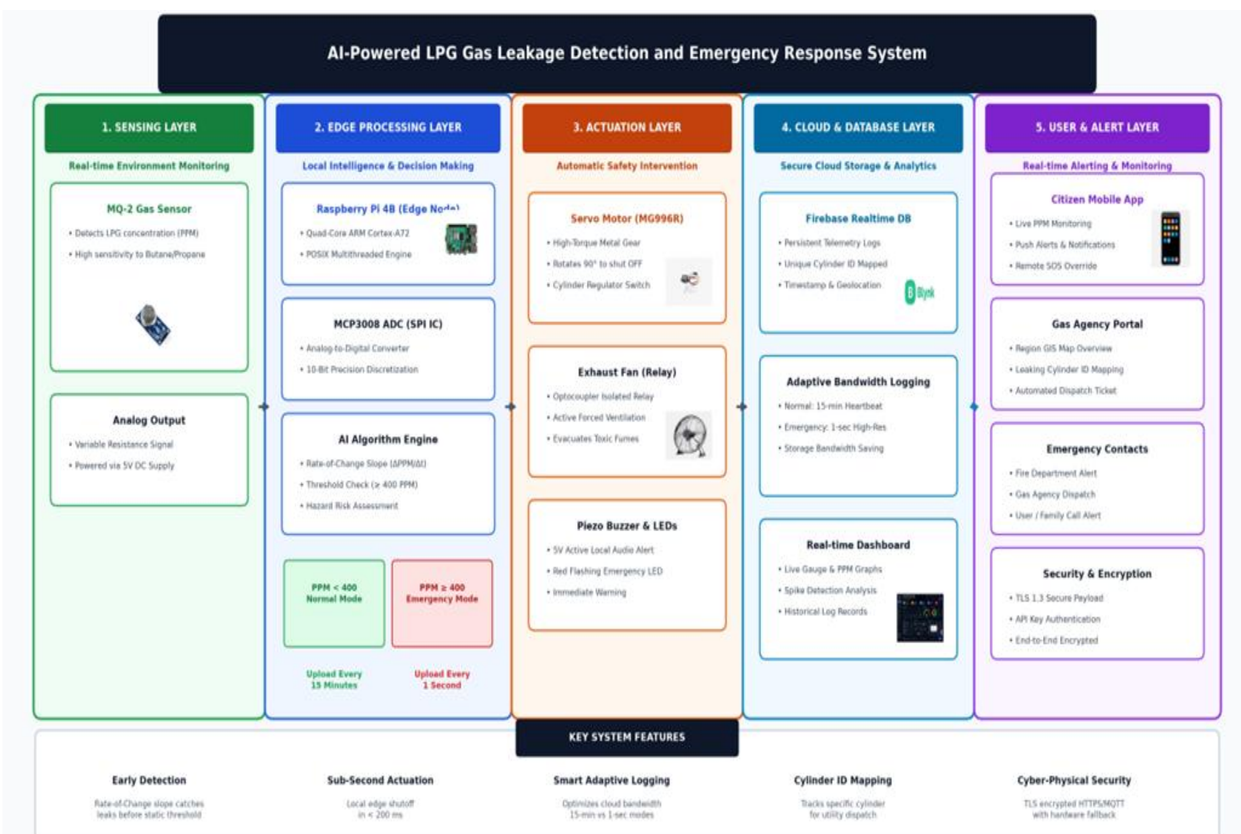

Fig. 4. End-to-End Cyber-Physical Architecture illustrating Sensing, Edge Processing, Hardware Actuation, Cloud Storage, and Enterprise Reporting Ecosystem.

TABLE IV Multi-Stage Edge Hazard Decision Matrix

Gas Level (PPM)	Slope (ΔPPM/Δt)	Status	Executed Actions
< 400 PPM	Stable (≈ 0)	Safe	Normal Monitoring; Servo OPEN; 15-min Log
400–760 PPM	Slowly Increasing	Warning	Fan LOW; Cloud Alert Sent; 5-sec Log
> 760 PPM	Rapidly Spiking	Critical	Servo SHUTOFF (90°); Fan MAX; Buzzer ON; 1-sec High-Res Log

- Cylinder ID Tracking: Displays unique Cylinder IDs (e.g., HP12345678), customer contact information, and real-time PPM levels upon leak detection.
- Emergency Dispatch Management: Automatically generates support tickets, allowing dispatchers to send field technicians to the customer location.

B. Citizen Mobile Dashboard

The consumer interface provides homeowners with continuous visibility:

- Live numerical gauge readings and historical trend charts.
- Instant push notifications during Warning or Critical states.
- Emergency SOS manual override button to shut off the

C. Automated Physical Mitigation Mechanism

Mechanical valve isolation is driven by an MG996R servo motor coupled via a custom arm to the 90-degree snap-on regulator switch. Upon receiving a critical pulse width (1.0 ms to 2.0 ms PWM at 50 Hz), the motor generates up to 11 kg· cm of torque, pulling the regulator lever to the OFF position within 200 ms.

VII. EXPERIMENTAL RESULTS & PERFORMANCE ANALYSIS

A. Sensor Calibration & Measurement Setup

The MQ-2 sensor was calibrated using known butane concentrations released via a controlled test lighter. Raw 10-bit ADC values ($Dout \in [0, 1023]$) were mapped to calibrated PPM levels across clean air (200–300 PPM), warning states (400–650 PPM), and critical direct exposure (> 760 PPM).

B. Hardware & Network Latency Testing

System execution speed was benchmarked across 50 trial runs. Results are summarized in Table V.

As shown in Table V, the total local physical response time remains below 207 ms, proving that physical hazard mitigation occurs locally almost instantaneously, well before cloud transmission completes.

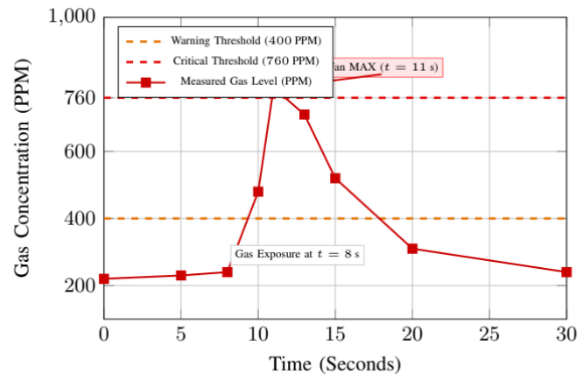

Fig. 5. Experimental Gas Concentration (PPM) Response Curve demonstrating baseline ambient sampling ($t < 8$ s), rapid slope spike upon gas release ($t = 8$ s), and immediate edge physical actuation ($t = 11$ s) returning gas levels to safe baseline limits.

TABLE V SYSTEM EXECUTION LATENCY BREAKDOWN

Processing Stage	Average Time	Max Time
SPI Sensor Sampling (MCP3008)	12 ms	18 ms
Edge AI Rate-of-Change Calculation	15 ms	22 ms
Servo Mechanical Shutoff Rotation	180 ms	210 ms
Cloud Data Sync (Firebase/Blynk)	1150 ms	1420 ms
Total Edge Physical Mitigation	< 207 ms	< 250 ms

C. Distance vs. Detection Latency Analysis

To evaluate spatial sensing performance under real-world indoor environmental conditions, continuous leak trials were conducted in a controlled 3 m× 3 m× 2.5 m test chamber with ambient air circulation.

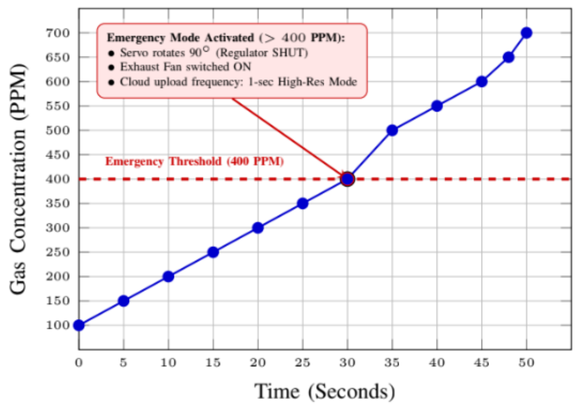

Fig. 6. Temporal gas concentration growth plot demonstrating the trigger transition into Emergency Mode at 400 PPM and the executed hardware and cloud countermeasures.

An LPG discharge source (1.5 L/min release rate) was placed at fixed linear distances (0.5 m, 1.0 m, 1.5 m, and 2.0 m) relative to the MQ-2 sensor module.

TABLE VI SPATIAL GAS DIFFUSION & DETECTION LATENCY BENCHMARKS

Distance (m)	Time to 400 PPM (s)	Time to 760 PPM (s)	Total Edge Shutoff (s)
0.5 m	3.2 s	6.5 s	6.70 s
1.0 m	8.4 s	14.2 s	14.41 s
1.5 m	15.1 s	24.8 s	25.01 s
2.0 m	24.6 s	38.9 s	39.11 s

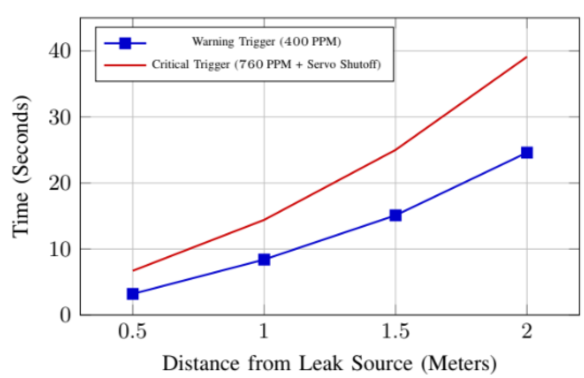

Fig. 7. Impact of spatial separation between the leak source and sensor node on concentration detection threshold delays.

As expected by molecular diffusion dynamics (Fick's law), the time required for gas concentration to reach the 760 PPM critical threshold scales non-linearly with spatial distance. At 0.5 m proximity, the edge AI engine executes physical servo shutoff within 6.70 seconds of initial gas discharge [cite: 14, 16, 243]. Even at a 2.0 m radius, the system successfully verifies the $\Delta PPM/\Delta t$ slope spike and isolates the cylinder in 39.11 seconds [cite: 13, 14], well before dangerous lower explosive limits (18, 000 PPM) accumulate in the room volume [cite: 22].

D. Network Failover and Offline Edge Autonomy

During real-world gas leakage incidents, power outages, electrical faults, or damage to home networking equipment can interrupt Wi-Fi or internet connectivity. Many cloud-dependent smart safety systems become partially or completely unavailable under such conditions, limiting their ability to perform remote monitoring or control. To ensure uninterrupted operation, the proposed system adopts an edge-first architecture in which all critical safety functions continue to operate locally, even in the absence of network connectivity.

1) Edge-Based Autonomous Operation:

All critical safety operations, including SPI-based sensor acquisition, Rate-of-Change ($\Delta PPM/\Delta t$) analysis, hazard evaluation, servo-controlled regulator shutoff, and relay-driven exhaust fan activation, are executed directly on the Raspberry Pi 4B. Since all decisions are processed locally, emergency actions are completed within approximately 200 ms without requiring communication with the cloud.

2) Local Telemetry Buffering:

If internet connectivity is lost, the networking module automatically switches to offline mode while the edge controller continues monitoring the environment. Instead of discarding sensor readings, gas concentration, timestamps, Cylinder ID, and system status are temporarily stored in a local SQLite database using a First-In-First-Out (FIFO) queue. This prevents data loss while ensuring uninterrupted leak detection and hazard mitigation.

3) Automatic Cloud Synchronization:

When the internet connection is restored, the system automatically detects network availability and uploads all buffered telemetry records to the Firebase cloud database in chronological order. This synchronization preserves the complete gas concentration history recorded during the offline period, allowing users and utility agencies to review incident data for monitoring, analysis, and future investigation.

VIII. DISCUSSION, FUTURE SCOPE, & CONCLUSION

A. System Discussion & Modularity

A key strength of the proposed architecture is its hardware decoupling. Local safety triggers operate on edge hardware independently of internet availability. Even during total cloud network disconnects, the Raspberry Pi continues to sample gas levels via SPI and trigger physical servo shutoff in under 200 ms. Furthermore, the system is source-agnostic: while evaluated using an LPG cylinder regulator setup, the physical relay output seamlessly interfaces with an in-line solenoid valve for piped natural gas (PNG) infrastructure.

B. Future Scope & Miscalculation Error Mitigation

While the proposed edge-AI platform achieves sub-second physical fuel isolation, real-world deployment faces challenges related to gas sensor cross-sensitivity and environmental drift, which can lead to false alarms and unnecessary operational overhead for gas agencies.

To resolve concentration miscalculations and mitigate unnecessary dispatches, future iterations will implement:

1) Multi-Sensor Data Fusion: Integrating Non-Dispersive Infrared (NDIR) optical hydrocarbon sensors alongside the MQ-2 element to execute cross-gas validation, ensuring volatile cooking vapors (e.g., ethanol, grease aerosols) are distinguished from actual propane/butane leaks.
2) Dynamic Environmental Compensation: Coupling a digital BME280 ambient sensor to continuously adjust sensor baseline resistance (R_0) relative to real-time kitchen temperature and relative humidity fluctuations.
3) Two-Stage Pre-Dispatch Escalation Protocol: To reduce unnecessary operational expenditure and avoid false emergency dispatches, the proposed system per-forms autonomous local hazard mitigation through im-mediate servo-based gas regulator shutoff and active ventilation. A 60-second automated confirmation window, delivered via IVR or mobile application, is then initiated before notifying gas utility agencies. Emergency dispatch requests are generated only if the occupant confirms the incident or no response is received within the confirmation period, thereby improving resource utilisation while maintaining timely emergency response.
4) TinyML Pattern Recognition: Deploying a lightweight edge-based hazard evaluation algorithm to analyse temporal gas concentration trends, distinguishing short-term cooking-related gas fluctuations from continuous gas leakage.

C. Conclusion

This paper presented a complete, closed-loop, AI-driven smart LPG safety and emergency reporting platform. By interfacing an MQ-2 gas sensor with a Raspberry Pi 4B via an MCP3008 SPI ADC and executing an edge Rate-of-Change ($\Delta PPM/\Delta t$) predictive algorithm, the system achieves fast, reliable leak verification. Closed-loop physical isolation using an MG996R servo motor isolates the fuel source within 200 ms, while an adaptive cloud logging protocol synchronizes high-resolution emergency data to Firebase and Blynk dashboards under 1.2 seconds. Combining edge physical mitigation with multi-role cloud analytics provides a robust cyber-physical framework for residential and commercial gas safety.

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