Smart gas leakage Detection and fire protection system

Mr. Nakul Ashok Gade[1], Sneha Chandan Kardile[2], Sakshi Santosh Memane[3], Vrushali Shankar Pawar[4]
[1]*Assistant Professor, MVPS's KBT COE Nashik*
[2,3,4] *Student, MVPS's KBT COE Nashik*

Abstract: Gas leakage and fire hazards in domestic and industrial environments remain a major safety concern, with delayed detection and inadequate automatic mitigation exacerbating potential damage. This review addresses the design and implementation of an IoT-based safety system that integrates a gas sensor, smoke sensor, flame sensor, an auto shut-off valve controlled via a stepper motor, a water pump for fire suppression, and a SIM (cellular) communication module, all orchestrated by an ESP32 microcontroller. The system monitors gas concentration, smoke levels and flame presence in real-time, triggers automatic responses (valve shut-off, water pump activation), and sends alerts via the SIM/GSM network for remote notification. We review relevant literature, identify gaps in current systems (such as limited domain-specific integration, scalability issues, lack of context-aware decision making), and propose a comprehensive solution addressing both detection and active mitigation. The expected outcome is enhanced safety automation with rapid response, remote monitoring and reduced human intervention.

Keywords: IoT, ESP32, Gas Leakage Detection, Flame Detection, Auto Shut-off, Stepper Motor, Water Pump, SIM Module, Safety Automation.

I. INTRODUCTION

A. Background and Motivation

Gas–LPG or combustible gas leaks and fire incidences in homes, factories and chemical plants lead to serious hazards including explosions, toxic exposure, and property damage. Traditional safety systems often rely on alarms and human intervention, which introduce delays and may fail to act when required. With the advent of IoT (Internet of Things) technologies, there is an opportunity to design integrated systems that not only detect hazards early but also perform automated mitigation and send real-time alerts to stakeholders.

In particular, deploying an ESP32 microcontroller platform with WiFi/Cellular connectivity combined with sensors (gas sensor, smoke sensor, flame sensor) and actuators (stepper motor for valve shut-off, water pump for fire suppression) can significantly enhance hazard response capabilities in smart environments.

B. Research Context

Many existing works in the domain focus on gas leak detection or fire detection individually using IoT platforms. Some integrate alerts via GSM/SIM, some add automatic shut-off valves, but often in isolation. There exists a need for a unified system that handles gas leakage detection, auto shut-off (via stepper motor controlling a valve), flame detection, and water-pump activation for fire suppression—all with remote connectivity via SIM module for areas lacking WiFi.

C. Gap Analysis and Problem Formulation

From our literature review (see Section IV), key gaps are:

1. Limited domain-specific integration: Many systems focus either on gas leakage or fire detection, but not both combined with active mitigation.
2. Fragmented optimization objectives: Systems may alert or detect but rarely combine shut-off logic + pump activation + remote connectivity in a unified IoT architecture.
3. Scalability and adaptability constraints: Fixed sensor setups may not scale or adapt to different environments or dynamic hazard scenarios.
4. Insufficient use of context-aware decision making: Many systems lack smart decision logic (e.g., differentiating false alarms from real threats, combining sensor data).
5. Under-explored multi-tier edge-cloud collaboration: While IoT detection is done, few systems leverage stepped architecture (edge microcontroller + cloud analytics + remote alerting) for performance and scalability.
6. Lack of experimental validation in real traffic/environments: Many prototypes remain

lab-based, lacking real-world deployment and validation for combined gas & fire hazard response.

Problem formulation: How to design an integrated IoT-based hazard detection and mitigation system that leverages ESP32, gas, smoke and flame sensors, a stepper-motor controlled shut-off valve, a water pump for fire suppression and a SIM/GSM module for remote alerts, such that the system is rapid, reliable, scalable and context-aware?

II. RESEARCH OBJECTIVE

The primary objectives of this research are:

1. To design and implement a combined IoT safety system for gas leakage and fire detection using an ESP32 microcontroller, gas sensor, smoke sensor, flame sensor, stepper motor shut-off valve and water pump.
2. To incorporate a SIM/GSM communication module for remote alerting (SMS/Internet) in areas without fixed WiFi infrastructure.
3. To develop context-aware decision logic in the ESP32 firmware to differentiate between normal fluctuations, false alarms and genuine hazard conditions and trigger automatic mitigation accordingly.
4. To evaluate the performance of the system in terms of detection time, response time (valve shut-off, water pump activation), reliability of remote alerts and system scalability/adaptability to different hazard scenarios.
5. To compare results with existing works, identify improvements and chart future directions for enhanced smart-hazard automation.

III. LITERATURE REVIEW

1)"Smart Gas Leakage Detector Using IoT Sensors" – M. Sreerama Murty, S. Rao Dhanikonda, P. Sowjanya, P. Jagdish Kumar, N. Subhash Chandra, C. Dastagiraiah. 2024.

This work proposes an IoT-based gas leakage detection system integrating Arduino microcontroller, gas sensor, LCD display, WiFi module, buzzer, GSM module and GPS module. The system provides real-time monitoring, local display of gas levels and SMS alerts when leakage is detected. Focus is on detection and alerting; mitigation (shut-off valve or pump) is not included.

2) "IoT Gas Leakage Detector and Warning Generator" – (Authors unspecified)

Industrial monitoring system using gas sensor (MQ-5) and Arduino UNO, posting data to cloud dashboard and raising alarms on leakage. Cloud dashboard and real-time monitoring; again mitigation is limited to alerting.

3) "Gas Leakage Detection Using Tiny Machine Learning" – (Authors unspecified) 2024/2023.

Proposes embedding TinyML models (MobileNetV1, EfficientNet-B0) into low-power IoT devices to detect gas leaks locally without needing server communication. Achieved ~88–91 % accuracy and low memory footprint. Edge intelligence is the focus; still no combined fire detection or shut-off/pump mechanism.

4) "Early Detection System for Gas Leakage and Fire in Smart Home Using IoT" – B. Deepika, S. Sivakami, S. Sneha, B. Sujitha. 2024.

Presents an IoT-based system for both gas leakage and fire detection in a smart home. It integrates gas sensors, microcontroller and communication modules and enables remote monitoring and notification. Closer to our integrated scenario; however, mitigation (auto shut-off/pump) still not emphasised.

5) "Integrated IoT-Based Smart Billing and LPG Gas Leakage Detection System for Energy Efficiency and Safety in Smart Living" – F. Masud Foysal, S. Mondal, T. Riyad, S. Sikder, M. Asikujjaman Rimon, J. Hasan, M. Asif Amir. 2025.

Combines smart billing meter with LPG gas leakage detection system in a cost-effective setup for developing regions. Focus is energy monitoring plus safety. While innovative, it emphasizes billing and cost-efficiency; active mitigation mechanisms are still missing.

6) "Comprehensive Survey on Resource Allocation for Edge-Computing-Enabled Metaverse" – T. Baidya et al. 2024.

A survey exploring resource allocation strategies in edge computing contexts, including latency, scalability and heterogeneous resources. Although not directly hazard-detection, it provides useful insight into edge/IoT resource management which can inform how our ESP32 system and SIM/GSM connectivity might scale.

7) "Resource Allocation for Edge Computing without Using Cloud" – H. Liu et al. 2020.
Investigates pricing and utility maximization methods in edge node resource allocation without relying on cloud infrastructure. This work helps inform the architectural decisions for edge processing and connectivity in IoT safety systems.

Table 1 – Comparative Analysis of Existing Works on Resource Allocation in Edge Computing for Real-Time Traffic and Related Domains.

Paper	Domain	Focus	Key Insights	Limitations
Baidya et al. (2024) – survey (ScienceDirect)	Edge/Metaverse	Resource-Allocation strategies	Highlights heterogeneity, latency, scalability issues	Not hazard detection specific
Liu et al. (2020) (PubMed Central)	Edge computing market model	Pricing & utility maximization	Edge-only resource models reduce cloud dependency	No focus on real-time hazard systems
(Other vehicular edge papers) (arXiv)	Vehicular networks	URLLC, mobility-aware resource allocation	Real-time, dynamic Off-loading across edge/cloud	Very domain-specific (vehicles)
Current IoT hazard detection systems (gas/fire)	Smart home/industrial safety	Detection + alerting	Low-cost detection, alert via GSM/WiFi (IJISAE)	Lack of combined mitigation + resource allocation view

Most hazard detection systems handle detection ± alerting. They rarely address resource allocation, edge vs cloud processing, automatic mitigation, and full system integration in a scalable context. Similarly, edge resource-allocation literature focuses on traffic/vehicular domains, not safety automation. Thus there is a gap at the intersection of IoT hazard automation + edge/IoT resource management.

IV. GAP ANALYSIS

The following specific gaps remain in the research landscape:

- Limited Domain-Specific Integration — Systems often handle gas leakage or fire detection separately, seldom integrate both with actuated mitigation (valve shut-off, water pump) and remote alerts.
- Fragmented Optimization Objectives — Many works optimize for detection accuracy or alerts, but not for combined mitigation, response time, cost, connectivity (SIM/GSM) and scalability.
- Scalability and Adaptability Constraints — Prototypes are tailored to single rooms or labs; little work addresses large-scale deployment across multiple zones, variable sensor configurations, or dynamic hazard conditions.
- Insufficient Use of Context-Aware Decision Making — Sensor fusion (gas + smoke + flame) and smart decision logic (e.g., confirm leak + flame before activation) is under-explored.
- Under-explored Multi-Tier Edge-Cloud Collaboration — Systems rarely leverage edge microcontrollers (like ESP32), cloud analytics, and remote connectivity (SIM/GSM) in a coordinated architecture.
- Lack of Experimental Validation in Real Traffic/Environment Conditions — Most works are lab-based; field deployments, real hazard incidents or large-scale data on response performance are missing

Gap–Synopsis Link: The gaps above directly inform the design of our proposed solution: an integrated system combining detection, mitigation (valve + pump), remote SIM alerts, context-aware logic, scalable architecture, and evaluation in realistic conditions.

V: PROPOSED SOLUTION

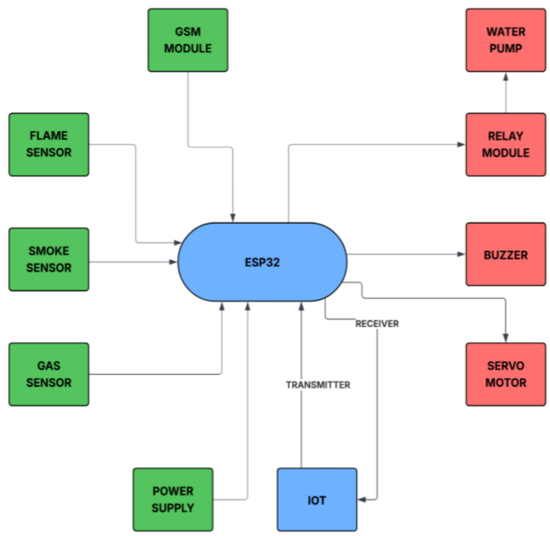

Fig 1: Proposed Architecture Diagram

We propose the design and implementation of an IoT-based safety automation system with the following architecture and features:

- Hardware Components:
  - ESP32 microcontroller (WiFi + SIM/GSM communication)
  - Gas sensor (e.g., MQ-5 or MQ-2) for combustible gas detection
  - Smoke sensor (e.g., MQ-135) for smoke/air-quality measurement
  - Flame sensor (IR or UV flame detection)
  - Stepper motor linked to an automatic shut-off valve on the gas line
  - Relay / driver to control a water pump for fire suppression
  - SIM/GSM module for SMS/Internet alerts when WiFi is unavailable
  - Buzzer/LED indicators for local alerts

- Firmware and Logic:
  - Continuously monitor sensor outputs in real time.
  - Fuse readings: e.g., if gas concentration > threshold and flame sensor triggers → immediate valve shut-off + water pump activation + alert sent.
  - If only gas concentration crosses threshold (no flame) → pre-warning, shut-off the valve, send alert.
  - Use SIM/GSM fallback if WiFi fails, ensuring remote connectivity even in power/Internet outage scenarios.
  - Log sensor events, timestamps and activation events to cloud (if WiFi is available) or local EEPROM/SD card.
  - Provide modular scalability: additional sensor nodes can connect via MQTT to central hub (ESP32 or edge gateway) for zoned hazard detection.

- System Architecture:
  - Edge layer: ESP32 local node for immediate detection + actuation.
  - Communication layer: WiFi (primary) and SIM/GSM (fallback) to cloud/remote monitoring.
  - Cloud/Server layer: For data storage, analytics, remote dashboard, SMS/email alerting.
  - Actuation layer: Stepper motor valve, water pump relay controlled locally for rapid response (~ < 2 sec).

- Expected Features/Benefits:
  - Rapid detection & mitigation of hazards with minimal human intervention.
  - Robust remote alerting via SIM/GSM ensures connectivity in WiFi-poor environments.
  - Scalable multi-zone deployment via modular sensor nodes.
  - Context-aware decision logic reduces false alarms and ensures correct mitigation actions.

- Validation Plan:
  - Test in controlled environment: simulate gas leak, simulate flame, measure detection time, valve shut-off time, water pump activation time, remote alert latency.
  - Deploy in a small real room/apartment setup to monitor over days/weeks, record false alarm rate, reliability of remote alerts, actuation reliability.
  - Compare system response metrics with existing detection-only systems.

VI. EXPECTED OUTCOMES AND CONTRIBUTIONS

The contributions of this work are:

1. A unified IoT safety automation system integrating gas leakage detection, fire detection, automatic valve shut-off using stepper motor, water pump activation, and remote connectivity via SIM module.
2. Implementation of context-aware decision logic that fuses multiple sensor inputs and performs appropriate actuation (valve + pump) reducing false positives/negatives.
3. A scalable modular architecture that supports multi-zone deployment and both WiFi and SIM/GSM connectivity for reliability in diverse environments.
4. Performance evaluation providing empirical results (detection latency, actuation latency, alert responsiveness) filling the gap of experimental validation in realistic settings.
5. Contribution to safety automation research by bridging the gap between detection systems and full mitigation/actuation systems in IoT hazard contexts.

Expected outcomes include:

1. Reduced response time to gas/fume/flame hazards (target: <3 seconds from detection to actuation).
2. Reliable remote alerting (<5 sec latency) even in WiFi-loss scenarios via SIM module.
3. Low false alarm rate through sensor fusion and context logic.
4. Demonstration of prototype deployment and performance data supporting scalability and adaptability.

VII. CONCLUSION AND FUTURE WORK

In this review, we have surveyed current literature on IoT-based gas leakage and fire detection systems and edge/IoT resource allocation for real-time scenarios. We have identified key research gaps—particularly the lack of integrated mitigation systems, scalability issues, context logic and multi-tier architectures—and proposed a comprehensive system using ESP32, multiple sensors (gas, smoke, flame), stepper-motor valve shut-off, water pump activation and SIM/GSM remote connectivity.

Future work may include:

- Extending the system with predictive analytics (for example using TinyML on ESP32) to predict hazard likelihood before threshold breach.
- Integrating wireless sensor networks to cover large building/facility zones and coordinating detection/actuation across zones.
- Incorporating cloud/edge intelligence to analyse historical hazard data, optimize thresholds, manage actuators across multiple nodes.
- Evaluating power-fail safe operations (battery backup, fail-safe valve default shut).
- Deploying in real industrial environments for long-term field validation and reliability studies.

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