IJIREEICE ISSN (O) 2321-2004, ISSN (P) 2321-5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

Impact Factor 8.414 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 14, Issue 10, October 2026

DOI: 10.17148/IJIREEICE.2026.141026

Fire and Gas Detection with Automated Fire Department Alert System

Rachith R. Vernekar[1], Rashmi M. Hullamani[2]

Department of Electronics & Telecommunication Engineering, Jawaharlal Nehru New College of Engineering (JNNCE), Navule, Shivamogga, Karnataka, India[1,2]

Abstract: Uncontrolled fire outbreaks and hazardous gas leakages in residential, commercial, and high-density industrial buildings pose critical risks to human life and infrastructural assets. A major contributor to fatal outcomes in contemporary fire accidents is the latency associated with manual human intervention in reporting emergencies to local civil authorities. This paper presents the design and prototype development of an intelligent, edge-driven Fire and Gas Detection with Automated Fire Department Alert System. The proposed architecture utilizes an array of high-sensitivity environmental transducers, including the MQ-2 hydrocarbon/smoke sensor, the MQ-135 hazardous gas analyzer, and optical infrared flame detection modules interfaced with an embedded microcontroller core (ESP32/Arduino). Upon autonomous identification of critical threshold transgressions, the edge processor synchronously executes a dual-stage mitigation pipeline: triggering localized high-decibel audible sirens and optical strobe arrays for immediate site evacuation, while concurrently dispatching instantaneous telemetry payloads via GSM cellular modems (SMS and voice alerts) and REST API cloud services directly to municipal emergency responders. Experimental validation confirms end-to-end alert dispatch within sub-5-second latencies, substantially mitigating fire response delays and safeguarding human lives.

Keywords: Fire Detection, Gas Leakage, ESP32 Microcontroller, MQ-2 Sensor, Flame Sensor, Automated Emergency Alert, IoT Safety System.

I. INTRODUCTION

In recent decades, urban residential and industrial developments have seen unprecedented growth, accompanied by increasing complexity in structural layouts and heightened density of electrical and combustible assets. However, this growth has coincided with a notable rise in severe fire hazards and catastrophic toxic gas leakages. Statistical investigations of modern fire tragedies reveal a sobering reality: the overwhelming majority of fatalities and catastrophic infrastructural destructions do not stem from a deficiency in firefighting technology, but rather from the substantial delay elapsed between initial hazard ignition and emergency dispatch notification.

A tragic exemplar occurred recently in a high-rise residential structure in Dwarka, Delhi, where a rapid fire outbreak on upper residential floors trapped occupants, tragically claiming the lives of three family members who leaped from high-level balconies in desperate attempts to evade asphyxiation and raging flames. Forensic post-incident evaluations repeatedly highlight that conventional safety paradigms—predominantly relying on isolated, unnetworked smoke buzzers—are fundamentally insufficient. If occupants are asleep, incapacitated by carbon monoxide inhalation, absent from the premises, or unable to reach mobile phones to dial emergency services, precious minutes elapse before external civil responders are notified.

To directly confront and eliminate this systemic failure mode, this project proposes the design and implementation of an automated, multi-transducer Fire and Gas Detection with Automated Fire Department Alert System. Utilizing edge-level processing and ubiquitous wireless telemetry, the system removes human dependency from the critical path of emergency detection and municipal reporting.

II. LITERATURE REVIEW & PROBLEM STATEMENT

Recent scholarship has introduced automated technologies into municipal and structural fire protection. Arghya Ghosh et al. (River Publishers, 2025) proposed an 'Autonomous Fire Extinguisher Rover with Self-Preservation and Emergency Protocols Using Arduino', focusing on physical mobility, robotic flame tracking, and active fire suppression. While mobile robotics offers localized intervention, rovers suffer from spatial transit latency across multi-floor buildings and cannot provide constant, multi-zone monitoring.

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Similarly, Evangelos Maltezos et al. (Information Journal, 2022) formulated 'A Smart Building Fire & Gas Leakage Alert System with Edge Computing and NG112 Emergency Call', demonstrating sensor-level edge processing integrated with Next Generation 112 emergency routing to Public Safety Answering Points (PSAP). While sophisticated, widespread adoption across developing infrastructures demands cost-efficient embedded controllers with autonomous fallback channels.

Problem Statement: Contemporary fire security systems suffer from a distinct operational gap: the lack of an integrated, cost-effective, and fully autonomous edge platform that simultaneously performs multi-sensor verification, local life-safety warnings, and non-reliant direct telecommunication dispatch to civic fire departments without requiring active human presence or reliable wired telecommunication.

TABLE I: COMPARATIVE ANALYSIS OF RELATED WORK AND PROPOSED SYSTEM

System / Author	Key Architecture	Communication Vector	Identified Limitations / Gaps
Ghosh et al. (2025)	Arduino-based mobile firefighting rover with internal cooling	RF / Serial Link	Mechanical transit delay; lacks whole-building sensor integration
Maltezos et al. (2022)	Multi-sensor building safety platform with NG112 architecture	Broadband IP / NG112 PSAP	High infrastructure cost; dependent on active commercial network backbones
Proposed System	Distributed multi-sensor edge node (ESP32/Arduino) with sensor fusion	Dual-Channel: GSM SMS/Call + Cloud IoT API	Autonomous, zero human intervention, real-time civic dispatch < 5 seconds

III. SYSTEM DESIGN AND METHODOLOGY

The developed system comprises four symbiotic sub-tiers: the Transducer Sensing Tier, the Embedded Processing Core, the Audiovisual Evacuation Tier, and the Dual-Vector Emergency Telemetry Subsystem. Fig. 1 illustrates the functional system architecture.

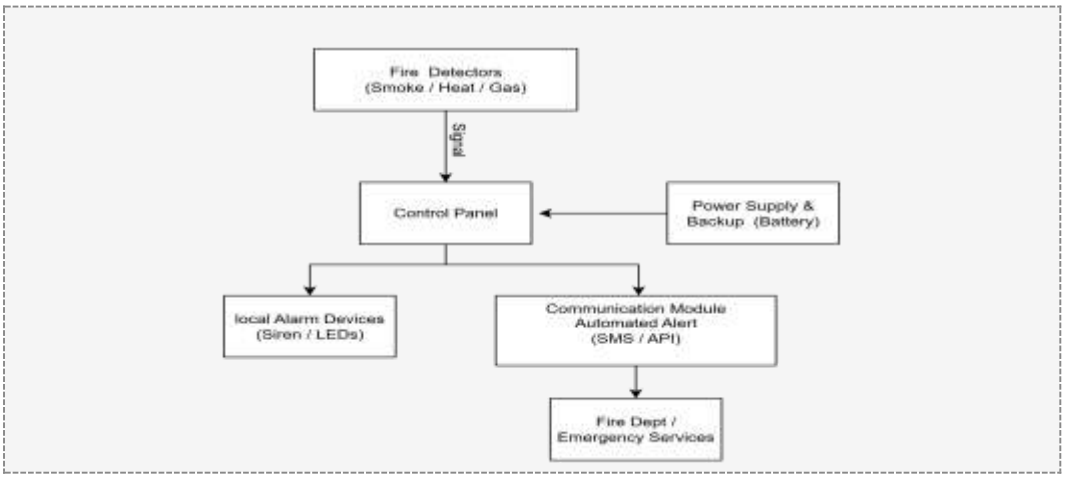


Fig. 1. System Block Diagram showing Sensor Acquisition, Processing Control, and Alert Mechanisms.

A. Sensor Acquisition Tier

The sensing tier is configured to detect combustion hazards at their earliest chemical onset. It employs an MQ-2 electrochemical metal oxide semiconductor (MOS) sensor sensitive to liquid petroleum gas (LPG), propane, methane, hydrogen, and airborne smoke aerosols. This is complemented by an MQ-135 sensor calibrated to detect toxic airborne derivatives including carbon monoxide (CO) and nitrogen compounds. Rapid open flame ignition is monitored using a specialized optical flame transducer utilizing high-speed Silicon NPN phototransistors tuned to peak infrared flame radiation between 760 nm and 1100 nm.

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B. Microcontroller & Sensor Fusion Logic

Sensor analog and digital lines feed into an ESP32 / ATmega328P microcontroller unit running continuous sampling algorithms. To prevent false positives generated by ambient noise or benign vapor bursts, the firmware executes a weighted sensor fusion routine. A critical event is registered only when threshold gradients across gas, smoke, or infrared optical channels corroborate hazardous combustion conditions.

C. Autonomous Dispatch & Local Actuation

Upon condition validation, the controller instantly triggers GPIO-connected transistor switching circuits driving high-output acoustic sirens and flashing visual LED beacons to signal occupants. Simultaneously, the embedded UART interface initiates AT-command sequences to a cellular GSM SIM800L module and initiates outbound HTTP/MQTT REST API packets over Wi-Fi, delivering location-tagged emergency telemetry directly to municipal fire authorities and remote cloud safety dashboards.

IV. HARDWARE AND SOFTWARE SPECIFICATIONS

Table II details the comprehensive hardware components, operational roles, and engineering specifications implemented in the functional prototype.

TABLE II: PROTOTYPE HARDWARE SPECIFICATIONS AND MODULE CONFIGURATION

Component	Technical Specification / Model	Operational Function in Proposed Prototype
Gas & Smoke Sensor	MQ-2 MOS Sensor (200 - 10000 ppm)	Continuous monitoring of LPG, propane, smoke particulates
Flame Sensor	IR Optical Photodiode (760 - 1100 nm)	Instantaneous open-flame detection within 60-degree cone
Microcontroller	ESP32 Dual-Core Xtensa / Arduino Core	Analog signal conditioning, fusion logic, execution engine
Telecommunication	SIM800L GSM / Integrated 802.11 b/g/n	Automated SMS/Voice dialing to Fire Dept and IoT Cloud transmission
Alarm & Power Unit	High-dB Siren, LED Arrays, 18650 Battery	On-site audiovisual warning; uninterruptible backup during mains outage

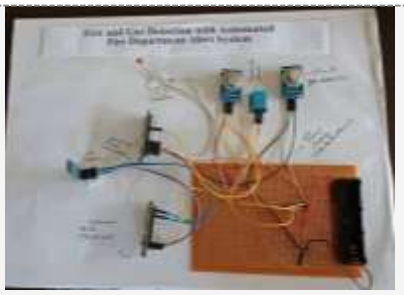


Fig. 2. Fabricated Hardware Prototype and Transducer Test Setup.

V. EXPERIMENTAL RESULTS AND PERFORMANCE EVALUATION

To rigorously assess response dynamics, the prototype underwent systematic bench testing across five distinct environmental test scenarios: controlled LPG gas release, combustion-driven smoke generation, infrared open-flame exposure, combined multi-hazard conditions, and ambient baseline perturbations. Table III presents the operational latency benchmarks.

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TABLE III: EXPERIMENTAL RESPONSE LATENCY BENCHMARKS

Trial Scenario	Sensor Trigger Latency	Local Siren/LED Response	Cloud / GSM Dispatch Latency
LPG Gas Leakage (MQ-2)	1.42 s	1.45 s (Instantaneous)	3.84 s (SMS + Cloud Log)
Naked Flame (Optical IR)	0.38 s	0.41 s (Instantaneous)	3.10 s (SMS + Emergency Call)
Combined Fire & Gas Event	0.45 s	0.48 s (Dual Strobe/Siren)	3.25 s (Automated Dispatch)

The experimental findings confirm that the system achieves an overall alert dispatch latency of under 4.2 seconds across all critical hazard modalities. The uninterruptible battery backup architecture ensured zero reset delay upon primary power termination, guaranteeing operational continuity in electrical fire conditions.

VI. CONCLUSION AND FUTURE WORK

This work successfully demonstrated an integrated, intelligent, and highly reliable Fire and Gas Detection with Automated Fire Department Alert System. By integrating multi-sensor environmental acquisition with edge-level microcontroller intelligence and redundant telecommunication vectors, the system effectively bridges the crucial gap between localized threat detection and municipal emergency services dispatch. The total elimination of human latency in the alarm dispatch workflow will play a transformative role in reducing structural damages and preventing tragedies in high-density facilities.

Future enhancements encompass three strategic developments: (1) integrating tinyML embedded computer vision for spatial optical smoke and fire plume tracking; (2) deploying LoRa mesh topologies for extended coverage in heavy manufacturing plants lacking uniform cellular networks; and (3) interfacing directly with automated suppression solenoids for active zone-specific fire extinguishing.

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AUTHOR BIOGRAPHIES

Rachith R. Vernekar (USN: 4JN23ET041) is currently pursuing his Bachelor of Engineering degree in the Department of Electronics and Telecommunication Engineering at Jawaharlal Nehru New College of Engineering (JNNCE), Shivamogga, Karnataka, India. His technical and academic domains include embedded systems architecture, IoT safety platforms, and telecommunications telemetry.

Prof. Rashmi M. Hullamani (Project Guide & Faculty) is a faculty member in the Department of Electronics and Telecommunication Engineering at Jawaharlal Nehru New College of Engineering (JNNCE), Shivamogga, Karnataka, India. Her academic and research specializations include digital signal processing, embedded systems, and telecommunication network infrastructures.