JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

DESIGN AND DEVELOPMENT OF AN AI-ENABLED AUTOMATED LPG GAS LEAKAGE AND FIRE DETECTION SYSTEM WITH REAL-TIME MONITORING AND SMART SAFETY CONTROLS

[1]Selvakumar T, [2]Dr. S. Somasundaram
[1]PG Scholar, M.Tech (Mechatronics), [2]Professor and Head (Research Supervisor)
[1,2]Department of Mechanical Engineering
[1,2]National Institute of Technical Teachers Training and Research (NITTTR), Chennai, Tamil Nadu, India

Abstract : *Gas leakage and fire incidents originating from domestic and industrial Liquefied Petroleum Gas (LPG) installations remain a persistent cause of injury, property damage, and loss of life. Conventional safety devices rely on a single gas sensor and a fixed alarm threshold, making them prone to false alarms, insensitive to cylinder depletion, and incapable of autonomous corrective action. This paper presents the design, development, and experimental evaluation of an AI-enabled automated LPG gas leakage and fire detection system that fuses multiple sensing modalities with a rule-based decision-making framework built around an ESP32 microcontroller. The system employs an MQ-2/MQ-6 combustible gas sensor for leakage detection, an infrared flame sensor supplemented by camera-based image-processing verification (Python/OpenCV) for reliable fire detection, and a Force Sensitive Resistor (FSR) for continuous cylinder-load monitoring. On a confirmed hazard, the system autonomously actuates a servo-controlled gas valve and a relay-controlled exhaust fan, and dispatches real-time alerts through a Telegram bot. A working prototype was assembled and subjected to structured bench-level and system-level testing across more than 200 trials. The results show 96.5% gas-leak detection accuracy, a sub-2.3-second mean detection-to-actuation response time, and a reduction in false fire-alarm rate from approximately 32% to 8.7% attributable to the image-verification stage, confirming that a carefully engineered rule-based multi-sensor fusion approach can deliver dependable, low-cost, field-deployable hazard protection without the computational overhead of a full machine-learning pipeline.*

IndexTerms *- LPG gas leakage detection, fire detection, rule-based artificial intelligence, sensor fusion, Force Sensitive Resistor, image processing, ESP32, Telegram bot, real-time monitoring, smart safety controls.*

I. INTRODUCTION

Liquefied Petroleum Gas (LPG) is the dominant domestic cooking fuel across urban and semi-urban India and is also widely used in small commercial kitchens and light industrial processes. LPG is a compressed, highly flammable hydrocarbon mixture, and any uncontrolled leakage in a confined space can rapidly accumulate to a concentration capable of supporting combustion or explosion. Conventional gas safety devices installed in Indian households are, in the overwhelming majority of cases, standalone electrochemical or semiconductor gas alarms that sound a local buzzer once a fixed concentration threshold is crossed. Such devices depend entirely on a human being present, awake, and able to act on the alarm; they offer no automatic corrective action, no remote notification, and no discrimination between a genuine leak and sensor drift caused by cooking fumes or humidity. Most fire alarms installed in kitchens likewise rely on a single flame or smoke sensor, which is highly susceptible to false triggering from sunlight, kitchen flames, or artificial lighting.

Data compiled from Oil Marketing Companies indicate that more than 6,700 LPG-related accidents were reported nationally between 2016-17 and 2024-25, with Maharashtra, Uttar Pradesh, Tamil Nadu, Bihar, and Rajasthan together accounting for roughly half of the reported cases [7]. Reported causes span pilferage, unauthorised transfer of gas between cylinders, worn hose pipes and O-rings, improper handling, and neglect of routine maintenance. Users typically have no early or predictive indication of how much LPG remains in a cylinder, and conventional fire and gas alarms provide no means of remote awareness when the occupant is away from home. These gaps, together with the well-documented problem of false alarms in single-sensor fire detectors, define the motivation for the present work: an integrated system that senses gas concentration, verifies fire optically, tracks cylinder load continuously, acts autonomously, and notifies the user remotely in real time.

The aim of this work is to design, develop, and experimentally evaluate an intelligent, fully automated gas leakage and fire detection system that combines multi-sensor fusion, rule-based artificial intelligence, and image-processing verification to accurately detect hazards, autonomously actuate ventilation and gas-isolation mechanisms, continuously monitor gas cylinder load, and provide real-time remote notifications via a Telegram bot for timely user intervention. The specific objectives are to: (i) design a multi-sensor system for gas leakage and fire detection; (ii) integrate an FSR sensor for continuous cylinder-load monitoring with low-level alerts; (iii) develop an OpenCV-based image-processing verification module to reject false fire alarms; (iv) implement a rule-based decision-making framework to control the safety actuators; (v) enable real-time remote notification through a Telegram bot; and (vi) experimentally validate the integrated system against conventional single-sensor approaches reported in the literature.

II. LITERATURE REVIEW

Ahmed and Primajaya [2] designed and experimentally evaluated an ESP32-based early-warning system for LPG leakage using an MQ2 sensor with local buzzer/LED alarms and remote notification through the Blynk IoT platform, reporting a detection sensitivity of 96.7% and an average local response time of 1.4 s across 30 controlled trials. Sherin et al. [13] integrated an MQ-2 gas sensor and an infrared flame sensor into an ESP32-based autonomous housekeeping robot, combining hazard monitoring with relay-controlled ventilation, but relying on a single static threshold per sensor rather than a fused decision rule. Susilo and Rakhmawati [15] implemented an ESP32-based fire and LPG leakage detection system with multiuser Telegram notification, reporting 100% detection accuracy within a miniature test enclosure and an end-to-end notification delay of 1.8-1.9 s.

A well-established limitation of hardware flame and smoke sensors is their susceptibility to false triggering from sunlight, artificial lighting, and reflective surfaces. Irianto et al. [9] developed a dual-stage fire crisis management system on a Raspberry Pi in which an infrared flame sensor provides an initial trigger and an OpenCV-based HSV colour-segmentation and contour-analysis pipeline subsequently confirms the flame, achieving 96.4% detection accuracy and a 91.7% reduction in false-alarm rate relative to a single-sensor baseline. This fast-trigger-plus-vision-confirmation pattern is adopted, in a simplified rule-based form suited to a resource-constrained microcontroller, in the present work. Mondal et al. [10] developed an IoT-based smart kitchen in which a load-cell arrangement continuously measures LPG cylinder weight alongside MQ-series gas detection and Telegram-based alerts, demonstrating that continuous weight monitoring can be practically combined with gas-leak detection and automated actuation in a single low-cost embedded design.

Across the reviewed literature, Telegram-based alerting is consistently reported as reliable and low-latency (typically one to a few seconds end-to-end) [15][10]. Two broad decision paradigms recur: fixed-threshold rule-based logic executed directly on a microcontroller, and machine-learning inference typically executed on a more capable edge or cloud node. For a bench-level, cost-constrained prototype targeting deterministic, explainable, and easily verifiable safety behaviour, a rule-based multi-parameter fusion approach, augmented with a lightweight image-verification step, was judged the more appropriate design choice. However, no single reviewed system combines gas-leak detection, image-verified fire detection, continuous cylinder-load monitoring, and autonomous dual-actuator response within one rule-based, ESP32-centred architecture with Telegram-based remote alerting. This combination constitutes the specific research gap addressed by the present work.

III. PROPOSED SYSTEM METHODOLOGY

A. Overall System Architecture

The system follows a sense-decide-act-notify architecture built around an ESP32 microcontroller as the central processing node. Four input sensors (MQ-2/MQ-6 gas sensor, IR flame sensor, a paired camera for image verification, and the FSR cylinder-weight sensor) feed the ESP32, which executes rule-based decision logic and drives two categories of output: safety actuators (servo-controlled gas valve, relay-controlled exhaust fan, and a buzzer) and a communication path (the device's built-in Wi-Fi, used to reach the Telegram Bot API for real-time remote alerts). Fig. 1 illustrates the complete block diagram of the system.

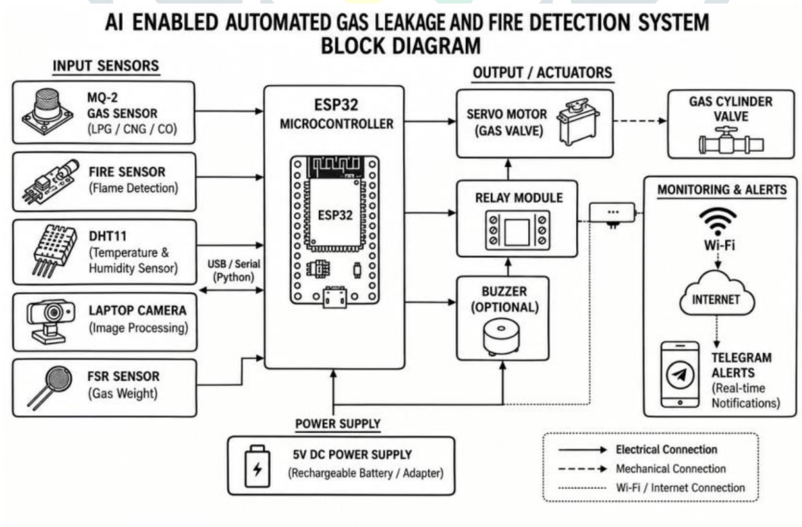

Fig. 1 Overall system architecture / block diagram

The MQ-2 and IR flame sensors interface directly with the ESP32's digital and analogue input pins, while the camera used for fire-image verification is interfaced through a paired computer running the OpenCV-based verification script over a USB/serial link, since continuous image processing of this kind exceeds the resource budget appropriate for the ESP32 itself. The FSR sensor provides a further analogue input that is converted into a cylinder-load percentage. On the output side, the ESP32 drives a servo motor connected to the gas cylinder valve through direct PWM control, and a relay module that switches the exhaust fan. All confirmed hazard events are relayed over Wi-Fi to the Telegram Bot API.

B. Hardware Description

The ESP32 is a low-cost, low-power system-on-chip from Espressif Systems that integrates a dual-core Xtensa processor (up to 240 MHz) with built-in Wi-Fi/Bluetooth, providing sufficient GPIO, ADC, and PWM peripherals to interface all sensors and actuators on a single board. Gas leakage is sensed using an MQ-2/MQ-6 tin-dioxide sensor whose conductivity increases with combustible-gas concentration (LPG, propane, hydrogen), providing both a digital threshold output and a proportional analogue output. Flame detection uses a BPV10-type silicon PIN photodiode (spectral range 570-1040 nm, peak sensitivity 920 nm) that produces a digital flame-present signal. Cylinder-load monitoring is achieved with a Force Sensitive Resistor (FSR) mounted beneath the cylinder base; its resistance, read through a voltage-divider circuit connected to the ESP32's ADC, is mapped after calibration to an approximate load percentage. An FSR was preferred over a strain-gauge load cell for this prototype for its low cost, thin profile, and mechanical simplicity, at the expense of fine linear accuracy.

Gas-supply isolation is implemented using a hobby servo motor mechanically coupled to the cylinder valve lever, driven by the ESP32 through 50 Hz PWM and moved incrementally to avoid mechanical shock and current surges. Ventilation is provided by a 12 V DC exhaust fan switched through a relay module, which electrically isolates the fan's higher current draw from the ESP32's GPIO. A piezo buzzer provides an immediate local audible warning independent of network connectivity. Table I summarises the complete hardware component list.

TABLE I. Hardware Components and Functions

No.	Component	Function
1	ESP32 Dev. Board	Central processing, sensor acquisition, actuator control, Wi-Fi
2	MQ-2 / MQ-6 Gas Sensor	Combustible gas (LPG) concentration sensing
3	BPV10 IR Flame Sensor	Initial flame / fire trigger
4	Camera (paired PC)	Live image capture for OpenCV flame verification
5	Force Sensitive Resistor	Continuous cylinder-load estimation
6	Servo Motor	Gas cylinder valve open/close actuation
7	Relay Module	Switches the exhaust fan under ESP32 control
8	Exhaust Fan (12 V DC)	Ventilates the area on confirmed hazard
9	Piezo Buzzer	Immediate local audible alarm
10	Regulated Power Supply	5 V logic supply and 12 V actuator supply

C. Software and Image-Processing Verification

The ESP32 firmware was developed in C++ using the Arduino IDE; it initialises all peripherals, samples the gas, flame, and FSR sensors, executes the rule-based decision logic, drives the servo/relay outputs, and manages the Wi-Fi connection to the Telegram Bot API. Fire-image verification runs as a Python/OpenCV script on a paired computer connected over USB/serial. When the IR flame sensor triggers, the ESP32 signals the paired computer to capture and analyse a camera frame: the frame is converted from RGB to the HSV colour space, flame-coloured pixel regions are isolated using an empirically tuned hue/saturation/value range, morphological erosion-dilation removes isolated noise pixels, and the remaining candidate regions are filtered by contour area and boundary irregularity before a flame trigger is confirmed. Remote alerting uses the Telegram Bot API over HTTPS; on a confirmed hazard event the ESP32 issues an HTTPS request to the Bot API's message-sending endpoint, delivering an alert to the user's Telegram account typically within a few seconds.

D. Rule-Based Decision Logic

The core intelligence of the system is a compact rule set that fuses evidence from the gas sensor, the image-verified flame sensor, and the FSR before commanding any actuator. This design deliberately avoids a full machine-learning classifier: a small, explicit rule set is fully deterministic, is straightforward to test exhaustively, and executes comfortably within the ESP32's resource budget, while still providing meaningful sensor fusion. Table II summarises the four rules (R1-R4) implemented in the firmware.

TABLE II. Rule-Based Decision Logic (R1-R4)

Rule	Condition	Action
R1 - Gas Leakage	Gas concentration exceeds calibrated threshold, sustained over sampling window	Buzzer + Telegram alert; exhaust fan ON; servo valve closed
R2 - Fire / Flame	IR flame sensor triggers AND camera image analysis confirms flame signature	Fire alert + fan ON + valve closed; rejected as false trigger if image analysis does not confirm
R3 - Cylinder Depletion	FSR-derived weight/weight-loss rate falls below calibrated low-cylinder threshold	Low-cylinder alert dispatched to user
R4 - Combined Evidence	Gas leakage (R1) and confirmed fire (R2) both active simultaneously	Highest-priority emergency action: immediate valve cutoff, fan ON, priority alert

The complete system operates continuously through initialisation, sensor sampling with multi-sample averaging, flame verification on trigger, rule evaluation, actuation, remote notification, and a conservative recovery policy once readings return to normal for a sustained period, avoiding premature re-opening of the gas valve.

IV. IMPLEMENTATION

The hardware prototype was assembled on a breadboard-based test rig with the ESP32 as the central node, each sensing and actuation function wired to an independent GPIO pin to avoid contention between safety-critical signals. The firmware was implemented and uploaded through the Arduino IDE, using standard, well-documented libraries for Wi-Fi connectivity, servo PWM generation, and I2C communication with an onboard status display, avoiding the need for custom low-level driver code. The image-processing verification module was implemented in Python using OpenCV on a paired laptop connected to the ESP32 over USB/serial, and the Telegram bot was registered once, with its bot token and the user's chat identifier stored in the firmware configuration.

During integration, the principal challenges encountered were current-surge-induced brown-outs during servo actuation, mitigated by incrementally stepping the servo angle in 2-degree increments; cross-sensitivity of the MQ-2/MQ-6 sensor to cooking vapours, mitigated by multi-sample averaging and threshold calibration against a controlled LPG release; and occasional false flame triggers from ambient light, addressed through the image-verification stage described in Section III(C).

V. Results and Discussion

Testing was carried out in a staged manner: bench calibration of the gas sensor and FSR, controlled LPG-leak trials, flame and light-interference trials (with and without image verification), cylinder-depletion simulation, a simulated-kitchen field test, and full end-to-end integration runs exercising the complete sense-decide-act-notify chain. Table III summarises the component-level validation outcomes, and Table IV summarises the quantitative system-level performance results obtained across more than 200 trials.

TABLE III. Component-Level Validation Summary

Module	Component	Validation Outcome
Gas Sensing	MQ-2 / MQ-6 sensor	Calibrated and validated against controlled LPG release
Fire Detection	IR flame sensor + camera	Validated; false-alarm filtering against light sources confirmed
Cylinder Monitoring	FSR weight sensor	Calibrated; depletion-rate detection verified
Safety Actuation	Servo valve + exhaust fan	Fully tested end-to-end under all rule-triggered scenarios
Remote Alerts	Telegram bot	Verified live across gas, fire, and low-cylinder-weight events

TABLE IV. System-Level Performance Results

Metric	Observed Result
Gas-leak detection accuracy (final trial set)	96.5%
Detection-to-actuation response time	< 2.3 s (mean)
False fire-alarm rate, flame sensor only	≈ 32% of light-interference trials
False fire-alarm rate, with image verification	8.7% of light-interference trials
Light-flash false-trigger rejection rate	92.0%
FSR cylinder-weight measurement error	± 3%
Telegram alert delivery latency	< 3 s (mean)

Adding the image-verification stage reduced the false fire-alarm rate under light-interference conditions from approximately 32% (flame sensor alone) to 8.7%, consistent in direction, though smaller in absolute magnitude on this bench-level prototype, with the larger reductions reported for dual-stage sensor-plus-vision fire detection in [9]. The gas-leak detection accuracy of 96.5% and the sub-2.3-second detection-to-actuation response time are consistent with results reported for comparable ESP32-based single-parameter gas-detection systems [2], while additionally providing multi-parameter fusion, autonomous dual-actuator response, and cylinder-load monitoring.

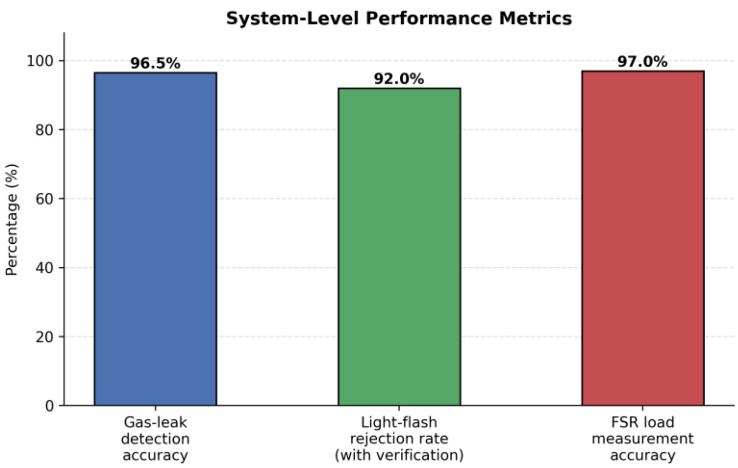

Fig. 2 System-level performance metrics

To isolate the specific contribution of the image-verification stage, flame-detection trials were repeated under four controlled conditions (30 trials per condition), summarised in Table V.

TABLE V. Flame-Detection Trial Breakdown (30 trials/condition)

Stimulus Condition	True Flame	Flame-Only Alarm	With Image Verif.
Open flame, close range	Yes	30/30	30/30
Open flame, moderate range (~40 cm)	Yes	27/30	26/30
Direct sunlight through window	No	11/30 (false)	2/30 (false)
Torch / camera flash	No	9/30 (false)	3/30 (false)

The flame sensor alone retains high sensitivity to genuine flame but generates a substantial number of false triggers under non-flame light-interference conditions; enabling image verification reduces these false triggers markedly, at the cost of a small reduction in true-positive confirmation at moderate range, reflecting the expected trade-off of adding a confirmatory filtering stage. Table VI compares the proposed system against the typical single-sensor systems reported in the literature reviewed in Section II.

TABLE VI. Comparison with Typical Reported Systems

Feature	Typical Reported Systems	Proposed System
Detection parameters	Gas only, or gas + single flame sensor	Gas + cylinder weight + image-verified flame
Decision logic	Static single threshold per sensor	Multi-parameter rule-based fusion (R1-R4)
False-alarm handling	None, or basic buzzer only	Image-verification stage filters light-based false triggers
Autonomous actuation	Rarely implemented	Servo valve cutoff + exhaust fan, closed-loop
Cylinder-load monitoring	Present in some load-cell designs [10]	Present, via low-cost FSR sensing
Remote alerts	SMS/email in some designs; Telegram in others	Telegram bot, real-time (< 3 s observed)

The experimental results confirm that all individual modules function correctly in isolation and are fully integrated end-to-end, with the combined-evidence rule (R4) consistently producing the fastest and most decisive safety response. Telegram-based notifications for gas leakage, confirmed fire, and low cylinder weight were delivered reliably and with low latency across all tested scenarios. Overall, the results support the conclusion that a carefully engineered, multi-parameter, rule-based fusion approach offers a practical, deterministic, and cost-effective balance of detection accuracy, false-alarm suppression, response speed, and remote awareness for a bench-level domestic LPG safety prototype, without the computational overhead of a full machine-learning pipeline.

VI. Conclusion and Future Work

This paper has presented the design, implementation, and experimental evaluation of an AI-enabled automated LPG gas leakage and fire detection system that fuses combustible-gas concentration, image-verified flame detection, and continuous cylinder-load monitoring through a compact, rule-based decision framework built around an ESP32 microcontroller. The system autonomously actuates a servo-controlled gas valve and a relay-controlled exhaust fan on confirmed hazard detection and dispatches real-time alerts through a Telegram bot. A working prototype, subjected to structured component- and system-level testing, demonstrated 96.5% gas-leak detection accuracy, a sub-2.3-second mean detection-to-actuation response time, and a reduction in false fire alarms from approximately 32% to 8.7% attributable to the image-processing verification stage, together with reliable, low-latency Telegram-based remote alerting. The specific contribution of this work lies in combining, within a single low-cost, rule-based, ESP32-centred architecture, elements individually reported in the literature but not previously combined in one system: image-verified fire detection, continuous FSR-based cylinder-load monitoring, dual-actuator autonomous response, and Telegram-based real-time remote alerting.

The present work has limitations: evaluation was conducted at bench and simulated-kitchen scale rather than long-duration field deployment; the image-verification module requires a paired computer rather than running entirely on the ESP32; and the FSR-based load estimate, while adequate for coarse-grained warning, is less precise than a calibrated strain-gauge load cell. Future work will explore on-device TinyML inference for flame verification, fuzzy or graded response logic, a mobile companion application with live sensor graphs and manual override, cloud-based data logging for predictive maintenance, multi-cylinder/multi-room scaling, extended field trials with regulatory compliance evaluation, and a load-cell upgrade for higher-precision cylinder-weight estimation.

VII. Acknowledgment

The authors thank the Department of Mechanical Engineering, National Institute of Technical Teachers Training and Research (NITTTR), Chennai, for the laboratory facilities and support extended during this work.

VIII. References

[1] Adafruit Industries, Force Sensitive Resistor (FSR) Guide, Adafruit Learning System, 2013.

[2] A. Ahmed and A. Primajaya, “Design and Experimental Evaluation of an ESP32-Based IoT Early Warning System for LPG Gas Leakage,” Jurnal Janitra Informatika dan Sistem Informasi, vol. 6, no. 1, pp. 1-7, 2026.

[3] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, “Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications,” IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2347-2376, 2015.

[4] Bureau of Indian Standards, IS 4246: Specification for LPG Regulators for Domestic, Commercial and Industrial Applications, BIS, New Delhi, 2002.

[5] Espressif Systems, ESP32 Series Datasheet, Version 3.9, 2022.

[6] Espressif Systems, Arduino-ESP32 Core Programming Guide, https://docs.espressif.com, 2023.

[7] Factly Media & Research, “Maharashtra, UP, Tamil Nadu, Bihar and Rajasthan Account for Half of LPG Accidents in Last Few Years,” Factly Data Story, Dec. 2024.

[8] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, “Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions,” Future Generation Computer Systems, vol. 29, no. 7, pp. 1645-1660, 2013.

[9] Irianto, J. A. J. Alsayaydeh, A. Wong Yoon Khang, M. Farid, and S. G. Herawan, “Design and Implementation of a Smart Dual-Stage Fire Crisis Management System Using Raspberry Pi for Safety and Security Applications,” International Journal of Safety and Security Engineering, vol. 15, no. 10, pp. 2081-2091, 2025.

[10] B. Mondal, B. Goswami, N. Banik, R. Kundu, and N. Sowmya, “Automation and Monitoring Smart Kitchen Based on IoT,” International Research Journal of Modernization in Engineering Technology and Science, vol. 5, no. 5, pp. 2220-2229, 2023.

[11] OpenCV, OpenCV Open Source Computer Vision Library Documentation, https://docs.opencv.org, 2024.

[12] Petroleum and Explosives Safety Organisation, Guidelines for Safe Handling, Storage and Transport of LPG Cylinders, Government of India, Nagpur, 2023.

[13] N. R. Sherin, P. J. Mubarak, Aseem Manoj, S. Ashkar, and Akber Saifudeen, “Fire Gas Leakage Detection Housekeeping Robot using ESP32,” International Journal of Engineering Research & Technology, vol. 15, no. 7, 2026.

[14] Songle Relay, SRD-05VDC-SL-C Single-Pole Double-Throw Relay Datasheet, n.d.

[15] M. M. Susilo and L. Rakhmawati, "Implementation of Internet of Things (IoT) in Fire and LPG Leakage Detection System Based on ESP32 with Multiuser Notification," INAJEEE (Indonesian Journal of Electrical and Electronics Engineering), vol. 8, no. 2, pp. 59-68, 2025.

[16] Telegram, Telegram Bot API Official Documentation, https://core.telegram.org/bots/api, 2024.

[17] Texas Instruments, LM393 Low-Offset Voltage Dual Comparators Datasheet, SNOSBK9F, 2015.

[18] TowerPro, SG90 9 g Micro Servo Motor Datasheet, n.d.

[19] Vishay, OLED-128O032D-LPP3N00000 128×32 Graphic OLED Datasheet, n.d.

[20] Vishay Semiconductors, BPV10 Silicon PIN Photodiode Datasheet, Document No. 81502, Rev. 3, 1999.

[21] Waveshare, MQ-2 Gas Sensor User Manual, n.d.