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Autonomous Fire Extinguisher Rover with Self-Preservation and Automatic Emergency Alert System

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Abstract: Fire accidents remain one of the most serious hazards threatening human life, property, and the environment, and traditional firefighting methods frequently expose responders to dangerous conditions while suffering from delayed response in con-fined or hazardous areas. This paper presents the design and development of an Autonomous Fire Extinguisher Rover with Self-Preservation and Automatic Emergency Alert System, a mobile robotic platform that detects and suppresses fire in hazardous environments while simultaneously alerting nearby individuals and emergency responders in real time. The rover integrates infrared flame sensors, an MQ2 smoke/gas sensor, and a camera-based vision module to monitor environmental conditions and confirm fire presence through a two-stage, multi-modal detection scheme. A dual-controller architecture comprising an ESP32 microcontroller and a Raspberry Pi 4 enables real-time sensor polling, mo-tor and pump actuation, OpenCV-based HSV colour-segmentation fire detection, MJPEG live video streaming, and Telegram-based emergency alerting. On confirming a fire, the rover autonomously approaches the source, activates a servo-directed water-pump sup-pression mechanism, and notifies designated users wirelessly. Experimental evaluation across five complete end-to-end missions showed a camera detection latency of approximately 300–400 ms, an average approach distance of 48.4 cm from the flame, an aver-age fire-suppression time of 5.9 s, Telegram alert delivery within 1–3 s, and zero false activations after threshold tuning, confirm-ing that the proposed system provides a practical, low-cost, and reliable solution for reducing human risk and improving emer-gency response in fire-prone environments such as warehouses, industrial facilities, and residential buildings.
Keywords: Autonomous fire extinguishing rover, flame and smoke sensors, ESP32, Raspberry Pi, OpenCV fire detection, emergency alert system, self-preservation, finite state machine.

I. INTRODUCTION

Fire accidents are among the most dangerous hazards affecting residential, industrial, and public environments, often causing severe loss of life, property damage, and environmental de-struction. Rapid detection and immediate suppression are es-sential to control fire outbreaks before they escalate into major disasters; however, conventional firefighting methods expose human responders to significant risk, particularly in confined spaces, industrial zones, or areas filled with toxic smoke and extreme heat.

With advances in robotics, embedded systems, and sensor technology, autonomous robotic platforms are increasingly be-ing explored to assist in hazardous firefighting operations. Such robots can detect, monitor, and suppress fire continuously with-out direct human exposure, reaching locations that may be un- safe for human firefighters. This work proposes an Autonomous Fire Extinguisher Rover with Self-Preservation and Automatic Emergency Alert Sys-tem that combines multi-sensor fire detection, autonomous nav-igation, targeted water-spray suppression, and real-time wire-less alerting on a single mobile platform. The rover employs infrared flame sensors and an MQ2 smoke sensor for close-range fire confirmation, while a camera mounted on a Rasp-berry Pi 4 performs HSV-based colour segmentation for vision-based detection. An ESP32 microcontroller governs real-time sensor polling, motor control, and suppression actuation through a finite state machine, while the Raspberry Pi manages high-level tasks such as live MJPEG video streaming and Telegram-based emergency notification. The objective of this system is to reduce the risk faced by human firefighters, shorten response time during fire emergencies, and provide reliable, low-cost autonomous fire safety coverage for warehouses, industrial fa-cilities, and residential buildings.

II. LITERATURE SURVEY

The development of autonomous firefighting robots has gained considerable research attention due to the growing need for rapid response and improved safety during fire emergencies. Advances in embedded systems, sensor fusion, wireless communication, and robotic automation have enabled the design of intelligent platforms capable of detecting fire, monitoring envi-ronmental parameters, and performing suppression tasks with minimal human intervention.

Ghosh et al. [1] developed an autonomous fire-extinguisher rover using flame and smoke sensors on an Arduino platform, where sensor signals were processed to control a motor driver and relay module so that the rover could navigate toward a fire and perform suppression.

While the system demonstrated au-tomated detection and extinguishing, it lacked live video mon-itoring, remote communication, and relied on only basic ob-stacle handling. Espressif Systems [2] describes the ESP32 microcontroller as a versatile platform offering integrated Wi-Fi/Bluetooth communication and multiple peripheral interfaces (UART, SPI, I2C) suited to multi-sensor embedded applica-tions, although its computational capacity is limited for tasks such as video processing, motivating the pairing of the ESP32 with a more capable companion processor. The Raspberry Pi Foundation's documentation on the Raspberry Pi platform [3] highlights its suitability for higher-level processing tasks including computer vision and network services that comple-ment microcontroller-based real-time control.

Chen [4] examined multi-sensor fusion strategies for fire de-tection in autonomous systems, reporting that combining mul-tiple sensing modalities improves detection reliability over single-sensor approaches, a principle reflected in the two-stage IR-and-vision confirmation scheme adopted in this work. Smith et al. [5] explored AI-based fire recognition using Tensor-Flow Lite on embedded devices, indicating a pathway toward learning-based detection that could supersede simple colour-threshold methods. Kaur and Singh [6] reviewed wireless communication protocols for industrial IoT applications, informing the choice of Wi-Fi-based Telegram alerting used for emergency notification in the proposed rover.

Patel and Singh [7] presented a comprehensive review of autonomous firefighting robot design, cataloguing common architectural patterns and outlining open challenges such as limited payload, sensor re-liability in smoke, and power autonomy. Wang et al. [8] in-vestigated sensor fusion techniques specifically for fire detec-tion in robotic systems, reinforcing the value of combining IR, gas, and vision-based cues. Kumar and Park [9] stud-ied energy-efficient embedded system design for safety-critical applications, relevant to managing the limited onboard bat-tery capacity of mobile firefighting robots. Garcia et al. [10] proposed multi-agent coordination strategies for firefighting robotics, suggesting a direction for extending single-rover systems such as the one presented here toward cooperative multi-unit deployments.

Building on these works, the system proposed in this paper differentiates itself by combining a dual-controller (ESP32 + Raspberry Pi 4) architecture, a two-stage multi-modal fire confirmation pipeline (vision-based HSV segmentation together with redundant IR flame sensing), targeted servo-directed sup-pression, live MJPEG monitoring, and real-time Telegram alert-ing into a single low-cost, fully autonomous platform — ad-dressing the live-monitoring and remote-alerting gaps identi-fied in several of the systems reviewed above.

III. PROPOSED SYSTEM AND METHODOLOGY

A. System Overview

The proposed system is a four-wheeled mobile rover that au-tonomously detects, approaches, and extinguishes small fires while issuing real-time alerts. It is organised into six func-tional modules: the Sensor Module, the Processing and Con-trol Unit, the Navigation and Motor Control Module, the Fire Suppression Module, the Communication and Alert System, and the Monitoring System.

The Raspberry Pi 4 and ESP32 are mounted centrally; three IR flame sensors and the MQ2 gas sensor are positioned at the front for forward-facing fire detection; a servo-mounted spray nozzle is fixed at the front-centre; and the water reservoir is secured at the rear to balance the chassis.

B. Sensor Module

Three analogue infrared (IR) flame sensors (left, centre, and right) provide directional close-range flame detection and are interfaced to the ESP32 analogue GPIO pins, while an MQ2 gas/smoke sensor interfaced to the Raspberry Pi GPIO pro-vides an independent early-warning signal for elevated com-bustible gas concentration.

This arrangement allows the rover to both localise the direction of a flame and corroborate fire presence using a chemical-sensing modality.

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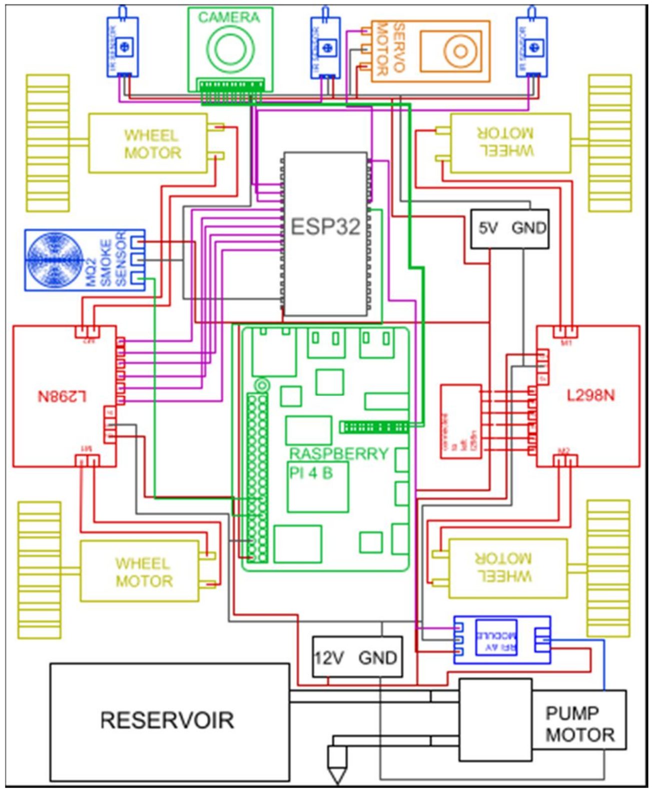

Figure 1: Overall architecture of the proposed autonomous fire extinguisher rover

C. Processing and Control Unit

A dual-controller architecture is used to balance real-time re-sponsiveness with computational capability.

1) *ESP32 microcontroller:* acts as the primary real-time controller, polling the IR flame sensors, executing a finite state machine governing navigation and suppression, and driving the motor and pump actuators with low latency.
2) *Raspberry Pi 4:* handles computationally heavier tasks OpenCV-based vision processing, MJPEG video streaming, and Telegram messaging — and communicates with the ESP32 over a GPIO signalling link, allowing the two controllers to coordinate detection and actuation decisions.

D. Navigation and Fire Suppression

Autonomous movement is achieved using an L298N dual H-bridge motor driver controlling four DC geared motors, en-abling forward, reverse, and turning manoeuvres under ESP32 control. Once fire is confirmed, the ESP32 transitions to a suppression state in which a relay module energises a small DC water pump (R385) while a servo motor orients the spray nozzle toward the detected flame direction, enabling targeted rather than omnidirectional water delivery.

E. Vision-Based Fire Detection

The Raspberry Pi captures live frames via a CSI camera mod-ule and converts each frame from RGB to HSV colour space to segment flame-coloured regions using two HSV threshold ranges combined with a bitwise-OR mask. Morphological open-ing and closing operations remove noise and fill small gaps in the mask, after which contours are extracted and validated using an area threshold together with a roundness criterion,

$$\text{roundness} = \frac{4\pi \cdot \text{area}}{\text{perimeter}^2}, \qquad (1)$$

Fire Detection Confidence

The fire confirmation process is based on the combined output of multiple sensing modalities.

$$F_c = w_1 F + w_2 S + w_3 V \qquad (2)$$

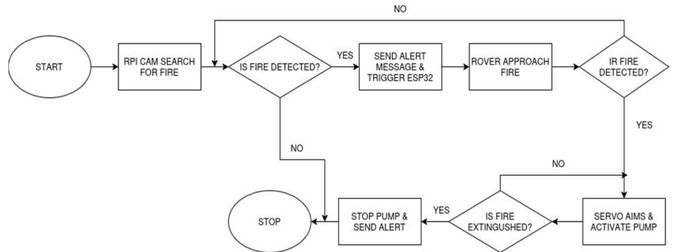

Figure 2: finite state machine of rover operation

where
F= flame sensor detection S= Smoke sensor detection V= vision based detection
w1, w2, w3= weighting factor
to reject irregular non-fire regions. A temporal confirmation rule requiring a minimum number of consecutive positive frames suppresses transient false detections before a GPIO trigger sig-nal is asserted to the ESP32.

F. *Communication, Alerting and Monitoring*
The Raspberry Pi hosts a lightweight MJPEG HTTP stream-ing server that publishes the annotated live video feed to any browser on the local network, and a Telegram bot that pushes status notifications — system startup, normal/idle state, fire-detected alert, and fire-extinguished confirmation — to desig-nated recipients, ensuring that users or emergency responders are informed within seconds of a fire event regardless of their physical location.

G. *Self Preservation Mechanism*
The self-preservation feature protects the rover from excessive heat exposure during fire suppression. The rover halts at a pre-defined safe distance before activating the water pump, thereby avoiding direct contact with the flame source. The targeted suppression mechanism reduces unnecessary approach toward hazardous zones while maintaining effective extinguishing per-formance. This strategy improves operational safety and pre-vents damage to onboard electronic components.

H. *Working Principle*
During normal operation the rover remains in an idle/searching state, continuously polling its sensors. When the IR array and/or the vision pipeline confirm a fire with the required temporal consistency, the ESP32 state machine transitions through ap-proach, suppression, and verification states: the rover advances toward the flame, halts within effective spray range, activates the pump and servo nozzle to extinguish the fire, sends a Tele-gram alert, and finally resets autonomously to the idle state, ready for subsequent fire events without manual intervention.

IV. EXPERIMENTAL RESULTS
The complete prototype was assembled and evaluated through module-level tests followed by five complete end-to-end mis-sion trials. Table I summarises the vision-based fire detection performance across different ambient lighting conditions, and Table II consolidates the overall system performance against the defined design targets.
The single false positive observed (caused by a sunlight re-flection on the floor) was eliminated by increasing the mini-

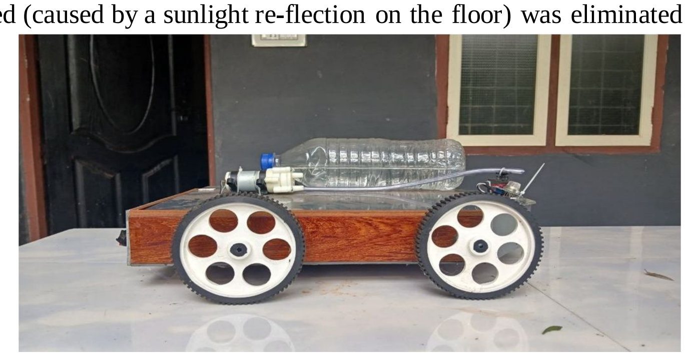
Figure 3: Experiment Setup Used For Fire Detection And Suppression Testing

TABLE 1
VISION-BASED FIRE DETECTION PERFORMANCE

Lighting Condi-tion	Detected	Avg. Con-firm Frames	Avg. Latency (ms)
Bright overhead	Yes	3	≈300
Dim lighting	Yes	3–4	≈400
Semi-dark room	Yes	3	≈300
Sunlight patch	Yes	3	≈300
No fire (baseline)	N/A	—	—

TABLE 2
OVERALL SYSTEM PERFORMANCE SUMMARY

Performance Metric	Target	Achieved
Camera detection la-tency	<500 ms	≈300–400 ms
IR sensor confirmation delay	<500 ms	200 ms
Average stopping dis-tance	40–60 cm	48.4 cm
Average extinguish time	<10 s	5.9 s
Telegram alert delivery	<5 s	1–3 s
MJPEG stream frame rate	≥8 FPS	8–10 FPS
False positives after tun-ing	0	0
End-to-end missions passed	5/5	5/5

mum fire-area threshold from 3,000 to 5,000 pixels, after which no further false activations were recorded.
The three IR flame sensors achieved stable detection at dis-tances up to 50 cm after individual potentiometer calibration, with intermittent detection at 100 cm, and the 200 ms debounce eliminated noise-induced false triggers under fluorescent light-ing. The MQ2 sensor registered a clear rise in ADC output (from a baseline of approximately 400–500 counts to above 1800 counts on a 12-bit ADC) within 2–3 seconds of gas in-troduction, confirming its role as a secondary early-warning detector. During navigation trials, the rover consistently halted within the effective spray range of the pump, and all test fires (single and dual candle configurations) were extinguished in under 8 seconds from pump activation. Across all five end-to-end missions, the system detected fire, approached the source, suppressed the flame, delivered the Telegram alert, and au-tonomously reset to the idle state without manual intervention or communication failure, confirming that all defined perfor-mance targets were met.

V. ADVANTAGES AND LIMITATIONS

The proposed rover offers enhanced human safety by remov-ing the need for direct human presence during initial fire re-sponse, rapid sub-second automatic activation, multi-sensor redundancy across vision, infrared, and gas-sensing modal-ities, targeted rather than omnidirectional suppression, real-time remote video monitoring without dedicated client soft-ware, instant mobile push notification through Telegram, fully autonomous state recovery for repeated deployments, and a low-cost, modular hardware design suited to educational and small-facility use.

The current prototype is nevertheless constrained by a lim-ited onboard water reservoir (approximately 500 mL) suited only to small fires, a restricted battery runtime of approxi-mately 20–30 minutes, the absence of active obstacle avoid-ance during navigation, operation limited to flat indoor sur-faces, reduced detection reliability in dense smoke, dependence on Wi-Fi connectivity for alerting and streaming, sensitivity to strong ambient infrared or fire-coloured objects, the use of wa-ter as a suppression agent unsuitable for Class B/C fires, and the absence of survivor or structural-hazard assessment capa-bility. These limitations define clear directions for future enhancement, including deep-learning-based fire classification, ultrasonic/ToF-based obstacle avoidance, multi-agent suppres-sion with selectable extinguishing agents, thermal imaging for smoke-penetrating detection, and multi-modal (cellular/LoRa) communication redundancy.

VI. CONCLUSIONS

This paper presented the design, implementation, and experi-mental validation of an Autonomous Fire Extinguisher Rover with Self-Preservation and Automatic Emergency Alert Sys-tem. The dual-controller architecture, combining an ESP32 for low-latency sensing and actuation with a Raspberry Pi 4 for vi-sion processing and wireless communication, proved effective in balancing real-time response with computational capability. The two-stage, multi-modal detection scheme — vision-based HSV segmentation together with redundant IR flame sensing achieved zero false suppression activations after threshold tuning, while the finite state machine ensured predictable and fully autonomous operation across repeated fire events. Exper-imental results across five complete end-to-end missions con-firm that the system reliably detects fire within a few hundred milliseconds, approaches and extinguishes the flame within seconds, and delivers emergency alerts almost instantaneously, demonstrating that a cost-effective, fully autonomous fire de-tection and suppression platform can be realised using widely available embedded hardware and open-source software. The modular architecture provides a practical foundation for future enhancements such as AI-based fire classification, obstacle-avoidance navigation, thermal imaging, and multi-agent co-ordination, supporting deployment in residential, commercial, and industrial fire-safety applications.

VII. ACKNOWLEDGMENT

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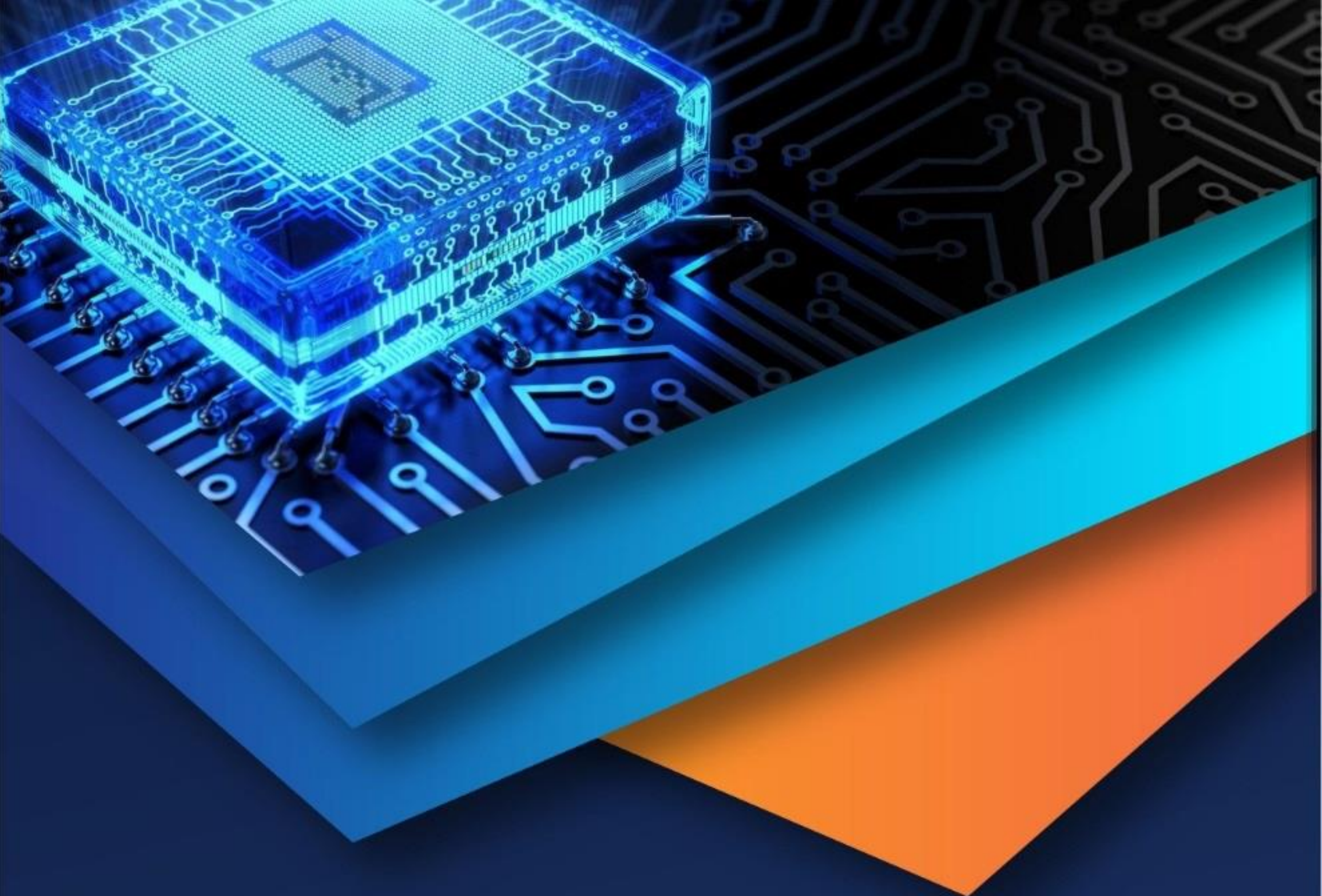
REFERENCES

[1] A. Ghosh, S. Guha, K. N. Singh, C. Misra, A. Samui, and A. Dutta, "Autonomous Fire Extinguisher Rover with Self-Preservation and Emer-gency Protocols Using Arduino," Journal of Mobile Multimedia, vol. 21, no. 3-4, pp. 599–618, 2025.
[2] Espressif Systems. (2024) ESP32 Technical Reference Manual. [Online]. Available: http://www.espressif.com/en/support/resources
[3] Raspberry Pi Foundation. (2024) Raspberry Pi 4 Model B. [Online]. Available: http://www.raspberrypi.org/products/
[4] H. R. Chen, "Multi-sensor fusion for fire detection in autonomous sys-tems," Journal of Fire Science and Technology, vol. 45, no. 3, pp. 234–247, 2023.
[5] J. Smith, A. Kumar, and L. Brown, "AI-based fire recognition using Ten-sorFlow Lite on embedded devices," IEEE Trans. Ind. Electron., vol. 69, no. 6, pp. 5678–5686, 2022.
[6] M. Kaur and N. Singh, "Wireless communication protocols for industrial IoT applications," Int. J. Embedded Syst., vol. 14, no. 2, pp. 112–123, 2024.
[7] S. Patel and R. Singh, "Design and development of autonomous firefight-ing robots: A comprehensive review," Int. J. Robot. Autom., vol. 36, no. 4, pp. 312–329, 2024.
[8] L. Wang, X. Zhao, and Y. Chen, "Sensor fusion techniques for fire detec-tion in robotic systems," Sensors, vol. 22, no. 3, p. 1150, 2022.
[9] D. Kumar and H. Park, "Energy-efficient embedded systems for safety-critical applications," IEEE Trans. Ind. Informat., vol. 18, no. 1, pp. 400–410, 2022.
[10] R. Garcia, T. Alvarez, and P. Romero, "Multi-agent coordination for fire-fighting robotics," in Proc. IEEE Int. Conf. Robot. Autom., 2023, pp. 540–547.
[11] X. Ren, Y. Zhao, and Z. Wang, "Research on Accurate Fire Source Local-ization and Seconds-Level Autonomous Firefighting," Scientific Reports, vol. 15, 2025.
[12] A. Hasib, M. Rahman, and S. Islam, "An IoT-Integrated Autonomous Fire Extinguishing and Monitoring System," Proceedings of the IEEE National Conference on Intelligent Machines, 2025.
[13] H. G. Medewar and S. Patil, "A Review on Fire and Smoke Detection with Intelligent Control for Enhanced Safety Using Machine Learning and Internet of Things," Cureus Journal of Engineering and Technology, vol. 2024, pp. 1–15, 2024.
[14] S. Danish, M. Afghah, and A. Khan, "Vision-Based Fire Management System Using Autonomous Aerial Vehicles and Artificial Intelligence," Artificial Intelligence Review, vol. 58, 2025.
[15] K. Jindal, A. Wang, D. Thakur, A. Zhou, and T. Krajnik, "Design and Deployment of an Autonomous Unmanned Ground Vehicle for Urban Firefighting Scenarios," Proceedings of MBZIRC, pp. 1–10, 2021.



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