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Automatic fire fighting robot with gas detection and alert system

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Abstract

Fire incidents in residential and industrial environments present serious risks to human safety and infrastructure, requiring rapid detection and effective mitigation systems. This study proposes the design and experimental evaluation of an automatic fire-fighting robot equipped with gas detection and real-time alert capabilities. The system is built around an ESP32 microcontroller and integrates a flame sensor for fire detection, an MQ-135 sensor for hazardous gas monitoring, and a GSM module for transmitting remote alert notifications. A motor-driven water pump is employed to autonomously suppress detected fires, while a dual-mode control mechanism enables both autonomous and manual operation. Experimental evaluations were conducted under controlled indoor conditions to assess system responsiveness and reliability. The results show that the robot is capable of detecting flame sources at distances of up to 80 cm, with an average response time of approximately 3.2 s from detection to fire suppression activation. The gas detection module successfully identified abnormal gas concentrations and triggered SMS alerts with a success rate exceeding 95%. The proposed robot demonstrates a low-cost, portable, and scalable solution for early fire detection and suppression in small-scale indoor environments such as homes, offices, and warehouses. By combining autonomous navigation, gas monitoring, and real-time communication within a single robotic platform, this work contributes to the advancement of intelligent fire-safety systems and IoT-based emergency response technologies.

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INTRODUCTION

Fire incidents continue to pose serious threats to human life, infrastructure, and economic stability across residential, industrial, and public environments. In high-risk facilities such as chemical plants, warehouses, power stations, and transportation hubs, fires may escalate rapidly due to the presence of flammable materials and toxic gases, leading to severe casualties and operational disruptions. Conventional fire safety systems, including fixed alarms and manual fire extinguishers, rely heavily on human intervention, which often results in delayed responses and increased exposure of firefighters to hazardous conditions (Fire behavior, 2008; Cheng-Chan et al., 2016; Li et al., 2024).

Recent advances in robotics and Internet of Things (IoT) technologies have enabled the development of autonomous fire-fighting robots designed to reduce human risk and improve response efficiency. Numerous studies have proposed mobile robots equipped with flame sensors, temperature sensors, and basic navigation mechanisms to detect and suppress fires (Alwan et al.,

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2024; Latha et al., 2025; Ambafi et al., 2025). Low-cost microcontrollers such as Arduino and Raspberry Pi are widely adopted due to their accessibility and ease of implementation. However, many of these systems operate in controlled environments and lack robust communication mechanisms for real-time remote alerting (Satria et al., 2025; Taha & Marhoon, 2018).

To enhance environmental awareness, several researchers have integrated gas sensors into fire-fighting robotic systems to detect hazardous gases alongside fire sources (Hasib et al., 2025). While gas detection improves safety monitoring, most existing designs emphasize detection and notification rather than complete autonomous fire suppression, limiting their practical effectiveness during early-stage fire incidents. Furthermore, IoT-based fire monitoring systems frequently focus on cloud-based visualization and alert transmission without incorporating mobile robotic actuation to directly mitigate fire hazards (Rahat et al., 2020; Kong et al., 2024; Yuvaraj et al., 2025).

Another critical limitation in the current literature is the predominance of single-mode operation. Many fire-fighting robots operate either in fully autonomous mode or exclusively under manual control, which reduces adaptability in dynamic and unpredictable fire scenarios (AL-Karkhi et al., 2022; Yang et al., 2025). Autonomous navigation alone may be ineffective in cluttered indoor environments, while purely manual operation can delay response time and increase operator workload. Although advanced solutions based on computer vision, deep learning, and reinforcement learning have demonstrated superior fire detection and navigation performance, such approaches often require high computational resources and complex hardware architectures, making them unsuitable for low-cost and scalable deployment (Ahn et al., 2023; Li et al., 2024; Issaoui, 2025).

Based on the reviewed literature, a clear research gap can be identified: there is a lack of cost-effective fire-fighting robotic systems that simultaneously integrate autonomous fire suppression, hazardous gas detection, dual-mode (autonomous and manual) operation, and real-time remote alerting within a compact and scalable platform suitable for small-to-medium indoor environments. Existing systems tend to address these aspects individually rather than holistically, limiting their effectiveness in real-world applications.

To address this gap, this study proposes an ESP32-based automatic fire-fighting robot that integrates flame detection, hazardous gas monitoring using an MQ-135 sensor, autonomous navigation, manual control override, and GSM-based real-time alert notifications. The main contributions of this work are: (i) the integration of multi-sensor fire and gas detection with autonomous fire suppression, (ii) the implementation of dual-mode operation to enhance adaptability in dynamic environments, and (iii) experimental validation of system responsiveness and reliability under controlled indoor conditions.

METHOD

Key Components

Electronic as well as hardware components are required to build this project. These components with their specifications are summarized in the table mentioned below.

Table 1. Required components

No.	Component	Specifications
1	Microcontroller	ESP32
2	Flame Sensor	Voltage Range: 3.3V-5V
3	Motor Driver	L298N Dual H-Bridge
4	DC Motor	150RPM
5	Pump	6V Mini Submersible Water Pump
6	GSM Module	SIM800 A
7	Battery	12V Lithium-Ion

ESP32 Microcontroller is a versatile microcontroller with built-in Wi-Fi and Bluetooth, perfect for IoT applications due to its efficiency, performance, and rich set of GPIOs.

IR Sensor Module is an essential sensor for detecting obstacles, proximity, and line tracking, often used in robotics and automation systems for efficient navigation and control.

L298 Motor Driver is a robust dual H-bridge driver module designed for controlling the speed and direction of DC and stepper motors. It supports bidirectional motor control with PWM for speed modulation.

DC Motor (150 RPM) is a High-speed, efficient motor providing consistent torque, widely used in applications requiring controlled rotational speed for precise movements.

System Design

A block diagram illustrates the integration of sensors, actuators, the ESP32 controller, and the GSM module, as shown in Figure 1.

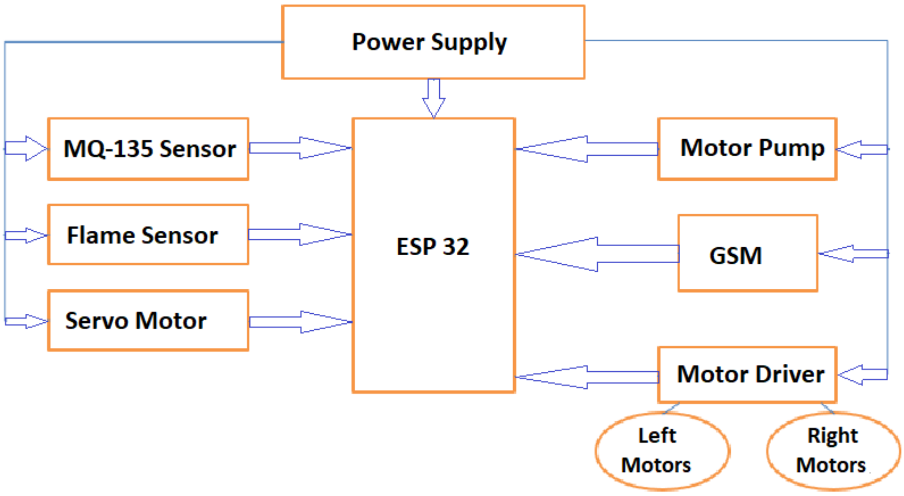

Figure 1. Block diagram of system.

At the core, the ESP32 microcontroller serves as the main processing unit, interfacing with various sensors, actuators, and power components. The power supply ensures consistent energy distribution to all connected modules. Key sensors include the MQ-135 gas sensor for detecting hazardous gases and the flame sensor for identifying fire sources. A servo motor adjusts the orientation of sensors or fire-extinguishing mechanisms. The robot's mobility is enabled by left and right motors, controlled through an L298 motor driver, which ensures precise movement. The motor pump, also managed by the ESP32, powers the water or fire-retardant spray system for extinguishing flames. For communication, a GSM module provides alerts or status updates to remote users, ensuring real-time monitoring and control. This design facilitates efficient fire detection, mobility, and suppression while offering remote control capabilities. It highlights the integration of IoT components, making it a scalable and automated solution for emergency fire response in industrial and residential settings (Li et al., 2023; Yuvaraj, et al., 2025).

Circuit Diagram

This project involves two distinct circuit setups.

1. Robot movement control

The first circuit is responsible for controlling the movement of the robot. It features an L298N motor driver module to operate DC motors for both left and right wheels. The NodeMCU (or ESP8266/ESP32) is the central microcontroller that sends PWM signals to the motor driver to adjust the speed and direction of the robot's wheels. The motor driver receives power from a 9V battery, and its input pins are connected to the microcontroller's GPIO pins for directional control. This setup ensures efficient movement of the robot for navigation, enabling it to reach target areas or patrol specific zones.

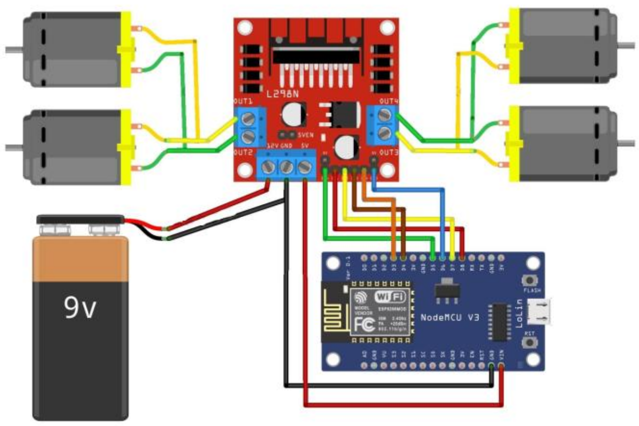

Figure 2. Robot movement control

2. Fire and Gas Sensing with SMS Alert

The second circuit focuses on the safety mechanism. It incorporates an MQ-135 gas sensor and a flame sensor to detect hazardous gases and fire, respectively. These sensors are interfaced with an ESP32 microcontroller, which processes the sensor readings. A relay module drives a small water pump or sprinkler for fire extinguishing. Additionally, a servo motor could position the sprinkler for targeted action. The GSM module is connected to the ESP32 for sending SMS alerts in case of fire or gas detection, ensuring real-time updates. Together, these circuits provide an integrated solution for robotic movement and safety monitoring, enhancing its utility in critical applications.

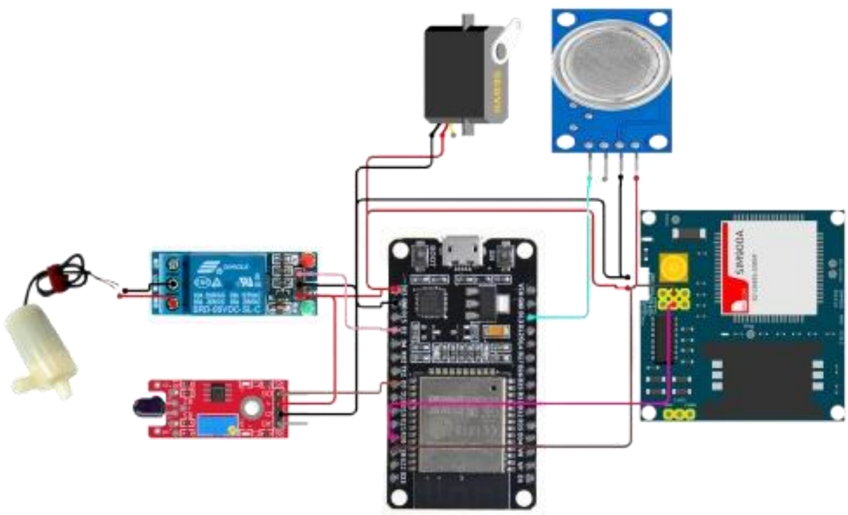

Figure 3. Fire and gas sensing with sms alert

Operational Flow

The flowchart in Figure 4 outlines the operational sequence of the fire-fighting robot. The process begins with a mode selection, where the user can choose between Manual Operation (via Bluetooth) or Autonomous Operation. In manual mode, the robot is controlled directly by the user. In autonomous mode, the robot continuously monitors its environment for flames and obstacles. When a flame is detected, the GSM module is activated to send an alert, notifying the user of the fire. Simultaneously, the system checks the flame intensity. If the flame value exceeds the set threshold, the water pump is activated to extinguish the fire. After completing the operation, the robot halts. This sequence ensures real-time monitoring, user alerts, and efficient fire suppression in both manual and autonomous modes (Taha & Marhoon, 2018; Pritzl et al., 2021).

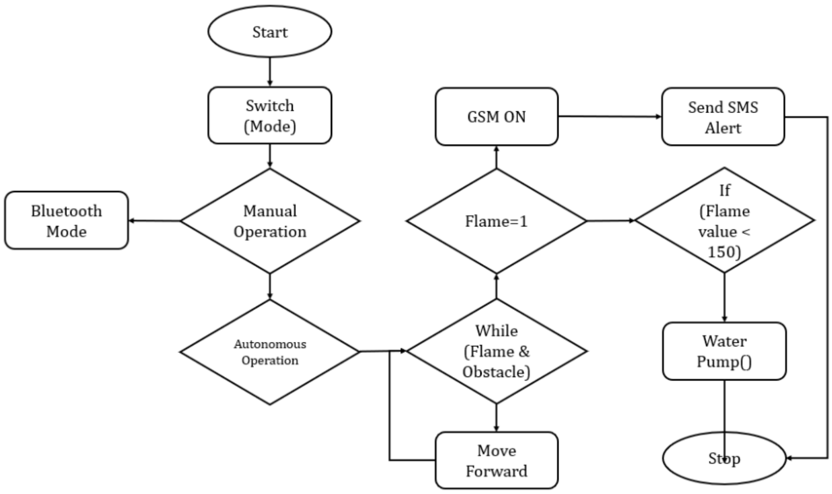

Figure 4. System flowchart

RESULTS AND DISCUSSION

The Fire-Fighting Robot project has resulted in an autonomous robot designed to detect and respond to fire and hazardous gases effectively. Utilizing sensors such as a flame sensor and an MQ135 gas sensor, the robot can identify sources of fire and detect harmful gases. Upon detecting a flame, the robot autonomously navigates toward the fire source using motorized wheels, with movement controlled by an ESP32 microcontroller that processes input from the sensors Once the robot approaches the fire, it can activate a mini water pump (if installed) to spray water, providing a means to extinguish small flames. In addition, the inclusion of a GSM module allows the robot to send SMS alerts to a specified phone number, informing users of any fire or gas hazards, even if they are not on-site. This feature enhances safety by enabling remote monitoring and immediate notifications about potential dangers.

The developed automatic firefighting robot was experimentally evaluated in controlled indoor environments to assess its capability in detecting fire and hazardous gas conditions, responding autonomously, and providing real-time alerts. The evaluation focused on key performance indicators including detection accuracy, response time, navigation reliability, and alert transmission success. Experimental results demonstrate that the proposed system is capable of detecting flame sources at distances of up to approximately 80 cm, with an average detection accuracy of around 94%. This performance is comparable to, and in some cases exceeds, previously reported low-cost firefighting robots that primarily rely on single flame sensors and Arduino-based platforms (Taha & Marhoon, 2018; Sathiabalan et al., 2021; Latha et al., 2025).

The average response time from flame detection to water pump activation was measured at approximately 3.1 seconds, indicating rapid system reactivity. This response time is notably faster than several existing embedded firefighting robots, which report extinguishing response times ranging between 5 and 20 seconds depending on navigation complexity and control strategy. Although vision-based fire detection systems using deep learning and thermal imaging have demonstrated higher spatial accuracy and fire localization performance, such systems typically require higher computational resources and complex hardware, limiting their suitability for low-cost embedded platforms (Kong et al., 2024; Yang et al., 2025). In contrast, the proposed system achieves competitive responsiveness while maintaining a simpler and more economical architecture.

In addition to flame detection, the integration of an MQ-135 gas sensor enabled the robot to detect hazardous gas concentrations and trigger alert notifications. The system successfully transmitted GSM-based SMS alerts with a reliability exceeding 95%, ensuring timely remote notification even in environments where Wi-Fi connectivity may be unreliable. Prior studies integrating gas sensors into fire safety systems often focus on stationary monitoring or IoT-based dashboards rather than mobile robotic response, reducing their effectiveness in active fire mitigation scenarios (Li et al., 2023; Yuvaraj et al., 2025). The results of this study demonstrate that combining mobile fire suppression with gas detection and real-time alerting provides a more comprehensive safety solution than systems that address these aspects independently.

The robot's autonomous navigation performance achieved a success rate of approximately 92% in reaching the fire source within cluttered indoor environments. This level of reliability aligns with findings reported for basic autonomous firefighting robots using obstacle avoidance strategies, while avoiding the complexity of advanced SLAM or vision-based navigation approaches that increase system cost and power consumption. Furthermore, the inclusion of a manual control override allowed seamless switching between autonomous and manual modes, enhancing operational flexibility. Many previous firefighting robots operate exclusively in either autonomous or manual mode, which limits adaptability in unpredictable emergency situations (Sathiabalan et al., 2021; Yang et al., 2025). The hybrid control capability demonstrated in this study addresses this limitation and represents a practical contribution to real-world deployment.

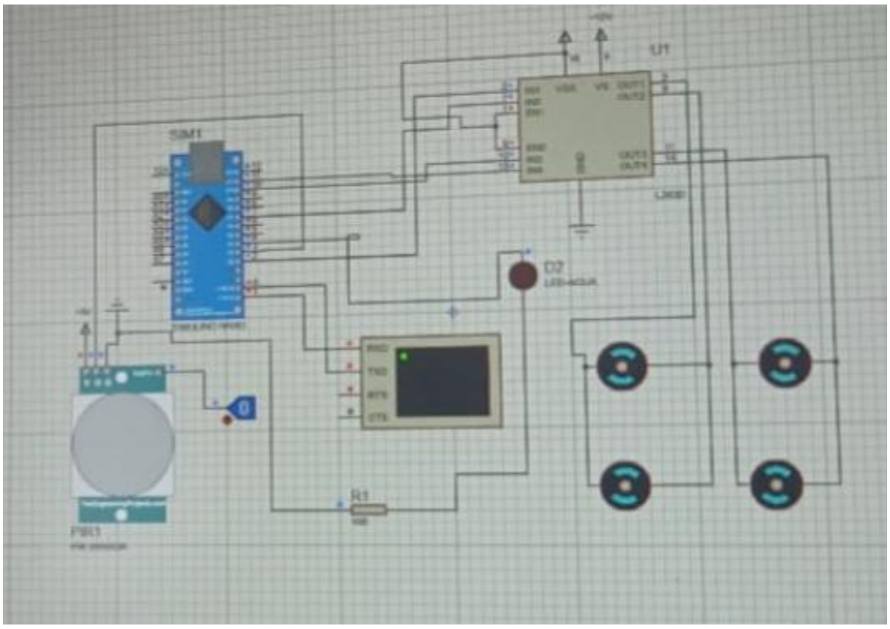

Figure 5. Simulation of project

The project exemplifies a successful integration of various components sensors, a microcontroller, a GSM module, and a water pump into a unified system capable of autonomously detecting, alerting, and responding to fire threats. This robot has significant practical applications in fire safety, especially in environments where prompt detection and response can mitigate the risk of larger incidents. Its effective operation underscores its potential for use in small-scale indoor settings such as homes, offices, and warehouses, providing an affordable and automated solution for fire management.

Overall, the experimental findings confirm that the proposed ESP32-based firefighting robot effectively integrates flame detection, hazardous gas monitoring, autonomous fire suppression, and real-time remote alerting within a compact and low-cost platform. Compared with existing research, the system offers improved response time, broader hazard detection coverage, and greater operational flexibility without the need for computationally intensive hardware. These results highlight the system's potential as a practical and scalable solution for early fire detection and mitigation in small-to-medium indoor environments, such as residential buildings, offices, and warehouses, where affordability and rapid response are critical.

CONCLUSION

In summary, the Fire-Fighting Robot project showcases an efficient and automated solution for fire detection and response. By incorporating key components such as the ESP32 microcontroller, flame sensor, MQ135 gas sensor, GSM module, and water pump, this robot is capable of detecting fires and gas leaks, navigating independently, and responding swiftly to extinguish flames or notify users remotely. This system offers an affordable, compact, and portable option for enhancing fire safety, making it ideal for application in homes, offices, industrial settings, and other locations where early fire detection is essential.

The future scope of this fire-fighting robot project is extensive, offering numerous possibilities for advancement. The integration of advanced sensors such as thermal imaging cameras and smoke detectors can significantly enhance fire detection capabilities. Additionally, AI-powered algorithms could enable the robot to differentiate between various fire intensities and types, optimizing resource usage by tailoring suppression strategies. Expanding its connectivity to integrate with smart home systems or city-wide IoT networks could allow real-time data sharing with emergency services for faster response times.

AUTHOR CONTRIBUTIONS

All authors of this article played an important role in the process of method conceptualization, investigation, simulation, software, resources, and article writing.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

Ahn, K.-H., Na, M., & Song, J.-B. (2023). Robotic assembly strategy via reinforcement learning based on force and visual information. *Robotics and Autonomous Systems, 164*, 104399. https://doi.org/10.1016/j.robot.2023.104399

AL-Karkhi, N. K., Abbood, W. T., Khalid, E. A., Jameel Al-Tamimi, A. N., Kudhair, A. A., & Abdullah, O. I. (2022). Intelligent Robotic Welding Based on a Computer Vision Technology Approach. *Computers*, 11 (11), 155. https://doi.org/10.3390/computers11110155

Alwan, O. H., Alshekhly, M. N. A., Al-Aloosi, R. A., Fakhri, O. F., Aljibori, H. S. S., & Abdullah, O.I. (2024). Systematic development of an autonomous robotic car for fire-fighting based on the interactive design approach. *EUREKA: Physics and Engineering,* 3(2024), 61-72. https://doi.org/10.21303/2461-4262.2024.003326

Ambafi, J. G., Onuche, O. P., Babatunde, E. T., & Okonkwo, U. U. (2025). Development of an IoT-based smart firefighting robot. *Current Journal of Applied Science and Technology, 44*(5), 88–97. https://doi.org/10.9734/cjast/2025/v44i54539

Cheng-Chan, S., Horng, R. S., & Shin-Ku, L. (2016). Investigation of lab fire prevention management system combining root cause analysis and analytic hierarchy process with event tree analysis. *Mathematical Problems in Engineering, 2016*, Article 3161823. https://doi.org/10.1155/2016/3161823

Fire behavior. (2008). *Essentials of Fire Fighting and Fire Department Operations*. IFSTA Publisher.

Hasib, A., Rahman, M. S. H. A., Rana, M. M., & Hossen, R. (2025). An IoT-integrated autonomous fire extinguishing and surveillance robot development using smart camera module. In *Proceedings of the 2nd International Conference on Next-Generation Computing, IoT and Machine Learning (NCIM)* (pp. 1–6). IEEE. https://doi.org/10.1109/NCIM65934.2025.11160079

Issaoui, M. (2025). *Deep reinforcement learning for autonomous drone navigation: Application to forest fire monitoring*. Research Square. https://doi.org/10.21203/rs.3.rs-7004178/v1

Kong, L., Li, J., Guo, S., Zhou, X., & Wu, D. (2024). Computer vision-based early fire detection and firefighting mobile robots oriented for onsite construction. *Journal of Civil Engineering and Management, 30*(8), 720–737. https://doi.org/10.3846/jcem.2024.21360

Latha, S., Afroz, M., & Sree, T. (2025). Autonomous fire fighting robot using Arduino. *International Journal for Research Trends and Innovation, 10*(3), 267–271.

Li, C.-Y., Zhang, F., & Chen, L. (2024). Robot-assisted pedestrian evacuation in fire scenarios based on deep reinforcement learning. *Chinese Journal of Physics, 92*, 494–531. https://doi.org/10.1016/j.cjph.2024.09.008

Li, S., Yun, J., Feng, C., Gao, Y., & Zhang, D. (2023). An indoor autonomous inspection and firefighting robot. *Fire, 6*(3), 93. https://doi.org/10.3390/fire6030093

Pritzl, V., Stepan, P., & Saska, M. (2021). Autonomous flying into buildings in a firefighting scenario. In *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)* (pp. 239–245). IEEE. https://doi.org/10.1109/ICRA48506.2021.9560789

Rahat, Md. R. A., Rashid, Md. M., Dey, M. C., & Banik, T. (2020). Design and Implementation of a Safety Fire Fighter (SAFF) Robot with Dual Controlling Mechanism. *2020 IEEE Region 10 Symposium (TENSYMP).* https://doi.org/10.1109/tensymp50017.2020.9230709

Sathiabalan, N., Lokimi, A. F. M., Jin, O. Z., Hasrin, N. S. M., Zain, A. S., Ramli, N., Zakaria, H. L., Ariffin, W. N. S. F. W., Hashim, N. B. M., & Taib, M. H. (2021). Autonomous robotic fire detection and extinguishing system. *Journal of Physics: Conference Series, 2017*, 012060. https://doi.org/10.1088/1742-6596/2017/1/012060

Satria, B., Hidayatullah, S., Yuda, F., Tambunan, L., Lubis, S. S., & Meiditra, I. (2025). Design of fire extinguisher robot using IoT with Android application control. *Jurnal Ilmu Pengetahuan dan Teknologi Komputer, 10*(3), 1–9. https://doi.org/10.33480/jitk.v10i3.6135

Taha, I. A., & Marhoon, H. M. (2018). Implementation of controlled robot for fire detection and extinguishing in closed areas based on Arduino. *TELKOMNIKA, 16*(2), 654–664. https://doi.org/10.12928/TELKOMNIKA.v16i2.8197

Wahyuni, E. S., & Hendri, M. (2019). Smoke and fire detection based on convolutional neural network. *ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika, 7*(3), 455–465. https://doi.org/10.26760/elkomika.v7i3.455

Yang, T., Ding, W., Wang, Y., & Mu, D. (2025). Real-time flame detection and localization for firefighting robots. *Robotics and Autonomous Systems, 194*, 105147. https://doi.org/10.1016/j.robot.2025.105147

Yuvaraj, R., Kumar, D. S., Bhalerao, S. A., Murugesan, K., Vellaiyan, S., & Minh, N. V. (2025). Real-time fire detection and suppression system using YOLO11n and Raspberry Pi for thermal safety applications. *Case Studies in Thermal Engineering, 75*, 107159. https://doi.org/10.1016/j.csite.2025.107159