

Autonomous Fire Detection and Suppression Robot using Machine Learning Algorithms

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Abstract: Fire incidents continue to pose substantial threats to human safety, infrastructure, and valuable assets. Traditional fire-monitoring systems commonly use smoke and thermal sensing techniques and frequently depend on manual action, which can delay emergency response and worsen fire-related losses. This introduces an autonomous robotic platform that combines embedded hardware with machine-learning-based fire identification and suppression to provide rapid and intelligent fire response. The proposed system utilizes flame, smoke, and thermal sensors for continuous observation of the surrounding environment. The collected measurements are analysed through machine-learning models such as Decision Tree and Random Forest classifiers to distinguish fire conditions while reducing incorrect detections. When the fire is detected, the robot autonomously navigates toward the affected location by while employing ultrasonic sensing to identify and bypass obstacles. A relay-controlled water pump is then activated to suppress the fire without direct operator involvement. With the help of artificial intelligence, autonomous navigation, and automated fire suppression strengthens response efficiency and safety while limiting personnel exposure to hazardous conditions in hazardous environments. The proposed solution offers an economical and dependable solution for deployment in laboratories, industries, warehouses, and other high-risk areas.

Keywords: Fire Detection, Machine Learning, Autonomous Robot, Decision Tree, Random Forest, Raspberry Pi, Arduino, Fire Suppression, Embedded Systems, Obstacle Avoidance

I. INTRODUCTION

Fire incidents represent a major safety concern across industrial plants, laboratories, commercial structures, and storage facilities. Such incidents often can cause substantial financial losses, environmental consequences, and danger to human occupants. Although traditional safety arrangements based on smoke detection, thermal sensing, and sprinkler systems, provide basic fire detection capabilities, they mainly provide warnings and may still require personnel to initiate effective suppression of fire. Delays in emergency response can allow fires to spread rapidly, increasing the severity of damage and exposing firefighters to dangerous conditions such as intense heat, toxic gases, and structural collapse.

Progress in AI, machine learning, embedded computing, and robotics has made it possible to develop automated platforms that can perform emergency-response tasks with limited operator involvement. Machine learning algorithms can evaluate sensor measurements to differentiate genuine fire events from non-fire conditions, thereby increasing the dependability of the detection process. When combined with autonomous robotic platforms, the mentioned technologies can significantly reduce response time and improve operational safety during emergency situations.

The proposed autonomous fire detection and suppression robot integrates multiple environmental sensors, embedded controllers, and multiple machine learning algorithms to create an intelligent firefighting system. Measurements from flame, smoke, and temperature sensors are acquired continuously during operation, which are analysed using the



machine learning models like Decision Tree or Random Forest to identify whether a fire condition exists. After confirming a fire event, the robot independently approaches the detected fire while using ultrasonic measurements to avoid obstacles. Upon reaching the target area, an automatic water pump mechanism is triggered automatically to extinguish the detected fire without operator control.

The designed system aims to offer a practical and economical automated safety mechanism suitable for industrial environments, laboratories, warehouses, and other hazardous locations. By combining autonomous navigation, machine learning-based decision-making, and automated fire suppression, the system enhances emergency response capabilities while minimizing risks to human life.

II. LITERATURE SURVEY

1) IoT Enabled Fire Fighting Robot (2024) - Irshad H. *et al.* developed a firefighting robot that combines flame and thermal sensing with IoT-based wireless notification. The platform detects fire conditions and communicates emergency information remotely. The robot moves toward the detected source and initiates water delivery through its pumping unit. The integration of IoT enables continuous remote monitoring and timely notifications during emergencies. However, the system relies heavily on stable internet connectivity, which may reduce its effectiveness in network-limited environments.

Key Insight: Integration of IoT with autonomous firefighting robots enhances remote monitoring but introduces dependency on communication networks.

2) Prototype of Fire Fighting Robot (2024) - Chaudhari R. R. *et al.* presented a robotic prototype employing flame and gas sensing together with automated water delivery. Upon identifying a fire condition, the platform uses microcontroller-driven DC motors to approach the detected source. The proposed design is economical, easy to implement, and suitable for educational as well as small-scale industrial applications. Although effective under controlled conditions, the system lacks intelligent decision-making capabilities and advanced navigation features.

Key Insight: Multi-sensor-based fire detection improves system reliability, but the absence of machine learning limits detection accuracy and adaptability.

3) An Autonomous Arduino-Based Firefighting Robot for Laboratory Environments (2025) - Maruf M. M. *et al.* introduced a robotic firefighting platform intended for laboratory environment. The system employs an array of infrared flame sensors to extend the monitored detection region and uses a servo-actuated mechanism for directing the extinguishing spray. Relay-controlled pumps and autonomous movement enable rapid response to fire incidents. Despite demonstrating high efficiency in laboratory conditions, the system has limited performance in complex environments containing dynamic obstacles and dense smoke.

Key Insight: Autonomous sensing and suppression improve firefighting efficiency, but intelligent navigation and real-world validation remain essential.

4) FI-BOT Smart Fire-Fighting Robot Using Arduino and Sensors (2025)

Kareem A. *et al.* introduced FI-BOT, an Arduino-based firefighting robot equipped with flame sensors and a servo-controlled extinguishing mechanism. The robot automatically detects fire, approaches the affected location, and sprays water over a wider area using a rotating nozzle. The design is lightweight, affordable, and suitable for indoor applications. However, the system depends primarily on threshold-based sensor readings, making it susceptible to false alarms under varying environmental conditions.

Key Insight: Automated fire suppression can be achieved with simple embedded systems, but intelligent classification methods are necessary to improve detection reliability.

III. MATERIALS AND METHODS

3.1 Study Design

An experimental methodology was adopted to construct and evaluate a robotic platform capable of identifying fire, approaching its location, and initiating suppression with limited operator involvement. The system combines embedded



hardware components with machine learning algorithms to increase classification reliability while limiting erroneous fire detections. Sensor data collected from the surrounding environment are processed in real time, enabling the robot to make intelligent decisions regarding fire identification, navigation, and suppression. The operating sequence incorporates environmental measurement, ML classification, robotic movement, collision avoidance, and automated extinguishing.

3.2 Hardware Components

The robot is assembled from interconnected hardware modules responsible for sensing, movement, processing, and extinguishing. The Raspberry Pi functions as the main computational unit for executing the machine learning model, while an Arduino Uno is responsible for controlling sensors, motors, and other peripheral devices. Flame, smoke, and temperature sensors continuously monitor environmental conditions and provide real-time data for fire analysis. An ultrasonic sensor assists the robot in detecting obstacles and selecting a safe navigation path. The movement of the robot is achieved using DC motors driven by an L298N motor driver. A relay-controlled water pump functions as the fire suppression mechanism by automatically spraying water when fire is confirmed. A rechargeable battery powers the complete system, while the robot chassis provides structural support for all components.

3.3 Fire Detection and Data Acquisition

Fire identification relies on the combined measurements obtained from flame, smoke, and temperature sensing units to improve reliability under different environmental conditions. The sensors operate continuously to capture current environmental measurements representing the presence of flames, smoke concentration, and temperature variations. The acquired measurements are forwarded to the Raspberry Pi for preprocessing before entering the classification stage. Using information from several sensing modalities rather than one variable, the system minimizes false alarms caused by environmental disturbances and improves the accuracy of fire detection.

3.4 Machine Learning Model

For fire-state classification, the system uses two supervised learning approaches: Decision Tree and Random Forest. Their task is to categorize incoming sensor conditions into normal and fire-related states. Training is performed using labelled sensor observations representing different environmental states. The learning stage establishes associations between measured sensor features and their respective class labels. During operation, the trained classifier evaluates newly acquired measurements and determines the corresponding fire state. Compared to conventional threshold-based methods, the machine learning approach provides improved classification accuracy and greater adaptability to changing environmental conditions.

3.5 Autonomous Navigation

After confirming the fire condition, the robot begins an independent approach toward its estimated location. Ultrasonic sensing provides continuous distance information about objects surrounding the robot, allowing safe movement through the environment. Navigation commands generated by the Raspberry Pi are transmitted to the Arduino controller, which regulates the speed and direction of the DC motors through the motor driver. The obstacle-avoidance mechanism supports safer movement toward the target while lowering the likelihood of physical collisions.

3.6 Fire Suppression Mechanism

Once the robot arrives near the detected source, the extinguishing subsystem is triggered without operator input. A relay controls activation of the pump, allowing water to be directed toward the identified fire through the nozzle. The suppression process continues until sensor readings indicate that the fire has been extinguished and environmental conditions have returned to safe levels. Automating this stage can shorten intervention time and reduce personnel exposure while the fire is being controlled.



IV. RESULTS AND DISCUSSION

The developed platform combines ML-based fire classification with embedded robotic control to support automated emergency response. The combined use of flame, smoke, and temperature sensors is expected to provide reliable detection of fire under different environmental conditions. By utilizing multiple sensor inputs, the system aims to minimize false alarms that commonly occur in conventional threshold-based fire detection systems.

Real-time sensor measurements are evaluated using the Decision Tree and Random Forest classifiers to distinguish fire states from normal conditions. Compared to traditional sensor-based approaches, the learning-based classifier can account for interactions among several environmental measurements, thereby enhancing the reliability of fire detection. This intelligent classification process is expected to reduce unnecessary activation of the suppression mechanism and improve overall system performance.

Independent movement toward the detected source forms another key component of the platform. The ultrasonic sensor continuously monitors obstacles in the robot's path, enabling safe movement toward the detected fire source. The integration of obstacle avoidance with autonomous navigation allows the robot to operate efficiently in indoor environments such as laboratories, warehouses, and industrial facilities where unexpected obstacles may be present.

Once the robot reaches the fire location, the relay-controlled water pump automatically activates to suppress the fire without requiring manual intervention. This rapid response mechanism is expected to reduce fire spread, minimize property damage, and improve operational safety by reducing human exposure to hazardous conditions.

The overall architecture brings ML-based classification, robotic navigation, and automatic extinguishing together in one embedded system. Although the current work represents the initial implementation stage, the proposed architecture provides a strong foundation for developing intelligent firefighting robots capable of supporting emergency response operations in real-world environments. Future experimental evaluation will further validate the effectiveness of the proposed approach under different fire scenarios.

V. CONCLUSION

This work describes an embedded robotic platform that applies machine-learning techniques for automated fire identification and suppression. The platform obtains continuous environmental measurements through flame, smoke, and temperature sensing units and employs Decision Tree or Random Forest algorithms to classify fire events with improved reliability. Ultrasonic-based navigation assists the robot in approaching the detected fire while avoiding surrounding obstacles, while the automatic water pumping mechanism suppresses the fire without continuous operator control.

The integration of intelligent fire detection, obstacle avoidance, and automated suppression Offers a practical and economical approach for applications in laboratories, warehouses, industries, and other hazardous environments. The proposed approach has the potential to reduce response time, minimize false alarms, and enhance firefighter safety during emergency situations.

Future work will focus on implementing advanced computer vision techniques, deep learning-based fire recognition, optimized path planning algorithms, and IoT-enabled remote monitoring to further improve the intelligence, scalability, and real-world applicability of the proposed firefighting robot.

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