

## OTHER

# Smart Fire Detection and Response System

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## Abstract

This paper presents the design and development of an IoT-based smart fire detection and autonomous fire-fighting robot using the ESP32 microcontroller. The system aims to reduce human risk in hazardous environments by enabling early fire detection and automatic suppression. It integrates multiple sensors, including flame sensors, a temperature sensor, and an ultrasonic sensor, to accurately detect fire and navigate obstacles. The ESP32 processes real-time data and controls the robot's movement through a motor driver while activating a water pump via a relay module to extinguish fire. A servo motor ensures directional water spraying for effective suppression. Additionally, IoT connectivity allows remote monitoring and manual control through a mobile application. Experimental results demonstrate reliable performance, fast response, and

## Keywords

*ESP32 · IoT · Fire-Fighting Robot · Autonomous Navigation · Smart Fire Detection*

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# Smart Fire Detection and Response System

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**Abstract**— This paper presents the design and implementation of an IoT-based autonomous fire-fighting robot using ESP32. The system is designed to detect and extinguish fire with minimal human intervention, thereby improving safety in hazardous environments. Flame and temperature sensors are used to identify the presence of fire, while an ultrasonic sensor enables obstacle detection and navigation. The ESP32 microcontroller acts as the central processing unit, controlling the movement of the robot through a motor driver and activating a water pump via a relay module to suppress the fire. A servo motor is used to adjust the direction of water spraying for effective fire extinguishing. Additionally, the system is integrated with an IoT platform, allowing remote monitoring and manual control through a mobile application. The proposed system offers a cost-effective, reliable, and efficient solution for fire detection and suppression in residential and industrial applications.

**Keywords**— ESP32, Fire-Fighting Robot, Internet of Things (IoT), Autonomous Navigation, Flame Sensor, Obstacle Avoidance, Smart Fire Detection

## 1. INTRODUCTION

Fire accidents are one of the major causes of damage to life and property in both residential and industrial environments. Traditional firefighting methods require human intervention, which can be dangerous and inefficient in critical situations. Therefore, there is a need for an automated system that can detect and extinguish fire with minimal human involvement. With the advancement of embedded systems and Internet of Things (IoT) technology, intelligent systems can be developed to handle hazardous situations effectively. This paper proposes an IoT-based autonomous fire-fighting robot using ESP32 that can detect fire, navigate obstacles, and extinguish fire efficiently.

### A. Need for Fire-Fighting Robots

Firefighting in hazardous environments poses a serious risk to human life. In industries, warehouses, and residential areas, fire accidents can spread rapidly and cause severe damage. Manual firefighting methods are often time-consuming and risky. The use of fire-fighting robots can significantly reduce human risk by performing operations in dangerous environments. These robots can reach areas that are difficult for humans and can respond quickly to fire incidents, improving safety and efficiency.

### B. Role of IoT and Embedded Systems

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The integration of IoT and embedded systems plays a crucial role in modern automation. The ESP32 microcontroller provides both processing capability and wireless communication, making it suitable for IoT applications. By integrating IoT, the proposed system allows real-time monitoring and remote control through a mobile application. This enhances the flexibility of the system, enabling users to control the robot from a distance and respond quickly in emergency situations.

### C. Overview of Proposed System

The proposed system consists of multiple sensors such as flame sensors, temperature sensors, and ultrasonic sensors for detecting fire and obstacles. The ESP32 acts as the central controller, processing sensor data and controlling the robot's movement through a motor driver. When fire is detected, the robot stops, activates an alert system, and uses a water pump to extinguish the fire. A servo motor is used to direct the water spray toward the fire source. The system can operate in both autonomous mode and manual mode through IoT-based control. This approach provides a cost-effective, efficient, and reliable solution for fire detection and suppression.

## 2. LITERATURE SURVEY

2.1 Fire Fighting Robot Using Arduino, Various Authors [1] This paper presents the design and development of a fire-fighting robot using an Arduino microcontroller. The system uses flame sensors to detect the presence of fire and a motor driver to control the movement of the robot. Once the flame is detected, a water pump mechanism is activated to extinguish the fire. The robot is capable of basic navigation and can operate in small environments. However, the system lacks advanced features such as real-time monitoring, remote control, and intelligent navigation. The absence of IoT integration limits its usability in modern smart systems.

2.2 Autonomous Fire Fighting Robot with Obstacle Avoidance, Various Authors [2] This research focuses on the development of an autonomous fire-fighting robot equipped with obstacle avoidance capabilities. The system uses ultrasonic sensors to detect obstacles and navigate through the environment efficiently. The robot is capable of identifying fire sources and moving toward them without human intervention.

Although the system improves navigation and automation, it lacks communication capabilities and remote accessibility.

The absence of IoT-based monitoring restricts its application in real-time emergency management.

2.2 Autonomous Fire Fighting Robot with Obstacle Avoidance, Various Authors [2] This research focuses on the development of an autonomous fire-fighting robot equipped with obstacle avoidance capabilities. The system uses ultrasonic sensors to detect obstacles and navigate through the environment efficiently. The robot is capable of identifying fire sources and moving toward them without human intervention.

Although the system improves navigation and automation, it lacks communication capabilities and remote accessibility. The absence of IoT-based monitoring restricts its application in real-time emergency management.

2.3 IoT-Based Fire Detection and Alert System Using ESP32, Various Authors [3] This paper proposes an IoT-based fire detection system using the ESP32 microcontroller. The system uses temperature and smoke sensors to detect fire conditions and sends alerts to users through a mobile application or cloud platform. While the system provides real-time monitoring and notification, it is limited to fire detection only and does not include any fire extinguishing mechanism. Therefore, it cannot actively respond to fire hazards.

2.4 Smart Fire Fighting Robot Using Wireless Communication, Various Authors [4] This study presents a fire-fighting robot that can be controlled remotely using wireless communication technologies such as RF or Bluetooth. The robot can be manually operated to approach the fire and activate a water pump to extinguish it. Although remote control is an advantage, the system lacks autonomous functionality and depends entirely on human operation. This reduces efficiency in critical situations where immediate response is required.

2.5 Obstacle Avoidance Robot Using Ultrasonic Sensor, Various Authors [5] This paper discusses the implementation of an obstacle avoidance robot using ultrasonic sensors. The system detects obstacles in its path and changes direction to avoid collisions. It demonstrates effective navigation in dynamic environments. However, the system is not designed for fire detection or firefighting applications. It lacks integration with fire sensors and extinguishing mechanisms, limiting its scope to navigation only.

2.6 Research Gap and Proposed System From the above literature survey, it is observed that most existing systems focus on individual aspects such as fire detection, obstacle avoidance, or remote control. Very few systems integrate all these functionalities into a single platform. The proposed system addresses these limitations by integrating fire detection, autonomous navigation, and IoT-based remote control using the ESP32 microcontroller. It combines both automatic and manual modes, along with an effective fire extinguishing mechanism, making it more efficient, reliable, and suitable for real-world applications.

### 3. METHODOLOGY

#### 3.1 Problem Definition

Fire accidents in industrial and residential environments pose significant risks to human life and property. Traditional firefighting methods involve manual intervention, which can be dangerous and time-consuming. There is a need for an automated and intelligent system capable of detecting fire at an early stage and performing real-time suppression while minimizing human involvement. The proposed system aims to develop an ESP32-based smart fire-fighting robot that can autonomously detect fire, navigate towards it, and extinguish it using a water pump mechanism, thereby improving safety and response efficiency.

#### 3.2 Problem planning and Designing the Robot

3.2.1 The proposed system is designed using a real-time embedded system architecture to achieve efficient fire detection, autonomous navigation, and suppression. The ESP32 microcontroller is selected as the central processing unit due to its high computational capability, low power consumption, and integrated Wi-Fi communication, enabling both local processing and IoT-based control. The system is planned to ensure low-latency response, high reliability, and continuous monitoring of environmental conditions.

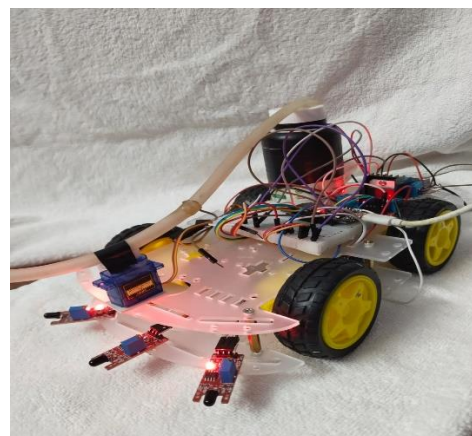


Fig -1: Robot Schematic Picture

3.2.2 The sensing layer is designed to provide comprehensive environmental awareness by integrating multiple sensors with complementary functions. Multiple flame sensors are strategically positioned (left, right, and front) to enable directional fire detection, allowing the system to identify the location of the fire source. The DHT11 temperature sensor continuously monitors ambient temperature and humidity, supporting early fire detection by identifying abnormal thermal variations even before visible flames occur. The ultrasonic sensor (HC-SR04) operates on the time-of-flight (ToF) principle, measuring the echo return time of ultrasonic waves to calculate distance, thereby enabling real-time obstacle detection and collision avoidance. All sensor inputs are processed collectively using a sensor fusion approach, where combined data improves decision accuracy and minimizes false positives caused by environmental noise, light interference, or temperature fluctuations, resulting in a more robust, reliable, and efficient fire detection system.

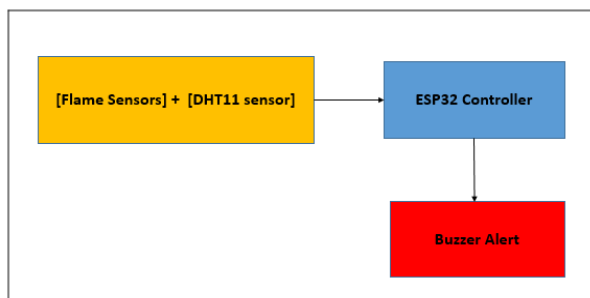


Fig -2: Primary Fire Detection System

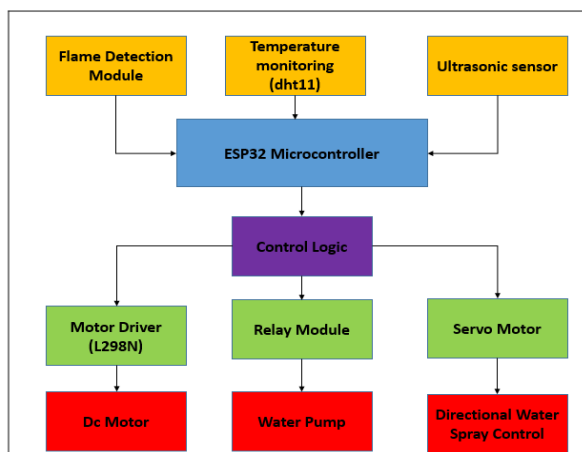


Fig -3: Secondary fire Detection System (using sensors)

system to adjust the angle of water spraying for precise targeting. This improves the effectiveness of fire suppression and reduces water wastage.

Table -1: Components Specifications

Components (Sensor/Actuator)	Working Voltage
ESP32 Microcontroller	3.3V–5V
Flame Sensor	3.3V–5V
DHT11 Sensor	3.3V–5V
Ultrasonic Sensor (HC-SR04)	5V
Motor Driver (L298N)	5V–12V
DC Motor	6V–12V
Servo Motor	4.8V–6V
Relay Module	5V
Water Pump	5V–6V
Buzzer	5V
LCD Display	5V
Battery	9V
Boost Converter	5–12V

### 3.3 WORKING

3.3.1 The system operates on a real-time embedded control mechanism using the ESP32 microcontroller. Initially, the flame sensors and DHT11 continuously monitor the environment for fire and temperature variations. When a flame is detected, the ESP32 processes the sensor data and confirms the presence of fire using sensor fusion.

3.3.2 After detection, the robot starts moving towards the fire source using DC motors controlled by the L298N motor driver. During navigation, the ultrasonic sensor continuously checks for obstacles and ensures collision avoidance.

3.3.3 Once the robot reaches the fire location, the ESP32 initiates the fire suppression process by sending a control signal to the relay module. The relay acts as an electrical switch, allowing the water pump to turn ON safely without directly loading the microcontroller. The pump starts spraying water through the nozzle to extinguish the fire. Simultaneously, the ESP32 generates PWM signals to control the servo motor, which adjusts the angle of the nozzle. This enables directional and targeted water spraying, ensuring effective fire extinguishing with minimal water wastage.

3.3.4 At the same time, the ESP32 activates the buzzer to generate an alert signal, warning nearby individuals about the fire. The LCD display provides real-time system updates, such as fire detection and suppression status. Additionally, the ESP32 uses its built-in Wi-Fi module for

3.3.3 The ESP32 continuously performs data acquisition, signal processing, and decision-making based on programmed logic. It reads digital and analog inputs from sensors and processes them in real time to determine the presence and intensity of fire. Based on this analysis, the controller generates control signals for navigation and suppression, ensuring a fast and efficient system response.

3.3.4 The mobility of the robot is achieved through four DC motors controlled by the L298N motor driver module. The motor driver acts as an interface between the ESP32 and motors, enabling bidirectional control and speed regulation. The robot performs movements such as forward motion, backward motion, and directional turning, allowing it to navigate toward the fire source. The integration of the ultrasonic sensor ensures collision avoidance, making the navigation process safe and autonomous.

3.3.5 The fire suppression mechanism is implemented using a relay-controlled water pump system. When fire is detected, the ESP32 activates the relay module, which in turn powers the water pump to extinguish the fire. A servo motor is integrated for directional control, allowing the system to adjust the angle of water spraying for precise targeting. This improves the effectiveness of fire suppression and reduces water wastage.

3.3.6 The fire suppression mechanism is implemented using a relay-controlled water pump system. When fire is detected, the ESP32 activates the relay module, which in turn powers the water pump to extinguish the fire. A servo motor is integrated for directional control, allowing the

IoT-based communication, transmitting system data to a mobile application or dashboard. This allows users to monitor the system remotely, receive alerts, and control the robot if required, thereby enhancing overall system efficiency and reliability.

## 4.RESULTS

4.1 The experimental results demonstrate effective performance of the proposed fire fighting robot. The sensor graphs show a significant increase in flame and temperature values during fire detection, indicating high sensitivity and fast response. This confirms the capability of the sensing layer to detect fire accurately in real time.

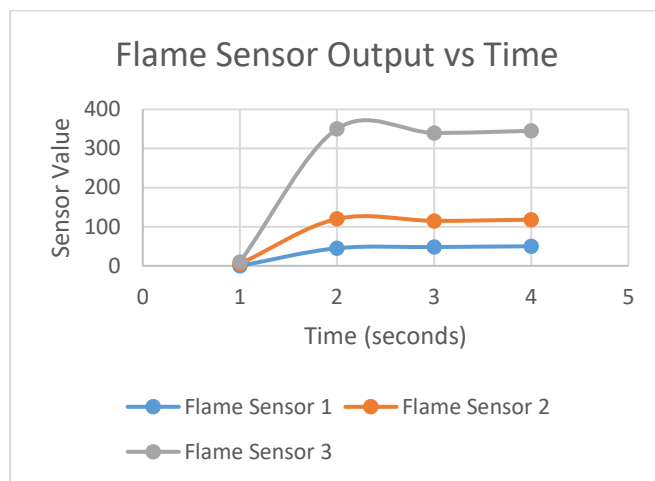


Fig -4: Sensor Response Graph

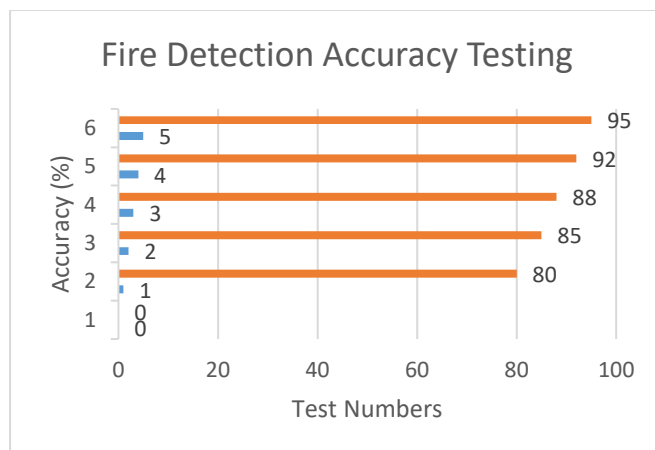


Fig -5: System Performance Analysis

4.2 The integration of multiple sensors using a sensor fusion approach improves detection accuracy and reduces false positives. The ultrasonic sensor enables real-time obstacle detection, ensuring smooth and collision-free navigation. Overall, the coordinated operation of sensors enhances system reliability and stability.

## 5.FUTURE SCOPE

5.1 The proposed system can be further enhanced by integrating advanced computer vision and AI-based fire detection techniques, enabling more accurate identification of

fire even in complex environments. This will also help in distinguishing real fire from false triggers such as lighting variations or reflections.

5.2 In addition to detection improvements, the system can be upgraded with GPS and real-time mapping technologies to support autonomous navigation in large-scale environments. This will allow the robot to operate efficiently in industrial zones, warehouses, and outdoor areas with better path planning and tracking.

5.3 Another important enhancement involves the integration of cloud-based IoT platforms and data analytics, which can provide real-time monitoring, remote access, and storage of operational data. This will help in analyzing system performance and improving response strategies over time.

5.4 Finally, the fire suppression mechanism can be improved by incorporating high-efficiency pumps and advanced nozzle systems, enabling faster and more effective extinguishing. Such upgrades will make the system more suitable for real-world emergency and disaster management applications.

## 6.CONCLUSIONS

The proposed ESP32-based smart fire-fighting robot provides an efficient and reliable solution for real-time fire detection and suppression using a robust embedded system architecture. The system integrates multiple sensors to achieve accurate detection through sensor fusion, while enabling autonomous navigation with obstacle avoidance for safe operation. The ESP32 microcontroller ensures fast processing, low power consumption, and efficient real-time control, making it highly suitable for time-critical applications. The implementation of a relay-controlled water pump and servo-based mechanism enables precise and effective fire extinguishing. Additionally, the inclusion of alert systems and IoT-based monitoring enhances system functionality by providing real-time feedback and remote accessibility. The experimental results demonstrate high accuracy, quick response, and stable performance, establishing the system as a cost-effective, scalable, and practical solution for modern fire safety and emergency response applications.

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