FIREBOT SENTINEL: AN INTELLIGENT IOT-ENABLED AUTONOMOUS FIRE DETECTION AND DISASTER RESPONSE SYSTEM

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ABSTRACT

Fire accidents in industrial, commercial, residential, laboratory, and other hazardous environments can result in severe damage to infrastructure, equipment, and human life. Conventional fire detection systems generally depend on fixed sensors and human intervention, which may lead to delayed response when the affected location is inaccessible or unsafe. This paper presents **FireBot Sentinel**, an intelligent IoT-enabled autonomous fire detection and disaster response system that integrates environmental sensing, robotic mobility, real-time visual monitoring, location tracking, and automatic fire suppression. The proposed system employs an ESP32 microcontroller as the central processing unit for acquiring and processing data from flame and gas sensors, while an ESP32-CAM provides real-time visual information from the affected environment. A GPS module can be used to determine the location of the incident, while an LCD and buzzer provide local status and warning information. Upon confirmation of a fire condition, the controller activates a water pump through an appropriate driver circuit to initiate suppression. The robotic platform enables the sensing and suppression mechanism to be positioned closer to the fire source while reducing direct human exposure to hazardous conditions. IoT connectivity further enables remote monitoring and transmission of incident information. The overall architecture follows the sensor-integration and real-time monitoring approach of the supplied reference work, adapting its ESP32-centered sensing, communication, visualization, and robotic framework from hazardous-object detection to autonomous fire detection and response.

Keywords: FireBot Sentinel, Internet of Things, ESP32, ESP32-CAM, Fire Detection, Gas Detection, Autonomous Firefighting Robot, GPS, Real-Time Monitoring, Fire Suppression.

1. INTRODUCTION

1.1 Introduction

Fire is one of the most destructive hazards encountered in residential buildings, industries, warehouses, laboratories, commercial facilities, and other infrastructure. A fire can develop rapidly, producing high temperatures, smoke, toxic gases, and reduced visibility that make direct human intervention dangerous. Conventional firefighting procedures generally require personnel to approach the affected area to identify the fire source and initiate suppression. Such dependence on human intervention increases the possibility of injury, particularly when the fire occurs in confined, inaccessible, or highly hazardous environments.

The development of Internet of Things technologies, embedded controllers, wireless communication, and mobile robotic platforms has created opportunities for developing intelligent fire response systems. IoT-based systems can continuously acquire environmental information and transmit it to remote monitoring platforms, while robotic systems can physically approach hazardous regions without immediately exposing human operators. The supplied reference work demonstrates a similar architecture in which an ESP32 functions as the central processing unit and coordinates multiple sensors, GPS, camera-based monitoring, local alerts, wireless communication, and robotic operation.

A single sensing mechanism may not always provide sufficient information to reliably determine an emergency condition. Environmental factors, smoke, temperature variations, gas concentration, lighting conditions, and sensor noise can influence individual sensor outputs. Consequently, the integration of complementary sensing mechanisms provides a more comprehensive representation of the surrounding environment. In the proposed FireBot Sentinel, flame and gas sensing are combined with camera-based visual monitoring to improve situational awareness. The ESP32 processes the acquired information and coordinates the response mechanism according to predefined fire-detection conditions.

Real-time visual monitoring is particularly important in firefighting because sensor readings alone cannot completely describe the physical condition of the affected environment. The ESP32-CAM provides a visual stream that can assist remote operators in understanding the fire location and surrounding conditions. Similar camera-integrated firefighting robots have demonstrated the usefulness of ESP32-CAM modules for real-time surveillance and fire-response operations. (IEEE Xplore)

The proposed FireBot Sentinel therefore combines sensing, processing, communication, mobility, visual monitoring, and suppression within a single embedded architecture. Instead of treating fire detection, monitoring, and suppression as independent functions, the proposed design integrates them into a coordinated system. This architecture is intended to provide rapid detection, remote situational awareness, and automatic suppression while reducing the requirement for immediate human presence in hazardous areas.

1.2 Problem Statement

Conventional fire detection and firefighting mechanisms are frequently dependent on fixed sensors, manual verification, and human intervention. Such systems may provide an alarm when smoke or temperature exceeds a predefined threshold, but they generally do not provide mobility, visual inspection, location information, or automatic movement toward the affected region. In hazardous environments, personnel may therefore be required to enter areas containing high temperatures, smoke, toxic gases, or restricted accessibility before effective firefighting can begin.

Existing robotic firefighting prototypes have demonstrated individual capabilities such as flame detection, water-pump activation, robotic movement, camera surveillance, and remote communication. However, there remains a need for an integrated low-cost embedded architecture that combines environmental sensing, real-time visual monitoring, location information, IoT communication, robotic operation, and automatic suppression. Recent systems using ESP32 and ESP32-CAM have demonstrated the feasibility of autonomous fire detection and suppression, while research on fire-source localization further emphasizes the importance of accurate detection and localization for autonomous firefighting. (IEEE Xplore)

The FireBot Sentinel addresses this requirement by integrating the major sensing and response functions through an ESP32-based controller. The system is designed to detect a fire condition, monitor the environment through a camera, provide local and remote alerts, and activate a water-based suppression mechanism while operating on a mobile robotic platform.

1.3 Objectives

The proposed FireBot Sentinel is designed to develop an integrated IoT-enabled robotic system capable of detecting fire conditions using environmental sensors and responding automatically through an embedded control architecture. The system aims to combine flame and gas sensing with ESP32-CAM-based visual monitoring to improve awareness of the affected environment. GPS integration provides location information for incident reporting, while LCD and buzzer mechanisms provide local system feedback and warnings. When the controller confirms a fire condition, the water pump is activated through a suitable driver circuit to initiate suppression. IoT connectivity enables remote monitoring and communication, while the robotic platform provides mobility so that sensing and suppression can be performed from a safer distance.

2. LITERATURE SURVEY

1 Kodali and Yerroju (2018)

Kodali and Yerroju presented an **IoT-based smart emergency response system for fire hazards** that integrates embedded sensing and wireless communication for fire monitoring. Their approach employs an ESP32-based architecture together with flame, smoke, and flammable-gas sensing mechanisms, GPS information, and IoT communication. The system demonstrates how multiple environmental parameters can be monitored and transmitted for emergency response. The study provides an important foundation for the proposed FireBot Sentinel because it establishes the integration of fire sensing, embedded processing, location information, and IoT-based emergency communication. (IJERT)

2 Yahya et al. (2023)

Yahya et al. developed a **remotely controlled firefighting robot with an ESP32-CAM module**. The system combines a wireless ESP32-CAM-based visual interface with a water-pump mechanism to support remote firefighting operations. Real-time video enables an operator to observe the environment while controlling the firefighting platform. This work demonstrates the importance of visual feedback in robotic firefighting and supports the integration of ESP32-CAM technology within the FireBot Sentinel architecture.

3 Godhane Dhanraj Umesh et al. (2023)

Umesh et al. proposed an **IoT-based rotating fire-fighting semi-autonomous robot** using an ESP32 controller, flame sensors, a multiplexer, water tank, pump, water-level sensing, and obstacle detection. The system combines environmental sensing with robotic movement and water-based suppression. The research demonstrates the feasibility of using a compact embedded controller to coordinate sensing and firefighting mechanisms. The proposed FireBot Sentinel extends this concept by additionally incorporating visual monitoring, gas detection, GPS, and IoT-oriented remote awareness.

4 Daganato, Berido and Dellosa (2024)

Daganato, Berido, and Dellosa proposed a **solar-powered IoT-based fire alarm system with integrated GPS and GSM** for enhanced emergency response. Their architecture combines fire detection with location identification and communication, demonstrating the significance of transmitting incident information to remote users. The integration of GPS and communication technologies is particularly relevant to FireBot Sentinel because a fire incident can be associated with location information and communicated beyond the immediate operating environment.

5 Fire Detection and Prediction Using Machine Learning for Fireworks Industry (2024)

A 2024 IEEE study on **fire detection and prediction for the fireworks industry** investigated the use of environmental sensors, ESP32-CAM, and machine-learning-based classification for identifying hazardous conditions. The work illustrates how conventional sensor information can be complemented by visual information and intelligent classification. Its approach supports the future expansion of FireBot Sentinel toward machine-learning-based fire verification, particularly in environments where threshold-based sensing alone may produce ambiguous results.

6 Joshi et al. (2025)

Joshi, Khandge, Jajoo, and Daund developed an **autonomous fire detection and extinguishing robot system with a camera module and sensors**. Their architecture integrates flame and gas/smoke detection with ESP32-based processing, ESP32-CAM visual monitoring, a display interface, and an automatic extinguishing mechanism. The study demonstrates the practical integration of sensing, image acquisition, embedded processing, and suppression within a mobile robotic platform and provides a close technological reference for the FireBot Sentinel architecture.

7 Mahmud, Ahmed, Siddiq and Sobhan (2025)

Mahmud et al. proposed an **edge-optimized firefighting robot using PID-based autonomous navigation and FOMO-based fire detection**. Their system employs ESP32-CAM-based computer vision together with machine-learning-based fire recognition and navigation mechanisms. The research demonstrates the transition from conventional threshold-based flame sensing toward vision-based fire recognition and intelligent navigation. Such techniques provide a potential future direction for FireBot Sentinel, particularly for improving fire localization and autonomous movement. (EurekaMag)

8 IoT-Integrated Autonomous Fire Extinguishing and Surveillance Robot (2025)

An IEEE conference study presented an **IoT-integrated autonomous fire extinguishing and surveillance robot** using an ESP32-CAM, Arduino controller, flame sensors, gear motors, motor driver, relay-controlled pump, and smartphone-based monitoring. The robot continuously monitors the environment and activates the water pump when fire is detected, while the ESP32-CAM provides real-time video. This work establishes the practical relationship between robotic mobility, fire sensing, automatic suppression, and visual surveillance and closely supports the architecture proposed in FireBot Sentinel. (IEEE Xplore)

9 Handoyo and Iqbal (2026)

Handoyo and Iqbal investigated an **IoT-based fire early-warning system using ESP32 and Telegram with multi-sensor integration**. The system combines an ESP32 controller with environmental sensors and wireless messaging to provide remote fire alerts. Their work demonstrates the value of combining multiple sensor measurements with IoT communication rather than relying exclusively on a local alarm. This concept is incorporated into FireBot Sentinel through integrated sensing, embedded decision-making, and remote monitoring.

10 Karpe et al. (2025)

Karpe, Targe, Patil, Gange, and Waghchaware developed an **automatic firefighting robot with gas detection and alert capability**. Their system uses an ESP32 controller, flame sensor, MQ-135 gas sensor, GSM communication, and a motor-driven water pump. The system was evaluated under controlled indoor conditions and demonstrated fire detection and automatic suppression capabilities. The study is particularly relevant to FireBot Sentinel because it combines fire detection with hazardous-gas monitoring and remote alert communication. (Foundae Journal)

3. Proposed System

The proposed FireBot Sentinel is an IoT-enabled mobile firefighting system in which the ESP32 functions as the primary processing and control unit. The architecture integrates flame detection, gas monitoring, camera-based visual observation, GPS-based location information, local status indication, wireless communication, and water-based suppression. The design is derived from the multi-input and multi-output organization of the supplied reference architecture, in which an ESP32 serves as the central hub connecting sensing modules, communication modules, visualization devices, and the robotic platform.

The flame sensor continuously monitors the surrounding environment for the presence of a flame signature. The gas sensor provides additional environmental information by identifying smoke or hazardous gases associated with fire conditions. The ESP32-CAM captures visual information from the operating environment and can transmit the video through a wireless network. GPS information can be associated with an identified incident so that the approximate location of the robot or detected event can be communicated to a remote monitoring system.

When the sensed conditions satisfy the programmed fire-detection criteria, the ESP32 generates a response command. The buzzer provides an immediate local warning and the LCD presents the current system condition. Simultaneously, the controller activates the water pump through a relay or suitable switching circuit. The pump transfers water from the onboard reservoir through the nozzle toward the detected fire region. A servo-controlled nozzle can be incorporated to adjust the spraying direction. Similar robotic systems have used servo-controlled water discharge to improve the targeting of the suppression mechanism.

The robotic drive system provides mobility to the platform. Depending on the implemented control algorithm, the robot can be remotely operated or extended toward autonomous movement based on the detected fire direction.

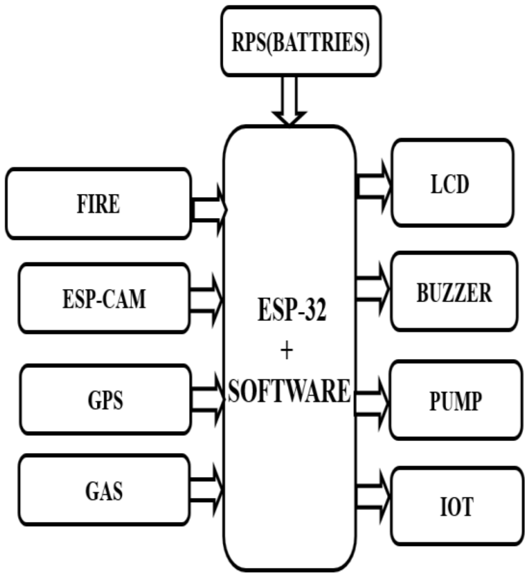


Fig. 1. Proposed block diagram of the FireBot Sentinel system.

The regulated power supply provides the required electrical power to the ESP32, sensors, communication modules, camera, display, and actuator circuits. In the reference architecture, the RPS is positioned as the common power source and provides stable voltage distribution to the system components.

The ESP32 acts as the central processing hub. It receives signals from the flame and gas sensors and obtains visual information from the ESP32-CAM. GPS data are acquired when location tracking is enabled. The controller processes these inputs according to the programmed detection logic and determines whether a fire-response condition exists.

The LCD is connected to the ESP32 to display operational information such as fire status, pump condition, sensor status, and other selected parameters. The buzzer is activated when a fire condition is confirmed, providing an immediate local warning. The reference architecture similarly uses LCD and buzzer outputs for local system feedback and emergency indication.

The water pump represents the primary suppression actuator. When the fire condition is confirmed, the ESP32 drives a relay, MOSFET, or appropriate switching circuit to energize the pump. Water is subsequently delivered through the nozzle toward the fire source. IoT communication enables system status and incident information to be transmitted to a remote monitoring interface.

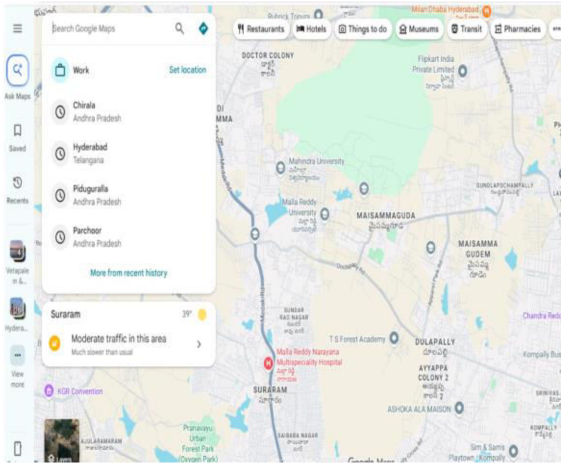
3.1 Hardware Implementation

The hardware implementation consists of an ESP32 development board, ESP32-CAM, flame sensor, gas or smoke sensor, GPS module, LCD, buzzer, water pump, switching circuit, servo motor, motor driver, DC motors, robotic chassis, water reservoir, regulated power supply, and wireless communication infrastructure. The ESP32 is responsible for coordinating the sensing and control operations, whereas the ESP32-CAM provides visual monitoring.

The flame sensor provides the primary indication of fire presence. The gas sensor supplements flame detection by monitoring hazardous combustion-related gases or smoke. The GPS module provides geographic information when the system is deployed in an outdoor or location-sensitive environment. The LCD provides local status information and the buzzer produces an immediate warning signal.

The pump and nozzle assembly constitutes the suppression mechanism. Because the pump requires considerably more current than the microcontroller output can directly provide, a relay, MOSFET, or suitable motor-driver interface is required between the ESP32 and the pump. The robotic drive system is similarly controlled through a motor driver to isolate the microcontroller from the motor current.

4. RESULTS



5. CONCLUSION

The proposed **FireBot Sentinel** presents an integrated IoT-enabled approach to autonomous fire detection and disaster response by combining embedded sensing, robotic mobility, real-time visual monitoring, location tracking, wireless communication, and automatic water-based suppression within an ESP32-centered architecture. The system transforms conventional fire detection from a predominantly stationary alarm mechanism into an intelligent mobile response platform capable of sensing environmental conditions, providing visual awareness, communicating incident information, and initiating suppression actions. The architecture is based on the integrated sensing, processing, communication, and robotic principles demonstrated in the supplied reference paper, while adapting these concepts specifically to fire detection and disaster response. Recent research further demonstrates the feasibility of ESP32-CAM-based surveillance, autonomous suppression, gas detection, and intelligent fire-source localization, supporting the technical direction of the proposed system. The proposed architecture can subsequently be extended with machine-learning-based fire classification, autonomous navigation, obstacle avoidance, thermal imaging, improved fire-source localization, and intelligent suppression control to increase the reliability of the system under complex real-world conditions.

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