“Autonomous Fire Fighting Robot”

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***Abstract* —** Fire accidents remain among the most destructive emergencies, where delayed detection and human-dependent response often result in severe loss of life, property, and infrastructure. This paper presents the design and implementation of an Autonomous Fire Fighting Robot capable of detecting the direction of a fire source and autonomously navigating toward it to perform targeted suppression, without requiring direct human intervention. The system employs three IR flame sensors positioned at the left, center, and right of the robot chassis, enabling directional fire localization rather than simple presence detection. Arduino uno and esp32 board serves as the central controller, processing sensor inputs, driving four BO motors through an L298N motor driver for navigation, and aiming a servo-mounted water pump nozzle precisely at the detected flame. The robot is further integrated with WiFi connectivity and a Firebase Realtime Database, enabling live sensor telemetry and camera feed transmission to a custom Android dashboard application, with instant push notifications alerting the operator upon fire detection. This paper details the system architecture, hardware integration, control logic, and testing methodology, demonstrating a low-cost, reliable, and remotely monitorable approach to autonomous fire response suitable for indoor and hazard-prone environments.

1. Introduction

Fire-related emergencies demand immediate detection and response, as even short delays can result in rapid escalation, causing severe damage to property and posing serious risk to human life. Conventional firefighting approaches rely heavily on human responders, whose entry into an active fire zone is inherently dangerous, particularly in confined spaces, industrial facilities, and chemical storage areas.

The emergence of embedded systems, robotics, and the Internet of Things (IoT) has introduced new possibilities for addressing this challenge through autonomous response systems. Among these, firefighting robots have gained attention for their ability to enter hazardous zones and perform detection and suppression tasks without exposing human responders to risk. However, many existing low-cost firefighting robot designs suffer from a critical limitation: they rely on a single flame sensor, which can confirm the presence of fire but cannot determine its direction, resulting in inefficient, often random search-and-approach behavior.

1.1 Problem Statement

The challenges that this project addresses can be summarized as follows:

Lack of Directional Awareness: Traditional low-cost firefighting robots use a single flame sensor, which can only detect that a fire exists, not where it is located relative to the robot. This forces the robot into inefficient, random search patterns, significantly delaying response time.

Imprecise Suppression Targeting: Many existing systems extinguish fire by driving directly toward it and spraying in a fixed, forward-only direction, without any mechanism to aim the suppression system precisely at the flame. This wastes extinguishing agent and reduces effectiveness.

No Remote Situational Awareness: Once deployed into a hazardous zone, most conventional firefighting robots operate as isolated units with no way to relay status, sensor readings, or surroundings back to a human operator, leaving the operator unable to verify whether the situation is under control.

The aim of this research is to design and implement a system that addresses these gaps. The objectives of this project are:

- To develop an autonomous robot capable of detecting the direction of a fire source using multiple flame sensors.
- To enable autonomous navigation of the robot toward the identified fire location.
- To implement a precision-aimed suppression mechanism using a servo-controlled water pump.
- To provide real-time remote monitoring and alerts via a cloud-connected mobile application.
- To ensure the system is low-cost, reliable, and deployable without requiring complex AI infrastructure.

1.2 Proposed Solution

To address these challenges, this paper presents an Autonomous Fire Fighting Robot built around a Raspberry Pi 3B+, designed to:

- **Detect Fire Direction:** Three IR flame sensors positioned at the left, center, and right of the chassis allow the robot to determine not just whether fire is present, but its approximate direction relative to the robot's current position.
- **Navigate Autonomously:** Based on the sensor readings, the Arduino uno commands an L298N motor driver to steer four BO motors, moving the robot progressively closer to the identified fire source while continuously reevaluating direction.
- **Suppress with Precision:** Once within range, a mini servo motor aims the water pump nozzle directly at the flame, and the pump — activated through a transistor switching circuit — sprays water through a connected pipe until the fire is no longer detected.
- **Enable Remote Monitoring:** Live sensor data and camera feed are transmitted over WiFi to a Firebase Realtime Database, displayed on a custom Android dashboard, with push notifications alerting the operator the moment fire is detected.

2. Literature Review

B. R. V. Prasad, Ch. Harsha Priya, and D. Bhuvana (2023) presented an autonomous firefighting robot using infrared flame sensors, microcontrollers, and ultrasonic sensors capable of detecting fire from three directions — left, right, and center — while simultaneously detecting and avoiding obstacles during navigation. Their work validates the multidirectional IR sensing approach adopted in this project, though it does not incorporate any cloud-based remote monitoring capability.

M. A. Hossain, M. H. Sarowar, M. A. Hossain, and M. F. K. Khondakar (2021) designed an IoT-based firefighting and affected-area monitoring robot that integrates flame, gas, IR, and temperature-humidity sensors with Wi-Fi based communication, supporting both manual and autonomous operating modes. Their system demonstrates the feasibility of remote area monitoring via IoT, but relies on single-point flame detection without directional awareness.

M. Kanwar and L. Agilandeeswari (2018) proposed an IoTconnected firefighting robot that reports fire type and location to a remote authority, allowing operator-issued instructions for movement and pump activation based on the detected fire type. This work supports the cloud-connected operator control architecture referenced in this project, though it depends on manual instruction rather than full autonomy.

H. C. Hemashree, T. Santhosh, and G. R. Manasa (2024) presented a complete design and implementation of an autonomous firefighting robot, covering sensing, control, and extinguishing subsystems within an integrated architecture. Their recent work offers a comprehensive system-level reference, though it provides limited detail on directional precision of fire detection.

T. Rakib and M. A. Rashid Sarkar (2016) focused on multisensor fire detection fused through a dedicated control algorithm, demonstrating improved detection reliability over single-sensor designs. Their work strengthens the case for multi-sensor fusion, though it does not include any cloud or IoT monitoring component.

A. Hassanein, M. Elhawary, N. Jaber, and M. El-Abd (2015) presented an autonomous firefighting robot integrating sensing, navigation, and extinguishing mechanisms within a single platform. This work is widely cited as foundational research in the domain, predating the IoT and cloud integration seen in later studies.

2.1 Research Gap

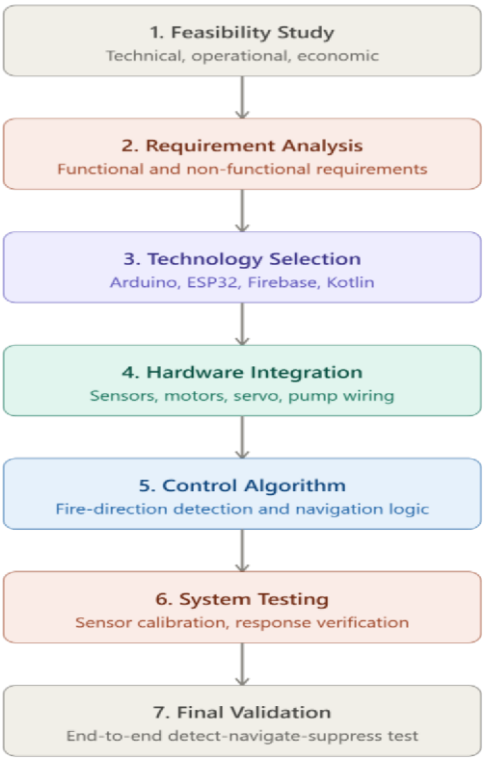
While the reviewed literature demonstrates significant progress in sensor-based and IoT-enabled firefighting robots, several gaps remain:

Limited Directional Precision in Low-Cost Designs: Many budget-oriented student projects still rely on single-sensor detection, lacking the directional awareness demonstrated in more advanced research implementations.

Absence of Aimed Suppression Mechanisms: Most reviewed systems extinguish fire through fixed-direction spraying or by driving directly into the flame, rather than using a precision-aimed nozzle, resulting in inefficient use of extinguishing agent.

Fragmented Integration of Monitoring and Control: While IoT-based monitoring and multi-sensor detection have each been individually demonstrated, few low-cost implementations combine directional detection, aimed suppression, and real-time cloud-based remote monitoring into a single, cohesive, and affordable system — the specific gap this project addresses.

3. Methodology



3.1 Feasibility Study: A feasibility assessment was conducted across three dimensions — technical, operational, and economic — confirming that Arduino Uno and ESP32, GPIO, and Firebase were accessible, well-documented, and achievable within the project timeline using low-cost, opensource tools.

3.2 Requirement Analysis: Functional requirements (directional fire detection, autonomous navigation, aimed suppression, live telemetry, push notifications) and nonfunctional requirements (sub-1-second response time, stable connectivity, minimum 30-minute operational endurance) were documented to guide system design.

3.3 Technology and Component Selection: Based on the requirement analysis, the following hardware and software components were finalized:

Hardware Components:

- Arduino Uno — central processing and control unit
- 3x IR Flame Sensors — directional fire detection (left, center, right)
- L298N Motor Driver — motor control interface
- 4x BO Motors with wheels — robot locomotion
- Mini Servo Motor — pump nozzle aiming mechanism
- 5–9V Water Pump with pipe — fire suppression
- NPN Transistor (BC547/2N2222) — pump switching circuit

- 1K Resistor — transistor base current limiting
- 104 (0.1µF) Capacitors (x4) — motor/pump noise suppression
- ESP32 Camera Module — live visual monitoring
- Battery Pack — power supply for motors and pump
- On/Off Switch, Jumper Wires, Mini Breadboard, Chassis — supporting hardware

Software Components:

- Arduino IDE— sensor reading and control logic

3.4 Hardware Integration: The chassis was assembled with the four BO motors and wheels, followed by wiring of the three IR flame sensors to GPIO input pins, the L298N motor driver to its control and PWM pins, the servo to its signal pin, and the pump switching circuit (transistor, resistor, capacitors) to its designated GPIO output pin, with the camera module connected via the CSI port.

3.5 Control Algorithm Development: A control loop was developed to continuously read the three flame sensors, resolve the fire's direction, issue corresponding motor commands through the L298N driver, aim the servo toward the detected direction, and activate the pump via the transistor circuit once the robot was correctly oriented.

3.6 System Testing and Calibration: Testing was conducted in incremental stages — individual sensor calibration against a controlled flame source at varying distances, motor and servo response verification, and pump activation timing — to finetune sensitivity and ensure reliable operation.

3.7 Final Validation: The complete detect–navigate–suppress pipeline was validated end-to-end under simulated fire conditions to confirm reliable autonomous operation of the integrated system.

Reference:

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