



ORIGINAL CONTRIBUTION

DESIGN AND DEVELOPMENT OF A LOW-COST INTELLIGENT ARDUINO-BASED FIRE FIGHTING ROBOT FOR AUTOMATED FIRE DETECTION AND EMERGENCY RESPONSE

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ABSTRACT

Fires cause extensive loss of life and property, and conventional firefighting methods often place human responders at considerable risk. This paper presents the design and development of a low-cost, intelligent, Arduino-based fire fighting robot capable of automated fire detection and remote-assisted fire suppression. The system integrates an infrared flame sensor for real-time fire detection, a dual-motor driver circuit for locomotion, a compact 5V water pump for extinguishing, and a Bluetooth communication module for wireless remote operation. An Arduino Uno microcontroller, built around the ATmega328P, forms the central processing unit, coordinating sensor inputs and actuator outputs to achieve a semi-autonomous firefighting response. Upon detecting a flame, the robot alerts the operator in real time and can be directed toward the fire source, where the onboard pump is triggered to spray water and extinguish the flame. Experimental testing on a working prototype demonstrates that the proposed system offers a reliable, inexpensive, and effective platform for early-stage fire suppression, particularly suited to confined or hazardous environments where direct human intervention is dangerous. The design emphasizes modularity, low cost, and ease of replication, and is intended as a foundation for further enhancement through AI-based multi-sensor fusion, autonomous navigation, and swarm robotics.

KEYWORDS: Fire Fighting Robot, Arduino Uno, Flame Sensor, Bluetooth Control, Embedded Systems, Automated Fire Detection, Robotics.

1. INTRODUCTION

Robots are versatile machines capable of performing complex tasks with a degree of precision, reliability, and endurance that often exceeds human capability, particularly in hazardous environments. Mobile robots, in particular, are widely deployed in logistics, agriculture, security, and disaster response owing to their ability to navigate dynamic environments autonomously or semi-autonomously. Among the many domains where robotics offers a clear safety advantage, firefighting stands out: fire emergencies are inherently unpredictable, and human firefighters routinely face risks from smoke inhalation, structural collapse, and extreme heat while attempting to locate and suppress a fire source. This work proposes a semi-autonomous, low-cost fire fighting robot built

around the Arduino Uno platform. The system is designed to detect a nearby flame using an infrared flame sensor and respond by alerting the operator and, upon command, navigating toward the fire and activating an onboard water pump to extinguish it. The robot can be wirelessly controlled through a Bluetooth link, allowing an operator to remain at a safe distance while directing firefighting operations. The primary objective of this work is to demonstrate that an effective, safety-enhancing firefighting aid can be built using inexpensive, readily available components, making the solution accessible for small-scale deployment in homes, laboratories, warehouses, and other confined spaces where early fire suppression can prevent escalation.

The remainder of this paper is organized as follows. Section II reviews related work in fire fighting robotics. Section III describes the

proposed system architecture and hardware components. Section IV details the working methodology and control logic. Section V discusses the implementation and circuit realization. Section VI presents the results obtained from the working prototype. Sections VII and VIII discuss applications and future scope, respectively, followed by the conclusion.

2. LITERATURE REVIEW

Chenchireddy et al. [1] proposed a prototype firefighting robot built around an Arduino microcontroller that incorporates a machine learning technique to improve the accuracy of fire detection, demonstrating the growing trend of combining low-cost embedded platforms with intelligent classification methods.

Kumar et al. [2] presented an Arduino-based firefighting robot integrating a fire detection and suppression system, highlighting a compact sensor-actuator pipeline capable of identifying a flame and triggering suppression with minimal latency.

Maruf et al. [3] developed an autonomous Arduino-based firefighting robot specifically targeted at laboratory environments, where confined spaces and sensitive equipment make rapid, unattended fire response particularly valuable.

Reddy et al. [4] and Kori et al. [5] each reported an Arduino Uno-based firefighting robot design emphasizing low-cost hardware realization, sensor-driven detection, and pump-based suppression, reflecting the continued relevance of the Arduino platform for accessible firefighting robotics research.

Bankapur et al. [6] proposed a flame sensor-based firefighting assistance robot and additionally validated a simulation-based multi-robot implementation, pointing toward the extension of single-robot designs into coordinated multi-robot firefighting scenarios.

Babu et al. [7] further extended the Arduino-based firefighting robot concept by incorporating metal detection alongside fire detection and suppression, illustrating how auxiliary sensing capabilities can be layered onto a common embedded control architecture.

While the reviewed systems demonstrate a range of sensing and control strategies, most rely on

either purely autonomous or purely remote-controlled operation, with only limited exploration of AI-assisted detection or multi-robot coordination in low-cost Arduino-based platforms. The system proposed in this paper adopts a semi-autonomous approach that combines automatic flame detection with operator-guided navigation and pump activation, aiming for a balance between responsiveness and operator oversight, while keeping the overall bill of materials low.

3. PROPOSED SYSTEM

3.1. System Architecture

The proposed robot is structured around four functional units: a sensing unit (flame sensor), a control unit (Arduino Uno), a locomotion unit (DC motors with motor driver), and an extinguishing unit (water pump with reservoir). A Bluetooth module provides the wireless link between the control unit and a handheld operator interface. The flame sensor continuously monitors the surroundings for infrared radiation characteristic of open flames. On detecting a fire, the microcontroller notifies the operator, who can then direct the robot toward the fire and trigger the pump to release water onto the flame.

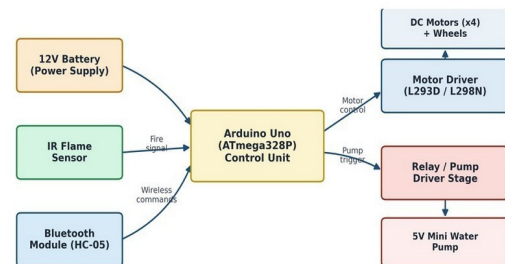


Figure 1: Block diagram of the proposed fire fighting robot system.

3.2. Hardware Components

Table I summarizes the principal hardware components used in the system, along with their function within the overall architecture.

Table I. Hardware Components and Functions

Component	Function
Arduino Uno (ATmega328P)	Central control unit; processes sensor data and issues actuator commands
Flame Sensor (IR)	Detects infrared emission from flames (760–1100 nm range)

Component	Function
L293 / L298N Motor Driver	Bidirectional control of DC motors for locomotion
DC Geared Motors (x4)	Drive the wheels for robot movement
Mini Water Pump (5V)	Sprays water onto detected flame
Bluetooth Module (HC-05)	Wireless link between robot and operator handset
LM2596 Buck Converter	Steps down battery voltage to regulated levels for logic circuits
12V Rechargeable Battery	Primary power source for motors and pump
Chassis, Wheels, Water Reservoir	Mechanical structure and water storage

3.3. Control Unit

The Arduino Uno, operating at 5V with a 16 MHz clock, forms the brain of the system. It reads the digital output of the flame sensor, processes incoming Bluetooth commands, and drives the motor and pump circuits accordingly. Its open-source IDE and extensive library support allow rapid development and straightforward modification of the control logic.

3.4. Locomotion and Extinguishing Units

Motion is achieved through four DC geared motors driven via a motor driver IC, which provides bidirectional control by switching the polarity of the voltage applied to each motor pair. The extinguishing unit consists of a 5V mini water pump connected to a small reservoir; the pump is switched on and off by the Arduino through a relay/transistor stage triggered by operator command once the robot is positioned near the fire.

3.5. Wireless Communication

A Bluetooth serial module interfaces with the Arduino through its UART pins, allowing an operator to send single-character commands (forward, backward, left, right, pump on/off) from a smartphone application. This allows the operator to remain outside the hazardous zone while maintaining full control of the robot's movement and extinguishing action.

4. METHODOLOGY

The operational logic of the robot follows a continuous sense–decide–act cycle, illustrated in the steps below.

1) Initialization: On power-up, the Arduino initializes the motor driver, pump control pin, and Bluetooth serial communication at 9600 baud.

2) Sensing: The flame sensor output is polled continuously; a LOW state on the sensor pin indicates the presence of a flame within its detection cone.

3) Alerting: On detecting a flame, the Arduino transmits a status flag over Bluetooth to notify the operator's handset in real time.

4) Navigation: Upon receiving directional commands (forward, backward, left, right) from the operator, the Arduino drives the corresponding motor pins through the motor driver to move the robot toward the fire source.

5) Suppression: Once positioned near the flame, the operator issues a pump-on command; the Arduino energizes the pump to spray water until a pump-off command is received or the flame is no longer detected.

This semi-autonomous approach retains a human operator in the loop for navigation and pump activation while automating the time-critical task of fire detection, reducing response latency compared to purely manual search-and-suppress approaches.

5. IMPLEMENTATION

The hardware was assembled on a four-wheeled chassis housing the Arduino Uno, motor driver, Bluetooth module, buck converter, battery, and water reservoir with an attached pump and nozzle. The Rx/Tx lines of the Bluetooth module were connected to the Arduino's serial pins, with the module configured for pairing prior to final assembly to avoid programming conflicts. The control firmware was developed in the Arduino IDE using the Software Serial library for Bluetooth communication, with dedicated functions for forward, backward, left, and right motion, and separate command handling for pump activation and deactivation. Serial debug output was used during development to verify correct command reception and actuator response before field testing.

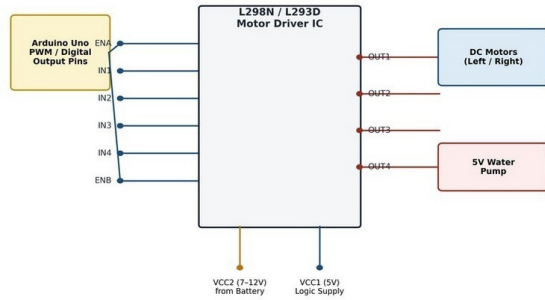


Figure 2: Motor driver (L293D/L298N) interfacing circuit used for motor and pump control.

6. RESULTS AND DISCUSSION

The assembled prototype was tested under laboratory conditions using a controlled small-scale flame source. The flame sensor reliably registered flame presence within its rated detection range, and the corresponding alert was received on the operator handset with negligible delay. Bluetooth-based directional control allowed smooth navigation of the robot toward the flame across a tiled test surface, and the water pump, once triggered, successfully extinguished the test flame within a few seconds of activation.

These results indicate that a semi-autonomous, low-cost design using commodity components can provide a functionally reliable first-response firefighting aid for small, enclosed spaces. The main limitations observed were the flame sensor's relatively short detection range and the pump's limited water capacity, both of which constrain continuous operation and are addressed in the future scope below. A detailed quantitative characterization of detection range, response time, and battery endurance is planned as part of ongoing testing and will be reported in a future extended version of this work.



Figure 3: Assembled prototype of the fire fighting robot (front view).

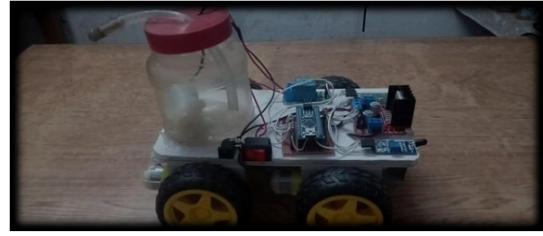


Figure 4: Assembled prototype of the fire fighting robot (side view).

7. APPLICATIONS

- Early-stage fire suppression in homes, laboratories, and small workshops where rapid response can prevent fire escalation.
- Deployment in confined or structurally unstable spaces that pose excessive risk to human firefighters.
- Use as a first-response scouting and suppression unit ahead of human firefighter entry.
- Educational and training platform for demonstrating embedded systems and robotics concepts in fire safety engineering.

8. FUTURE SCOPE

- Integration of additional sensors (gas, smoke, thermal imaging) for multi-parameter fire detection and reduced false positives.
- Incorporation of lightweight deep-learning-based vision models, such as the improved YOLOv5 architecture proposed by Yang et al. [8], for faster and more accurate fire and smoke detection in complex scenes.
- Development of swarm-robotics and multi-robot coordination, drawing on formation and path-planning strategies surveyed by Abujabal et al. [9], to enable multiple units to jointly cover larger fire-affected areas.
- Adoption of machine-learning-based fire-risk prediction approaches, such as the stacking ensemble method proposed by Ahn et al. [10], for predictive risk assessment ahead of fire outbreaks.
- Use of heat-resistant materials and improved battery management for extended operational endurance in high-temperature environments.
- Real-time communication with central monitoring stations for coordinated emergency response.

9. CONCLUSION

This paper presented the design, implementation, and evaluation of a low-cost, Arduino-based, semi-autonomous fire fighting robot. By combining infrared flame detection with Bluetooth-controlled locomotion and a pump-based extinguishing mechanism, the system demonstrates a practical and affordable approach to reducing human exposure during early-stage firefighting. Prototype testing confirmed reliable flame detection, responsive navigation, and effective fire suppression under controlled conditions. The proposed design is intended as an extensible platform, with clear directions identified for future enhancement through advanced sensing, autonomous intelligence, and

multi-robot coordination, contributing toward safer and more efficient emergency response technology.

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