

Dual-Purpose Flamethrower and Fire-Extinguishing Mobile Robot

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Abstract—This project presents a dual-purpose robotic system capable of both controlled flame ignition and fire suppression. Designed for hazardous or inaccessible environments, the robot enhances safety during training and emergency response. Its modular design, wireless control, and sensor-based safety features make it a versatile tool for industrial and firefighting applications.

Index Terms—Firefighting robot, quadruped locomotion, flame ignition, fire suppression, disaster response, industrial safety.

I. INTRODUCTION

Fire management in industrial, commercial, and disaster-prone environments remains one of the most challenging and high-risk tasks faced by emergency responders. While fire detection, suppression technologies, and safety protocols have advanced significantly, accessing and controlling fires in unstable, cluttered, or high-temperature zones still puts human lives in danger. Traditional firefighting approaches often depend on direct human intervention, exposing personnel to toxic gases, structural failures, intense heat, and unpredictable fire behavior.

To address these challenges, robotic systems have emerged as valuable tools, but many existing solutions are limited in capability. Most are designed solely for extinguishing fires or are restricted to smooth indoor surfaces, reducing their effectiveness in real-world outdoor or industrial terrain. Additionally, conventional robots used for training simulations lack integrated systems that allow both controlled fire ignition and suppression within a single platform.

This project introduces a dual-purpose robot capable of generating controlled flames for training exercises

and extinguishing active fires when required. With quadruped locomotion, wireless mobile control, and heat-resistant construction, the robot enhances both safety and operational flexibility. Its modular design and autonomous sensing systems make it suitable for educational training, disaster simulations, and emergency field operations where human access is limited or unsafe.

II. PROBLEM STATEMENT

Most firefighting robots available today are designed for a single function—typically fire suppression—and are optimized for flat and predictable environments. In real scenarios, however, fires occur in hazardous, uneven, and inaccessible areas where conventional systems cannot operate effectively. Existing solutions also lack integrated mechanisms for both controlled training fire ignition and actual fire extinguishing, requiring separate equipment and increasing operational risk. There is a need for a versatile robotic platform capable of safely generating controlled flames for training, detecting hazardous fire conditions, navigating uneven terrain, and suppressing fires in areas too dangerous or impractical for humans to enter.

III. OBJECTIVE

The primary objective of this project is to design and develop a multifunctional robotic system capable of performing both controlled flame ignition and fire extinguishing tasks in environments where conventional fire-control methods are limited. The robot aims to improve safety, efficiency, and accessibility in fire-related operations by integrating

ignition and suppression modules into one compact, mobile unit.

A key goal is to enable wireless remote operation through a mobile application developed using MIT App Inventor, ensuring full control without requiring the operator to approach hazardous zones. The robot will incorporate flame sensors to detect fire intensity and proximity, triggering alerts and enabling semi-autonomous responses. A fail-safe shutdown mechanism will protect the system in case of communication loss or abnormal operation.

Additionally, the robot is designed with quadruped locomotion to enhance movement across uneven or cluttered terrain, making it suitable for industrial sectors, training facilities, and disaster-response environments. Mechanical durability, achieved through heat-resistant materials, further supports safe operation during exposure to flames.

Overall, the objective is to create a flexible, safe, and practical robotic solution that enhances both firefighting training and emergency response capabilities while minimizing risk to human personnel.

IV. LITERATURE REVIEW

Robotic systems designed for fire safety, environmental monitoring, and autonomous operation have advanced significantly in recent years. Several studies explore the integration of thermal imaging, environmental sensing, and AI-based monitoring. Wang and Zhou developed an indoor mobile robot capable of monitoring thermal comfort using infrared thermography and environmental sensors, utilizing YOLOv8 and MTCNN for real-time human detection and analysis [1]. Mallick introduced a remote-controlled dual-purpose flamethrower and extinguisher robot using RF control, demonstrating early efforts toward integrating ignition and suppression within a single platform [2]. AIoT-based fire prediction systems have also evolved, as shown by Zhang, who developed a digital-twin-supported tunnel fire forecasting framework using YOLOv7, LSTM, and TCNN models [3].

More advanced autonomous fire-response robots have been explored in urban scenarios. Jindal et al. designed an autonomous unmanned ground vehicle equipped with thermal cameras, SLAM navigation, and a robotic arm for real-world firefighting in the MBZIRC

competition [4]. Similarly, Chau et al. proposed a mobile manipulator for standardized fire extinguisher testing, validated through MATLAB/Simulink and SolidWorks simulations [5]. IoT-based control frameworks have also been applied to robotic systems; Zulkarnain et al. implemented a master–slave robotic monitoring system using MIT App Inventor and Firebase for real-time data communication [6].

Robotic advancements in fire suppression technologies emphasize intelligent control, wireless monitoring, and integration of novel sensor systems. Maly et al. highlighted innovations in automatic fire-extinguishing systems incorporating smart materials and IoT-enabled detection [7]. Research on quadrupedal robots has also gained traction. Shin et al. developed a reinforcement-learning-based locomotion framework incorporating actuator constraints, enabling high-speed quadruped movement demonstrated on the KAIST Hound [8]. Meanwhile, Bhuiyan and Sabina designed a Bluetooth-controlled surveillance robot using MIT App Inventor, showing the suitability of low-cost platforms for hazardous environments [9].

Firefighting-focused robots using microcontrollers have also been studied extensively. Kumar and Nuthalapati developed a Bluetooth-based fire extinguisher robot using ATmega controllers and light intensity sensors [10]. Baballe and colleagues proposed autonomous robots using infrared flame sensors, MQ-2 gas sensors, and water pumps for indoor fire suppression [11][12]. Jadhav et al. developed an IoT-integrated mobile firefighting robot that provides real-time feedback through a smartphone interface [13].

Environmental monitoring systems contribute significantly to robotic design considerations. Preethichandra et al. reviewed environmental monitoring robots and highlighted gaps in sensor networks, air-quality measurement, and legged-robot deployment [14]. Additional studies on fire-resistant robots, robotic arms, and nuclear-environment rescue robots further demonstrate the breadth of modern robotic applications in hazardous conditions [15–25]. Furthermore, IoT-based master–slave architectures and adaptive frameworks have been shown to enhance mobile robot communication and reliability in active environments [26–30].

Collectively, these works highlight ongoing progress in fire-response robotics, autonomous locomotion,

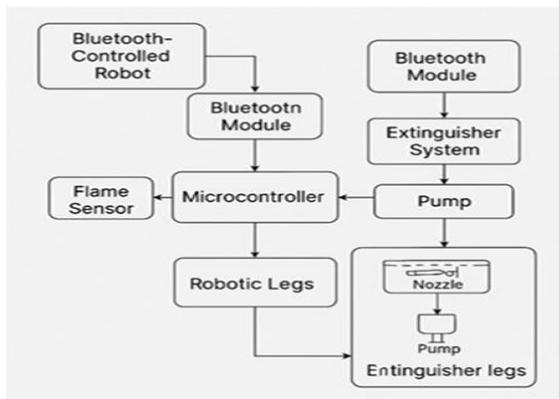
IoT-based control, and high-temperature system design. However, no existing system integrates quadruped locomotion, remote ignition, and fire suppression into a unified platform. This creates a research gap that the present work aims to address.

V. METHODOLOGY

The development of the dual-purpose flamethrower and extinguisher robot follows a structured methodology integrating hardware, software, wireless communication, and safety mechanisms into a unified system. The entire architecture is centered around the Arduino microcontroller, which acts as the core processing unit responsible for receiving wireless inputs, interpreting sensor feedback, and controlling all movement and fire-related modules.

5.1 System Architecture

The overall workflow begins with wireless commands issued from the mobile-based remote-control interface. These commands are transmitted via a Bluetooth module, enabling seamless real-time communication between the operator and the robot. The microcontroller then decodes these signals and activates the required subsystem—movement, ignition, or extinguishing.



This diagram shows the relationship between Bluetooth input, flame sensor feedback, microcontroller processing, robotic legs, pump, and extinguishing legs.

The system follows two input pathways:

1. Manual Input through Bluetooth for user-controlled movement, flame ignition, and extinguishing.

2. Sensor Input from flame detection hardware for safety-based autonomous actions.

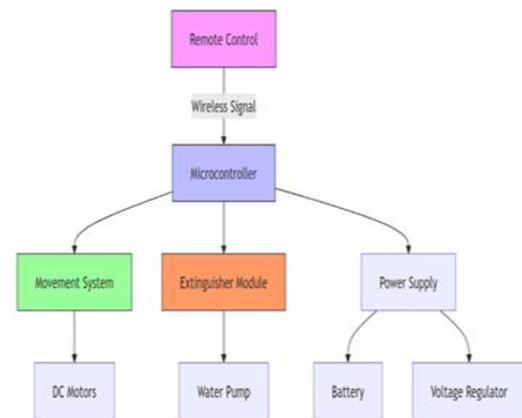
This dual-input architecture ensures both operator control and autonomous response when unsafe conditions arise.

5.2 Movement Control Module

Mobility is essential for reaching hazardous zones safely. The robot’s movement is controlled using DC motors or servo motors connected to the robotic legs. These actuators receive PWM signals from the Arduino, which vary based on the command received from the mobile interface.

The microcontroller translates directional inputs—forward, backward, left, and right—into appropriate motor movements. This allows the robot to maneuver toward or away from a fire source. Using quadruped-style motion ensures better stability on uneven surfaces, which is often a limitation in traditional wheeled robots used for firefighting applications.

The movement system is supported by the power module, which supplies regulated voltage to prevent motor overload and ensure consistent gait patterns even during extended operation.



This diagram shows the microcontroller branching into movement system, extinguisher module, and power supply.

5.3 Flame Detection and Safety Loop

The robot is equipped with flame sensors positioned toward the front. These sensors continuously monitor for flame presence and intensity. Their output signals are analyzed by the Arduino to detect unsafe or unexpected flames.

If a flame is detected within a dangerous threshold, the microcontroller initiates a safety response, which includes:

- Triggering an alarm or buzzer
- Automatically activating the extinguishing pump
- Disabling the ignition module to prevent accidental fuel discharge

This safety loop ensures that the robot can autonomously respond to fire without requiring human intervention, thereby reducing risks associated with delayed human reaction.

5.4 Flame Ignition Module

The ignition module enables controlled fire creation for training exercises. It consists of a fuel pump, solenoid valve, and ignition coil. When a command is received from the mobile controller, the Arduino activates the relay module, which powers the pump and opens the valve. Fuel is then pushed toward the nozzle, where the ignition coil generates a spark to create a flame.

The ignition system is carefully isolated from other circuits using relays to prevent electrical interference or accidental activation. Safety interlocks are programmed to ensure this module cannot operate simultaneously with the extinguishing system.

5.5 Fire Extinguishing Module

The extinguishing module operates through a pump connected to a reservoir containing water or CO₂. When manually activated by the operator or triggered automatically by the flame sensor, the Arduino sends a signal to engage the pump through a relay. The extinguishing fluid is discharged through a nozzle mounted on the robot's legs, allowing precise targeting of flames.

This design ensures rapid suppression of small fires and provides a safe training mechanism for controlled burn scenarios.

5.6 Wireless Control and Communication

The robot's remote-control system is built around the HC-05 Bluetooth module, which connects to the mobile interface created using MIT App Inventor. Through this app, users can control movement, start ignition, activate extinguishing, and initiate emergency stops. Bluetooth was selected for its simplicity, low power consumption, and reliability in

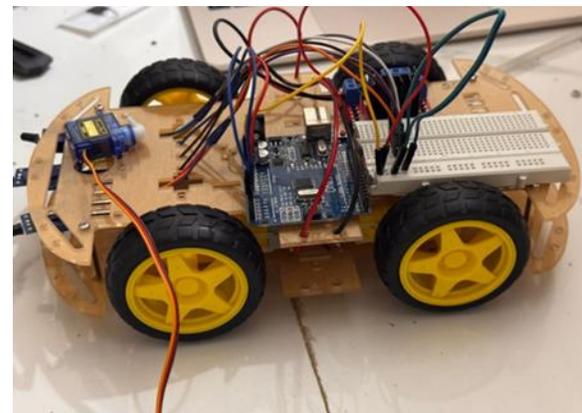
short-range, line-of-sight environments—typical conditions during training or indoor testing.

5.7 Power Supply and Voltage Regulation

A rechargeable battery serves as the primary power source. Since the system contains components with different voltage requirements, a voltage regulator ensures stable and appropriate power delivery. Motors, pumps, sensors, and the microcontroller receive regulated voltage to prevent overheating or malfunction. The power supply design ensures long operational time, stable performance, and protection against voltage fluctuations.

VI. RESULT

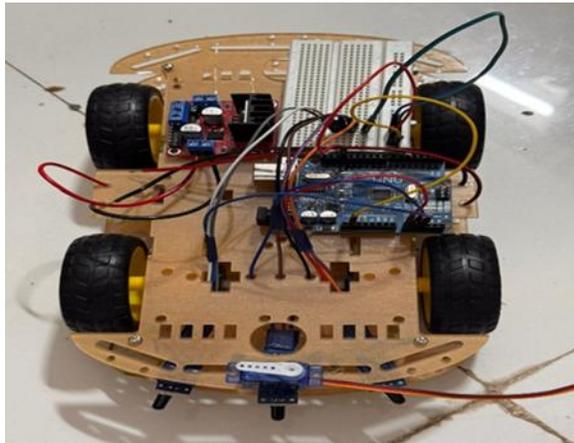
The developed dual-purpose flamethrower and extinguisher robot was tested under controlled laboratory conditions to evaluate its movement capability, wireless responsiveness, ignition performance, and extinguishing efficiency. During mobility testing, the robot demonstrated stable quadruped-based locomotion, successfully navigating straight paths, moderate turns, and uneven test surfaces. Bluetooth-based remote control showed an average response time of less than one second, ensuring smooth and continuous operation without communication delays.



The flame ignition module performed reliably, producing a consistent and controllable flame output when commanded. The safety interlock successfully prevented ignition when the extinguishing module was active, confirming the effectiveness of the system's programmed safeguards. The flame detection sensor accurately detected test flames at distances up to 80–

100 cm, triggering the autonomous safety response sequence. This included immediate pump activation and shutdown of the ignition system, validating the reliability of the safety loop.

The extinguishing module showed strong performance, effectively suppressing small test fires in an average of 4–6 seconds depending on the flame size and material. Water-based extinguishing proved most effective for paper and cloth fires, while CO₂ demonstrated superior performance for concentrated flame bursts.



Overall, the results indicate that the robot successfully meets the intended functional requirements of controlled fire creation, immediate flame detection, and rapid extinguishing. Its reliable wireless control, stable movement, and integrated safety mechanisms confirm its suitability for controlled training environments, laboratory demonstrations, and further development into field-ready firefighting assistance systems.

VII. CONCLUSION AND FUTURE SCOPE

The integrated flamethrower and fire-extinguishing robot successfully demonstrates the feasibility of combining controlled flame generation, real-time fire detection, and rapid suppression within a single mobile platform. The Arduino-based control system, wireless Bluetooth operation, and quadruped mobility together provide a reliable and adaptable solution for hazardous or inaccessible environments. Experimental results confirm stable locomotion, efficient extinguishing performance, and robust safety mechanisms, validating the effectiveness of the design

for training, testing, and basic emergency response scenarios. Overall, the system meets its primary objectives and establishes a foundation for more advanced firefighting robotics.

In the future, the robot can be enhanced with autonomous navigation using LiDAR, ultrasonic mapping, or thermal imaging to reduce dependence on manual control. Upgrading the chassis with heat-resistant composites will improve durability in high-temperature environments. The extinguishing system can be expanded to support multiple agents such as foam or dry chemicals for industrial applications. Integration of machine learning could enable intelligent fire-behavior prediction and adaptive suppression strategies. These improvements would significantly extend the robot's operational capability and readiness for real-world deployment.

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