

# Fire Rover: Smart Fire Defence Robot with 360° Mobility for Hazardous Fire Environments

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**Abstract** - Fire accidents in industrial plants, warehouses, residential complexes and disaster-affected areas can spread rapidly and expose emergency personnel to severe danger. This paper presents the design and development of a Smart Fire Defense Robot intended to reduce direct human involvement during firefighting operations. The robot is remotely operated using a dedicated wireless transmitter and receiver based on the nRF24L01 transceiver module. It incorporates 360-degree omnidirectional mobility, stair-climbing capability; a servo-controlled nozzle and a 12 V water pump for targeted fire suppression. The complete system is controlled by Arduino Nano microcontrollers in both the transmitter and receiver units. The mechanical platform is designed using heat-resistant materials and high-torque DC geared motors to ensure stable operation in challenging environments. Experimental testing under controlled conditions demonstrated reliable wireless communication, accurate movement control, and effective extinguishing of small fires. The proposed system is economical, modular and easily upgradeable with advanced technologies such as thermal imaging, gas sensors and artificial intelligence. The developed robot can be deployed in industries, warehouses, laboratories and disaster-response scenarios to improve safety and reduce property damage.

**Key Words:** Firefighting Robot, Arduino Nano, nRF24L01, Wireless Control, Omnidirectional Mobility, Water Pump, Disaster Management

## 1. INTRODUCTION

Fire is one of the most destructive hazards affecting human life, infrastructure and industrial assets. Conventional firefighting methods often require personnel to enter dangerous zones characterized by intense heat, smoke, toxic gases and unstable structures. Although trained firefighters are equipped with protective gear, direct exposure to such environments still presents substantial risk.

Robotics offers an effective alternative by enabling remote operation of machines capable of entering hazardous areas. Firefighting robots can navigate to the source of a fire and deploy suppression mechanisms while the operator remains at a safe distance. Recent advances in embedded systems, wireless communication and low-cost sensors have made such systems more practical and affordable.

The Smart Fire Defence Robot proposed in this work is designed as a compact and cost-effective solution. It combines omnidirectional motion, obstacle-climbing capability and a servo-directed water spray system. The robot can be controlled intuitively through joysticks and switches. Compared with manually operated firefighting methods, the proposed system reduces response risk, improves precision and provides a scalable platform for future automation.

## 2. LITERATURE SURVEY

Chen et al. developed a real-time firefighting robot controlled through wireless communication. Their work demonstrated remote mobility but suffered from latency and interference issues in congested environments.

Patel et al. integrated thermal imaging to identify hotspots. While the approach improved fire localization, the system was expensive and not tightly integrated with autonomous navigation.

Lee et al. proposed a sensor-fusion approach combining smoke, temperature and gas sensors. The technique improved detection accuracy but required calibration and could generate false alarms.

Basar and Roy introduced an IoT-based firefighting robot using ESP32-CAM and GSM modules. The system enabled monitoring and visual feedback but depended heavily on network connectivity.

The literature shows that an affordable platform combining reliable wireless control, enhanced mobility and effective suppression remain highly relevant.

## 3. PROBLEM STATEMENT

During fire emergencies, inaccessible and high-risk environments make conventional firefighting difficult and dangerous. Existing robotic systems often have restricted movement, short communication range, and limited ability to traverse stairs or debris. There is a need for a practical, low-cost and robust robotic platform capable of remote navigation and targeted fire suppression in hazardous locations.

#### 4. OBJECTIVES

1. To design and develop a remotely operated firefighting robot.
2. To implement 360° omnidirectional movement for agile navigation.
3. To provide stair-climbing and obstacle-crossing capability.
4. To integrate a servo-based directional water spraying mechanism.
5. To ensure reliable wireless communication between operator and robot.
6. To reduce human exposure to hazardous fire environments.
7. To create a modular platform that supports future upgrades.

#### 5. PROPOSED SYSTEM

The proposed system consists of a transmitter unit and a receiver unit.

The transmitter unit contains two joystick modules, two potentiometers, two toggle switches, an Arduino Nano and an nRF24L01 transceiver. The operator uses this handheld controller to issue movement and firefighting commands.

The receiver unit includes an Arduino Nano, nRF24L01 transceiver, L298N motor driver, four DC geared motors, two servo motors, a relay module, a 12 V DC water pump and a lithium-ion battery pack. Commands received wirelessly are decoded and translated into motion and pump-control actions.

The mechanical structure uses a sturdy chassis with heat-resistant components. Four motors provide omnidirectional motion, enabling the robot to move forward, backward, sideways and diagonally. The water nozzle is mounted on a two-axis servo arrangement for precise targeting.

#### 6. METHODOLOGY

The development process involved mechanical design, electronic integration, firmware programming and testing.

**Mechanical Design:** A stable chassis was designed to support motors, pump, and battery and controller boards.

**Circuit Integration:** The Arduino Nano was interfaced with the nRF24L01 module, motor driver, relay and servos.

**Firmware Development:** Programs were written in the Arduino IDE to read joystick data, transmit packets and control actuators.

**Testing and Optimization:** Individual subsystems were tested before full integration. Wireless range, movement response, nozzle positioning and pump operation were evaluated and refined.

#### 7. BLOCK DIAGRAM:

As shown in the figure below, the RC Receiver section is the main controlling unit of the Smart Fire Defence Robot. It receives wireless signals from the transmitter and controls the movement and firefighting operations of the robot. The RC Receiver block diagram consists of the following components:

##### 1. Receiver Module

The receiver receives wireless control signals transmitted from the RC transmitter using the nRF24L01 wireless communication module. These signals contain commands related to robot movement and firefighting operations.

##### 2. Arduino Nano

The Arduino Nano acts as the central processing unit of the receiver section. It processes the signals received from the receiver module and generates corresponding control signals for motors and servos. It coordinates the complete operation of the robot.

##### 3. Motor Driver

The motor driver interfaces between the Arduino Nano and DC motors. Since the Arduino cannot supply sufficient current directly to the motors, the motor driver amplifies the control signals and drives the motors efficiently.

##### 4. DC Motors (Motor 1, Motor 2, Motor 3, Motor 4)

Four DC geared motors are connected to the motor driver. These motors provide 360° movement to the robot, enabling forward, backward, left, right, and rotational motion for better navigation in fire-affected areas.

##### 5. Servo Motors (Servo 1 and Servo 2)

Servo motors are used to control the direction and positioning of the water spray nozzle. The Arduino controls the angular movement of the servos for accurate targeting of fire.

##### 6. Power Supply

The power block supplies electrical power to the Arduino Nano, receiver module, motor driver, motors, and servos. It ensures continuous and stable operation of the entire receiver system.

Thus, as shown in the figure, the RC Receiver section converts wireless commands into mechanical actions, enabling remote operation of the firefighting robot.

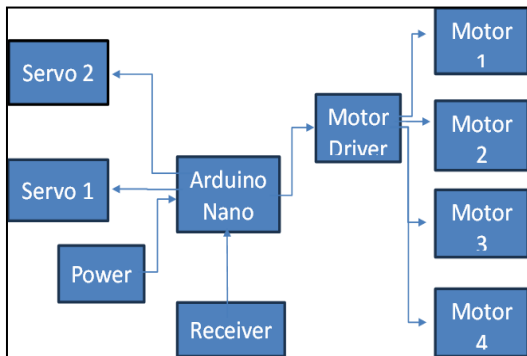


Figure 7.1: RC Receiver

As shown in the figure below, the RC Transmitter section is used by the operator to control the movement and firefighting functions of the robot remotely. It sends control commands wirelessly to the receiver section.

The RC Transmitter block diagram contains the following components:

1. Joystick Modules

The joystick modules are used to control the movement of the robot. By moving the joystick in different directions, the user can control forward, backward, left, and right movement of the robot.

2. Switch 1 and Switch 2

The switches are used for controlling specific operations such as turning the water pump ON/OFF or activating additional firefighting functions.

3. Potentiometer 1 and Potentiometer 2

Potentiometers are variable resistors used to control the angular position of the servo motors. These help in adjusting the direction of the water spray nozzle accurately.

4. Arduino Nano

The Arduino Nano acts as the controller of the transmitter unit. It reads the input values from the joysticks, switches, and potentiometers, processes them, and prepares corresponding control data.

5. Transmitter Module

The transmitter module wirelessly transmits the processed control signals to the receiver section using RF communication through the nRF24L01 module.

6. Power Supply

The power block provides electrical power to the Arduino Nano and transmitter module for proper functioning of the transmitter system.

Therefore, as shown in the figure, the RC Transmitter section acts as the user control interface that enables wireless operation and real-time control of the Smart Fire Defense Robot.

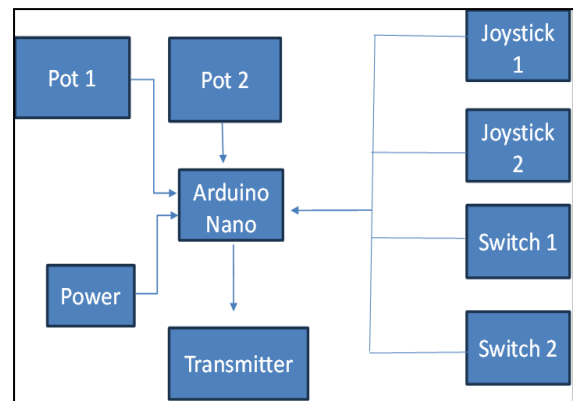


Figure 2.2: RC Transmitter

### 8. HARDWARE AND SOFTWARE REQUIREMENTS

**Hardware:** Arduino Nano, nRF24L01 transceivers, L298N motor driver, DC geared motors, servo motors, relay module, 12 V water pump, joysticks, potentiometers, toggle switches and lithium-ion batteries.

**Software:** Arduino IDE, embedded C/C++ firmware and serial debugging tools.

### 9. WORKING PRINCIPLE

The operator manipulates joysticks and switches on the transmitter. Input values are processed by the transmitter Arduino and sent as structured data packets through the nRF24L01 module. The receiver Arduino decodes the packets and generates control signals.

The motor driver adjusts motor direction and speed according to movement commands. Servo motors orient the nozzle in horizontal and vertical directions. When the firefighting switch is activated, the relay energizes the water pump and water is sprayed directly at the fire source.

### 10. RESULTS AND DISCUSSION

The prototype was tested in controlled environments using small open flames. The robot demonstrated stable omnidirectional movement and smooth directional changes. It successfully climbed moderate inclines and small steps. Wireless communication remained reliable throughout the test area with negligible response delay.

The servo-based nozzle enabled precise targeting, reducing water wastage and improving suppression effectiveness. The water pump extinguished test flames quickly. Battery performance was sufficient for extended demonstrations. The experiments confirmed that the robot can function as a practical first-response tool for small to medium fire incidents in hazardous zones.

## 11. ADVANTAGES

- Minimizes risk to firefighters.
- Provides 360° movement for superior maneuverability.
- Supports stair-climbing and obstacle traversal.
- Enables accurate directional water spraying.
- Uses low-cost and readily available components.
- Modular design simplifies maintenance and upgrades.
- Suitable for industrial, residential and disaster-response applications.

## 12. LIMITATIONS

The current system relies on manual operation and visual monitoring by the operator. Water storage is limited by onboard capacity. Communication range depends on surrounding interference and obstacles. The robot is best suited for early-stage or localized fires rather than large-scale incidents.

## 13. FUTURE SCOPE

Future improvements may include thermal cameras, flame, smoke and gas sensors, LoRa or GSM communication for extended range, AI-based path planning, computer vision and autonomous navigation. Integration with cloud dashboards and real-time video streaming can further enhance operational awareness.

## 14. CONCLUSION

The Smart Fire Defense Robot provides a practical and economical solution for firefighting in hazardous environments. By combining reliable wireless control, omnidirectional mobility, stair-climbing capability and targeted water spraying, the system reduces human exposure to danger while improving response effectiveness. Experimental results validate the feasibility of the design and demonstrate its potential for deployment in industrial safety, residential protection and disaster management.

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