Design, Fabrication, and Performance Analysis of a Cost-Effective Remote-Controlled Firefighting Vehicle (RCFFV)

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Abstract - Fire *incidents pose serious risks to human life and property, especially when they occur in hazardous, confined, or inaccessible locations such as chemical factories and restricted industrial zones. Conventional firefighting techniques require direct human intervention, exposing emergency personnel to dangerous conditions, including high temperatures, toxic gases, and unstable structures. To reduce these hazards, a Remote-Control Firefighting Vehicle (RCFFV) that enables remote suppression (water) operations was designed, fabricated, and analytically modeled. The prototype is a small, autonomous ground vehicle equipped with a specialized water-jet system and a wireless remote-control interface. With a metallic chain-track frame and a high-torque DC motor, the vehicle is designed to move on tough terrain. The vehicle's capacity to navigate obstacles, communicate over long distances, and put out small-scale fires efficiently was validated through experiments. This study confirms that Low-cost robotic technologies can greatly improve safety in disaster management scenarios.*

Keywords**:** **Firefighting Robot, Remote Control Vehicle, Unmanned Ground Vehicle (UGV), Disaster Management, Chain Track Mechanism.**

1. Introduction

Firefighting remains one of the most dangerous professions, frequently requiring responders to navigate unfamiliar, hazardous terrain. In complex environments—such as tunnels, industrial facilities, and dense urban infrastructure—the unpredictable behavior of fire severely compromises personnel safety. Consequently, the integration of robotics and remote-control technology has emerged as a vital innovation, offering a safer and more effective alternative to direct human intervention. By acting as an automated assistant, a remote-controlled firefighting vehicle can traverse rough terrain to approach a fire's epicenter and deploy suppressants from a secure distance. This capability not only mitigates the immediate threat to human life but also facilitates rapid, precise emergency responses in otherwise inaccessible areas. The primary objective of this research is to construct a functional, remote-controlled vehicle that combines mechanical robustness with advanced electrical control systems to operate effectively in these high-risk environments. Specifically, this study proposes a design capable of 360-degree water delivery and robust movement across difficult terrains. The subsequent sections detail the vehicle's architecture, critical parameters, and operational range.

2. Literature Review

Recent advancements in robotics have greatly improved autonomous firefighting technologies. Today, these robots are actively used to mitigate risks to human responders in dangerous environments [1-2]. *Cakir et al.* proposed a fan-based robot with unidirectional detection, which could risk spreading fires in open environments [3]. *Taha et al.* developed a robot for enclosed spaces that was limited by a complex deployment and a single flame sensor with a narrow 60^0 detection range [4]. *Sangewar et al.* developed a fire-detecting robot equipped with a gas sensor, a camera, and an Arduino Mega 2560, but its reliance on manual operation limited its effectiveness [5]. *Kucukdermenci et al.* developed a remote-controlled firefighting robot with a 120^0 detection angle, but it lacked autonomous capabilities and real-world validation [6].

Based on this literature review, the primary research gap highlights the lack of a remotely controlled firefighting vehicle design capable of omnidirectional water delivery, navigation across difficult terrains, and practical real-world usability.

3. Design specification and material selection

The design specifications for remote-controlled fire fighting vehicle are listed in Table 1 below:

Table 1 Design specifications remote-controlled fire fighting vehicle

parameter	specification
vehicle dimensions	length: 106.7 cm, width: 45.7 cm, height: 30.5 cm
chassis material	iron
locomotion	dual DC motors with mild steel metallic chain tracks
motors	24V DC motor, 3000 rpm (2 nos.)
control system	BTS 7960 motor driver with FX-iA6 receiver module
remote control range	up to 1000 meters
power supply	24V rechargeable lead acid battery
water pump	12V DC pump, flow rate: ~9.5 liters/min
water tank capacity	15 liters
speed	~20 km/h
weight	~100 kg
operation time	around 30-40 minutes per charge

Figure 1 represents the schematic diagram of the proposed remote-controlled firefighting vehicle, and Figure 2 illustrates the different parts of the remote-controlled firefighting vehicle along with its dimensions.

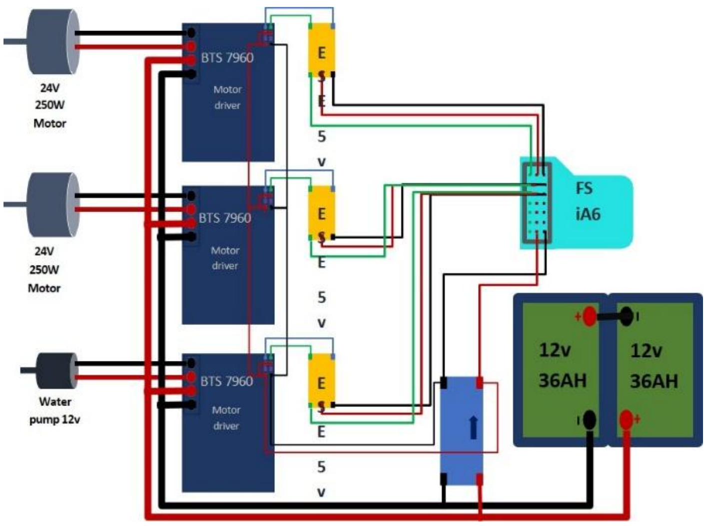

Figure 1. Schematic circuit diagram of the remote-controlled firefighting vehicle used in this project.

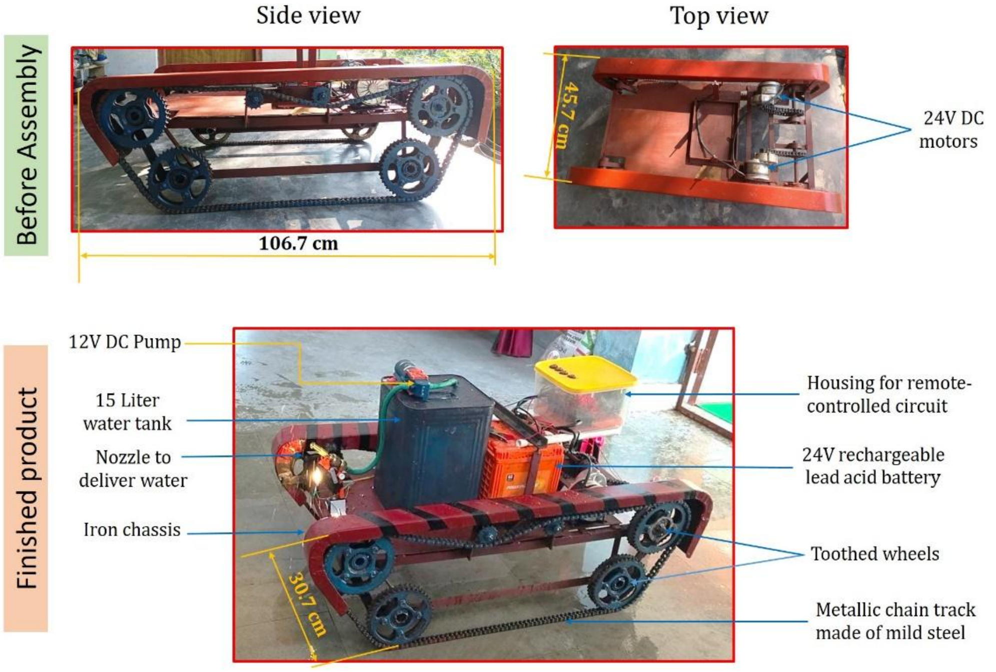

Figure 2. Illustration of different parts and dimensions of a remote-controlled firefighting vehicle.

4. Analytical work

The calculation of important parameters, such as power consumption, current requirements, and operational time, is presented below:

1. **Power Consumption of 24V DC Motors**

   Voltage supplied, Vm = 24V

   Each motor's current draw under load, Im = 2A

   Number of motors used = 2

   Total motor power:

$$\text{Pmotors} = \text{Vm} \times \text{Im} \times 2 = 24 \times 2 \times 2 = 96\ \text{W}$$

2. **Power Consumption of 12V Water Pump**

   Voltage supplied, Vp = 12V

   Current drawn by pump, Ip = 1.5A

   Pump power:

$$\text{Ppump} = \text{Vp} \times \text{Ip} = 12 \times 1.5 = 18\text{W}$$

3. **Total Power Consumption**

$$\text{Ptotal} = \text{Pmotors} = \text{Ppump} = 96 + 18 = 114\text{W}$$

4. **Battery Capacity and Operation Time**

   Battery voltage: Vb = 24V

   Battery capacity: C = 7Ah

   Total energy available:

$$\text{Ebattery} = \text{Vb} \times \text{C} = 24 \times 7 = 168\text{W}$$

5. **Estimated run time:**

$$T = \frac{E_{battery}}{P_{total}} = \frac{168}{114} \approx 1.47 \text{ hours } (\approx \ 88 \text{ minutes})$$

Actual runtime may be lower due to inefficiencies, losses, or intermittent usage patterns.

5. Test results and discussion

After fabrication, the RCFFV underwent a series of tests to evaluate its mobility, remote-control range, and fire-suppression capabilities. The vehicle navigated both level and mildly uneven terrain smoothly, with its metal tracks effortlessly clearing minor obstacles up to 2 cm high. It maintained an average speed of roughly 20 km/h, an ideal pace for controlled movement in confined areas. The remote-control system proved reliable up to 1,000 meters in open areas, though substantial metal barriers caused some signal interference. For fire suppression, the built-in 12V pump delivered a steady 1.5 liters per minute, reaching about 2 meters, proving highly effective at extinguishing small-scale test fires. However, the 15-liter water tank limited continuous spraying to about 15-20 minutes before requiring a refill. Power-wise, the vehicle operated continuously for 30 to 40 minutes under a combined load. While shorter than theoretical estimates, this battery life was completely sufficient for short-duration tasks. Throughout all testing, the chassis remained structurally sound, demonstrating minimal tilting or vibration.

6. Conclusion and Future Work

The project successfully achieved its primary objective: designing and fabricating a low-cost, remote-controlled firefighting vehicle capable of navigating hazardous environments. Through its chain-drive system and remote-operated pump, the prototype demonstrated both effective mobility and reliable fire suppression. Although the vehicle has certain limitations—namely, a restricted water capacity and a lack of extreme heat resistance—it serves as an excellent educational model and a solid proof of concept for affordable disaster management. Ultimately, the system's distinct advantages lie in its cost-effectiveness, compact portability, and ability to keep human operators safely out of the immediate danger zone.

To advance this prototype toward industrial use, future development will focus on four key upgrades: adding thermal and smoke sensors for autonomous navigation, utilizing Wi-Fi or LoRa for extended signal range, switching to CO_2 or foam suppression for chemical and electrical fires, and upgrading to a fire-retardant chassis for survival in extreme heat.

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