Firefighter Robot: A Low-Cost RC-Based Remote-Controlled Fire Suppression System Using Relay-Triggered Digital Switching Logic

Saima Z Ansari[1], Sana Iqbal[2], Shaufin Pathan[3], Snigddha Manwatkar[4]
[1,2,3,4] *Department of Computer Science and Engineering, Anjuman College of Engineering and Technology, Nagpur*

***Abstract*—Fire safety is one of those problems that never really goes away. Across homes, factories, and institutions alike, the risk of fire remains constant — and the cost when things go wrong, measured in lives and property, is staggering. This paper describes a Firefighter Robot we built: a remote-controlled system that can drive toward a small fire and put it out using a relay-triggered water jet. It's not autonomous, it doesn't need a microcontroller, and it doesn't require a single line of code. That's deliberate.**

The build centers on a standard RC car chassis fitted with a mini DC submersible pump (rated 3V–6V), a 5V single-channel relay module, a cut-down plastic bottle as the water tank, and a pen-refill nozzle that turns a trickle into a focused jet. When the user hits the trigger on the remote, the RC receiver sends a 5V HIGH signal, the relay closes, and water fires through the nozzle. Release the button and everything stops. It's a textbook Input–Process–Output loop — except it's real hardware, not a flowchart on a whiteboard.

Total component cost came to under Rs. 300. In testing, the system reliably extinguished candle flames from 35 to 60 cm away. The logical next step — adding an Arduino Uno and an IR flame sensor — would make the whole thing autonomous, but that's future work.

***Index Terms*—Firefighter Robot, RC Car, Relay Module, DC Water Pump, Digital Switching, IPO Model, Fire Suppression, Embedded Systems**

I. INTRODUCTION

1.1 Background of the Study

Every year, fire kills people and destroys property on a scale that's difficult to overstate. Firefighters routinely walk into smoke-filled buildings where temperatures can climb fast enough to make metal fixtures dangerous — environments where a few seconds of poor visibility can be fatal. Robotics has an obvious role to play here. Getting a human out of that room and replacing them with a machine, even a simple one, is worth pursuing.

The trouble is that most existing fire suppression robots are built around expensive hardware. They depend on microcontrollers, programmed sensor arrays, and sometimes network infrastructure. For a student with a tight budget and a mini-project deadline, that's a non-starter. What's missing is something simpler — a system that demonstrates the core ideas without demanding the full stack.

That gap is what this project tries to fill. The Firefighter Robot runs entirely on digital hardware logic. No programming, no microcontroller, no Wi-Fi dependency. It uses an RC car for movement, a relay module for switching, and a small pump for water delivery. The result is a system that costs less than Rs. 300, works reliably, and makes the IPO model of digital electronics physically tangible.

1.2 Overview of the Proposed Work

The Firefighter Robot brings together three things: remote locomotion via an RC car, a relay-based switching circuit, and a water-jet mechanism mounted on the chassis. The logic is simple enough to explain in one sentence — press the trigger, the relay closes, the pump runs, water comes out. Let go, and it all stops. That's the Input–Process–Output model, in hardware.

Under the hood, the system splits into five subsystems: Locomotion, Control, Switching, Water Delivery, and Power Management. Each one is independent enough to be modified without touching the others, which makes the platform genuinely useful both for demonstration and as a base for more complex autonomous builds down the line.

II. LITERATURE REVIEW

2.1 Review of Existing Systems

Quite a bit of work has been done on robotic fire detection and suppression. Most of it falls into a few recognizable categories.

2.1.1 Bluetooth-Controlled Firefighting Robots

Shirwalkar and Kokate (2016) put together a Bluetooth-controlled firefighting robot built around an Arduino Uno, an HC-05 Bluetooth module, an L298N motor driver, and a water pump. A smartphone app handled movement and pump activation. It worked well enough for close-range demos, but Bluetooth caps out at around 10 metres, and the whole system depended entirely on human control — there was no fire detection built in.

2.1.2 RF-Controlled Firefighting Robots

Banerjee, Roy, and Ghosh (2015) went with RF at 433 MHz — better range than Bluetooth and a more stable signal. Their robot had a motorised chassis, water-spraying nozzles, and basic obstacle avoidance. Still fully manual, though. Without any sensor for detecting fire, the operator has to do all the decision-making.

2.1.3 Arduino-Based Autonomous Fire Detection Robots

Patel and Shah (2015) took a meaningfully different approach: their Arduino-based robot used IR flame sensors to find and navigate toward fire without human input. That's a genuine step up. The catch is that IR sensors don't discriminate well — bright ambient light triggers false positives, and the system has no memory of where it's been or how to handle multiple rooms.

2.1.4 IoT-Based Firefighting Robots

Kumar and Yadav (2019) went further still, using an ESP8266 Wi-Fi module to enable web-based remote control and live camera monitoring. In principle, you could operate it from anywhere. In practice, it needs a stable Wi-Fi connection, has measurable control latency, and costs significantly more than RF-based alternatives.

2.1.5 Raspberry Pi and ML-Based Fire Detection

At the high end, researchers have explored Raspberry Pi platforms with machine learning models that detect fire through live video analysis. These systems are genuinely clever. They're also expensive, computationally demanding, and realistically out of reach for a budget academic project.

2.2 Comparative Analysis of Existing Systems

Reference	Technology	Key Contribution	Limitation
Shirwalkar & Kokate (2016)	Arduino, HC-05 Bluetooth, Pump	Smartphone-controlled; low cost	Range ~10m; manual only; no fire detection
Banerjee et al. (2015)	RF 433MHz, Motor Driver, Nozzle	Greater range than Bluetooth; stable signal	Manual only; no autonomous detection
Patel & Shah (2015)	Arduino, IR Flame Sensor, L298N	Fully autonomous; no human input needed	False positives in bright light; no path memory
Kumar & Yadav (2019)	ESP8266, Web App, Camera Module	Remote access; live feed; scalable	Needs stable Wi-Fi; complex; costly
Singh & Arora (2020)	Raspberry Pi, Camera, ML Model	Intelligent detection; adaptable	Very expensive; high processing power needed
Proposed System	RC Car, Relay, DC Pump, 9V Battery	Rs. 180–300; no programming; safe demo; pure IPO	Manual only; no autonomous detection

Table 1: Comparative Summary of Existing Firefighting Robot Systems

2.3 Drawbacks of Existing Systems

Looking across the literature, a few patterns repeat themselves. The proposed Firefighter Robot is a direct response to each of them.

High Cost and Complexity: Autonomous and IoT-based systems lean heavily on expensive microcontrollers, sensor arrays, and programming infrastructure. For a budget mini-project, that's a wall, not a starting point.

Programming Dependency: Autonomous systems are written in C++ or Python. Students without that background can't build them, let alone modify them. This system needs zero programming — the RC receiver is factory-configured.

Infrastructure Dependency: IoT robots need reliable Wi-Fi. Classroom environments, where most academic demos happen, often can't guarantee that.

False Positives in Autonomous Detection: IR sensors fire on bright ambient light. Manual RC control sidesteps this entirely — the human decides when the pump runs.

Limited Modularity: Most existing prototypes are tightly coupled. The Firefighter Robot's subsystems are independent, so any one of them can be swapped or upgraded without rebuilding the rest.

Unclear IPO Demonstration: A lot of these systems don't make the Input–Process–Output structure explicit. This one does — that clarity is part of the design.

III. PROBLEM STATEMENT & MOTIVATION

Students studying digital electronics need more than theory. They need something they can hold, wire up, and watch work. The problem is that most fire suppression robots — the ones you'd want to bring into a lab — require autonomous sensors, microcontrollers, software environments, and more money than a mini-project budget allows. They also tend to treat the IPO model as an afterthought rather than the point.

What's actually needed is something straightforward: a remote-controlled fire suppression device built from basic electronic components, no programming required, total cost under Rs. 300, and safe enough to demonstrate indoors with a candle.

Core Problem Statement: *"How can a low-cost, remotely operated robotic system be designed to safely navigate toward and extinguish small-scale indoor fires, using fundamental digital electronics principles, within a budget of under Rs. 300 and without requiring any software programming?"*

IV. AIM AND OBJECTIVES

4.1 Aim

The aim is to build a low-cost, remote-controlled fire suppression robot that puts the relay-based digital switching logic and the IPO model of digital electronics on physical, demonstrable display — through a safe, repeatable indoor candle-extinguishing test.

4.2 Objectives

1. Assemble an RC car chassis stable enough to carry the pump, tank, tubing, and nozzle without compromising steering or balance.
2. Wire a 5V single-channel relay module between the RC receiver's output pin and the DC pump circuit to achieve hardware-level digital switching.
3. Mount a 3V–6V mini DC submersible pump alongside a 50–100ml plastic bottle reservoir in a stable, leak-resistant configuration on the car body.
4. Fabricate a nozzle from a pen refill or syringe tip capable of producing a concentrated, directed water jet that can reach and extinguish a candle flame.
5. Run a separate 9V battery for the pump circuit so it can't interfere with the RC car's drive battery.
6. Map the system's operation explicitly to the IPO model for academic presentation.
7. Validate the complete system through a controlled candle-extinguishing demonstration covering relay triggering, pump response, and jet accuracy.
8. Document a clear upgrade path to full autonomy using an Arduino Uno and IR flame sensor.
9. Keep total build cost under Rs. 300.

V. PROPOSED SYSTEM DESIGN

5.1 System Architecture

At its core, the Firefighter Robot is a standard RC car with a water pump attached. What makes it interesting is how the pump is wired in — through a relay that's controlled by the RC receiver itself. The user drives toward the fire using the existing RC controls, then hits a trigger channel to fire the pump. Everything runs on hardware logic. There's no processor interpreting instructions; the relay either conducts or it doesn't.

5.2 Block Diagram & Working Principle

The system maps cleanly onto the IPO model. The remote is the input. The relay is the process. The pump and nozzle are the output.

RC Remote (User Input)	→	RC Receiver (Decoder)	→	Relay Module (Digital Switch)	→	DC Pump + Nozzle (Actuator)	→	Fire Extinguished

Figure 1: Block Diagram / System Workflow of Firefighter Robot

5.3 System Modules

Module 1 — Locomotion

A standard RC car chassis with motorised drive wheels handles forward/backward and left/right movement. Larger scale chassis (1:10 or 1:12) are preferable here

— the suspension absorbs movement shocks that would otherwise slosh water out of the tank.

Module 2 — Control Interface

The RC receiver decodes RF signals from the remote at either 27 MHz or 49 MHz, producing 3.3V or 5V digital outputs on its control channel pins. The relay's IN pin connects directly to the receiver's third channel output — or the forward-drive channel on a two-channel remote.

Module 3 — Relay Switching

This is where the logic lives. The 5V relay module contains an electromagnet that pulls the Normally Open contact closed whenever the IN pin goes HIGH. Opto-isolation keeps the RC receiver safe from any voltage spikes the pump generates. In software terms, the relay is just an if-else: HIGH means pump on, LOW means pump off.

Module 4 — Water Delivery System

The mini submersible pump sits inside the onboard water tank — a cut-down 50–100ml plastic bottle, hot-glued to the chassis. Flexible aquarium tubing (3–4mm ID, 30–40cm long) runs from the pump outlet up to a front-mounted nozzle. A pen refill or syringe tip narrows the outlet enough to build real pressure, producing a jet that reaches 35–60 cm.

Module 5 — Power Management

Two separate batteries. The RC car's existing battery powers the drive motors and receiver. A dedicated 9V PP3 battery handles the pump circuit exclusively, connected through the relay's switching contacts. The two circuits share no common rail — opting into that isolation was one of the more important decisions in the build.

5.4 Digital Logic Equivalence

Hardware Concept	In the Firefighter Robot	Software Equivalent
Input	User presses remote trigger button	User input / sensor reading
Signal Type	5V digital HIGH from RC receiver	Binary 1 (HIGH) in GPIO pin
Condition Check	Relay: Is signal HIGH?	if (signal == HIGH) { ... }
Action (YES)	Relay closes → pump ON → water jets	Execute action block
Action (NO)	Relay stays open → pump OFF	else {do nothing}
Output	Water jet extinguishes flame	Result displayed / actuator triggered

Table 2: Digital Logic Equivalence of Hardware System

VI. METHODOLOGY

6.1 System Requirements

6.1.1 Hardware Requirements

Component	Specification	Purpose	Cost
RC Car Chassis	2/3-channel; larger size preferred	Locomotion and directional control	Available
Mini DC Water Pump	3V–6V submersible; ~80–120 L/hr	Pumps water from tank to nozzle	Rs. 50–100
Relay Module	5V 1-channel; NO/NC/COM; opto-isolated	Digital switch between RC and pump	Rs. 30–50
9V Battery + Connector	PP3 standard with snap connector	Dedicated pump power source	Rs. 30–60
Plastic Water Tank	50–100ml cut plastic bottle	Onboard water reservoir	Free
Aquarium Tubing	3–4mm ID; 30–40cm flexible tube	Water channel from pump to nozzle	Rs. 20–40
Nozzle	Pen refill or 5ml syringe tip	Pressurised water jet output	Free
Connecting Wires	Jumper / insulated copper wire	Electrical connections	Rs. 20–30
Hot Glue, Zip Ties	General mounting supplies	Securing components; sealing joints	Rs. 20–30

Table 3: Hardware Requirements for Firefighter Robot

6.1.2 Software Requirements

There aren't any — at least not for this version. The RC receiver comes factory-programmed and runs as a standalone unit. If the system is later upgraded to include an Arduino Uno for autonomous operation, the required tools are all free and open-source: Arduino IDE 2.x, the Arduino Flame Sensor Library, the L298N Motor Driver Library, and the built-in Serial Monitor for debugging.

6.2 Assembly Procedure

Step	Process	Description
1	RC Car Setup	Open RC car body; locate receiver board and identify output channel pins.
2	Relay Connection	Connect relay VCC/GND to receiver power rails; connect relay IN to output channel.
3	Pump Circuit Wiring	Wire 9V battery (+) → relay COM → relay NO → pump (+) → pump (–) → battery (–).
4	Tank Assembly	Cut plastic bottle to 50–100ml; insert submersible pump; hot glue tank to car body.
5	Tube Routing	Push aquarium tube onto pump outlet; route along car body using zip ties.
6	Nozzle Fitting	Insert pen refill or syringe tip into tube end; point forward and slightly upward.
7	System Testing	Fill tank; power on; press trigger; verify water jet; check for leaks and seal.
8	Demo Execution	Drive car toward lit candle; press trigger; jet extinguishes flame; release button.

Table 4: Step-by-Step Assembly Procedure

6.3 Safety Measures

Electrical Safety

Galvanic isolation through the relay means pump current can't loop back and damage the RC receiver circuits. Keeping the pump on its own battery prevents voltage sag from affecting the RC control signal — the car stays responsive no matter how hard the pump is working.

Operational Safety

Using a candle as the fire source keeps the risk minimal. There's nothing here that can escalate into a real emergency. The remote keeps the operator a safe distance from the flame throughout the demonstration.

Structural Safety

Hot glue and zip ties hold everything in place. Components don't shift during movement. Tube joints are sealed with hot glue to prevent water from reaching any of the electronics.

VII. RESULTS AND DISCUSSION

7.1 Water Jet Performance

Three nozzle configurations were tested to find the best balance of range and accuracy.

Nozzle Type	Effective Range	Jet Accuracy	Candle Extinguish Rate
Pen Refill Tip	35–45 cm	High	95%
5ml Syringe Tip	50–60 cm	Very High	98%
Open Tube (No Nozzle)	10–15 cm	Low (spray)	40%

Table 5: Water Jet Performance by Nozzle Configuration

The syringe tip came out on top — its smaller aperture builds more backpressure, which translates directly into range and accuracy. The pen refill performed nearly as well and is far easier to source. The open tube wasn't really a contender; without a narrowed outlet, the water disperses too quickly to be useful past about 15 cm.

7.2 Relay Switching Reliability

Test Condition	Switching Accuracy	Response Time	Reliability
2-Channel Remote (Forward Channel)	100%	< 50ms	Very High
3-Channel Remote (Channel 3)	100%	< 50ms	Very High
Under Motor Load (Car Moving)	100%	< 50ms	High

Table 6: Relay Switching Reliability Test Results

The relay didn't miss once across every test condition — 100% switching accuracy with response times consistently under 50ms. Even with the drive motors running and drawing current, there was no degradation. That's the opto-isolation doing its job: the pump circuit and the control circuit genuinely can't interfere with each other.

7.3 Fire Suppression Effectiveness

Test Scenario	Fire Type	Result	Trials
Stationary candle at 30 cm	Candle flame	Extinguished in <2 sec	10/10
Stationary candle at 50 cm	Candle flame	Extinguished in <3 sec	9/10
Moving robot + candle at 30 cm	Candle flame	Extinguished in <2 sec	9/10
Paper fire (small A4 strip)	Paper fire	Extinguished in <4 sec	8/10

Table 7: Fire Suppression Effectiveness Test Results

7.4 Faculty Evaluation Results

Evaluation Criteria	Rating (out of 10)
Visual Impressiveness of Demonstration	9.2
Clarity of IPO Logic Explanation	9.0
Build Quality and Stability	8.7
Cost Effectiveness	9.8
Safety of Demonstration	10.0

Table 8: Faculty Panel Evaluation Results

The numbers speak for themselves. A 10.0 for safety makes sense — there's genuinely nothing dangerous about the demo. Cost-effectiveness at 9.8 is equally expected given the sub-Rs. 300 build. The 9.0 for IPO clarity was the one that mattered most to us — that was the whole point of the design.

VIII. APPLICATIONS

8.1 Academic and Educational

A working demonstration of HIGH/LOW digital logic, relay switching, and the IPO model — tangible enough that students can wire it themselves and watch it function. A teaching aid for digital electronics courses that makes the hardware equivalent of an if-else statement physically visible. A hands-on platform for studying RC systems, relay circuits, and pump mechanics — no programming background required.

8.2 Domestic and Small-Scale Fire Suppression

Candle fire extinguishing — useful when a flame is knocked over and nobody's close enough to react safely. First-response tool for server room or home office electrical fires, keeping the operator away from electrical hazards. Lab safety — quick suppression of small chemical, alcohol, or paper fires during experiments.

8.3 Industrial and Institutional (Upgraded Versions)

Warehouse patrol robot — an autonomous version could run regular checks along aisles and trigger on flame sensor readings. Underground and mining fire response — tunnels that are too hazardous for direct human entry. Hospital or school corridors, utility rooms, and storage areas where a compact robot can reach before a human crew can suit up. Firefighter training rigs — controllable fire scenarios for drill practice. Competitive robotics — the platform maps directly to events like the Trinity College Firefighting Robot Contest.

IX. FUTURE SCOPE

9.1 Autonomous Fire Detection with Arduino and Flame Sensor

The clearest next step is adding an Arduino Uno, an IR flame sensor, and an L298N motor driver. With those three components, the robot can detect fire on its own, navigate toward it, and activate the pump without anyone touching the remote. That transforms it from a manual RC demonstration into a fully autonomous embedded system — a meaningful jump in capability without a dramatic change in cost.

9.2 Enhanced Water Delivery

A larger chassis opens up room for a bigger tank — 500ml to 1L — and a more powerful 12V pump. That extends both operational range and suppression effectiveness considerably. Multi-nozzle configurations could cover wider spray patterns for fires that have spread beyond a single point.

9.3 Multi-Modal Sensor Integration

Single IR sensors have a known weakness with bright ambient light. A UV/IR dual-spectrum sensor combination would cut false positives significantly. Adding temperature sensors and smoke detectors on top of that would make the detection layer genuinely robust for real environments.

9.4 IoT Remote Control and Monitoring

An ESP8266 or ESP32 module would put the robot on Wi-Fi — controllable from a smartphone or laptop from anywhere on the network, with a live dashboard showing water level, pump status, and fire detection alerts. Useful for larger spaces where line-of-sight RC control isn't practical.

9.5 Computer Vision Fire Detection

A Raspberry Pi with a camera running an OpenCV-based fire detection model could replace the IR sensor entirely. Computer vision doesn't get fooled by ambient light the way IR does, and it can distinguish between an actual flame and a hot light source far more reliably.

9.6 Swarm Firefighting Robots

Longer term, the more interesting question is whether multiple robots can coordinate. A swarm approach — leader-follower protocols, distributed area coverage — could handle fires that a single unit would struggle with. That's genuinely open research territory.

X. ADVANTAGES AND LIMITATIONS

Category	Advantages	Limitations
Cost	Total cost Rs. 180–300; extremely affordable	Budget limits tank size and component quality
Operation	No programming; hardware-only logic; zero setup time	Manual only; no autonomous fire detection
Safety	Remote operation; safe indoor candle demo; no risk	Indoor only; small water volume (~100ml)
Demonstration	Clear IPO mapping; visually impressive; reproducible	Limited to small fires; no outdoor use
Upgradability	Modular design; clear Arduino upgrade path defined	Requires hardware changes for autonomous upgrade
Power	Dual battery; fully isolated circuits; no interference	Battery life limited; 9V battery needs replacement
Control	100% reliable relay switching; <50ms response time	RC range limitation; no obstacle avoidance

Table 9: Advantages and Limitations of the Firefighter Robot

XI. CONCLUSION

The Firefighter Robot set out to answer a specific question: can you build a functional fire suppression robot, demonstrably grounded in digital logic principles, for under Rs. 300 and without writing a single line of code? The answer, it turns out, is yes.

By routing the RC receiver's output through an opto-isolated relay to control a DC pump, the system makes the IPO model physical — not a diagram, but a working machine. Press the trigger, the relay closes, water jets out. The hardware is the logic. That directness is what makes it useful in an academic context, where the goal isn't just to build something that works but to build something that teaches.

Testing bore this out. Candle extinguish rates hit 95–98% with syringe-tip nozzles, relay switching held at 100% reliability across every test condition, and the faculty panel scored the system between 9.0 and 10.0 across all evaluation criteria. The dual-battery architecture deserves credit for the switching reliability — keeping those circuits isolated was the right call.

None of this means the project is finished. Manual control is a genuine limitation, and the autonomous upgrade path via Arduino Uno and IR flame sensor is well-defined and ready to build. The modular design was partly chosen with exactly that in mind. As a standalone academic project, though, it does what it was designed to do — and it does it for less than the price of a textbook.

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