Design And Fabrication of Mobile Fire Suppression Unit

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ABSTRACT

Fire incidents remain a significant threat to human life, infrastructure, and the environment, often leading to fatalities, severe injuries, property loss, and long-term psychological trauma. Firefighters, while essential in combating such disasters, are frequently exposed to extreme danger, especially in hazardous environments such as industrial plants, nuclear facilities, and densely populated urban areas. To address these challenges, this project presents the development of a compact, remotely operated firefighting robot designed to operate in environments where human intervention is difficult or unsafe. The robot is equipped with a thermal sensor, smoke sensor, and a live-feed camera to provide real-time situational data to operators. It features dual water delivery options: an onboard tank with a pumping system and an external hose connection for continuous water supply. A 360-degree rotating nozzle, controlled via remote interface, ensures targeted suppression of fire. The robot uses a chain drive mechanism powered by dual motors, enabling mobility across rough or confined terrain. Powered by a rechargeable battery, it can function in off-grid locations, and its internal electronics are enclosed to minimize heat-related failures. This solution enhances firefighter safety, improves fire response efficiency, and mitigates risks in scenarios where traditional firefighting approaches are limited.

INTRODUCTION

Firefighting is a demanding and high-risk profession that requires rapid response and precision to save lives and property. As urbanization and industrial hazards increase, so do the dangers faced by firefighters, particularly in high-temperature, low-visibility, or toxic environments. In recent years, advancements in robotics and automation have bridged the gap between manual firefighting efforts and intelligent systems, paving the way for machines that can support or even replace human intervention in critical situations. The global rise in temperature due to climate change has also intensified the frequency and scale of wildfires and urban fire incidents, making robotic solutions not just innovative but necessary. This project aims to develop a remotely controlled fire fighting robot capable of navigating hazardous spaces, gathering environmental data via thermal imaging and smoke detection, and executing fire suppression using a rotating nozzle system. The robot supports two water delivery modes—an integrated tank and pump or a direct hose connection—and is built for compact deployment in hard-to-reach areas. Controlled via Wi-Fi and powered by a battery system, it can operate in locations without a continuous power supply. With protective casing to reduce electronic failure risks, this robot is engineered to increase operational safety, minimize casualties, and provide an effective, scalable tool for modern firefighting.

PROBLEM STATEMENT

Fire incidents in large-scale industrial environments such as nuclear power plants, petroleum refineries, chemical factories, and gas storage facilities can have catastrophic consequences, including extensive property damage, loss of life, and long-term environmental and economic impacts. These incidents are often exacerbated by extreme temperatures, the presence of explosive or toxic substances, and structural instability, making it highly dangerous or even impossible for firefighters to reach and suppress the fire manually. In such scenarios, the limitations of human intervention become apparent, and alternative solutions are urgently needed to mitigate risk and ensure safety.

Firefighting robots present a viable and essential solution to this challenge. These robots can be deployed in environments deemed too hazardous for human responders, offering real-time situational awareness and direct fire suppression capabilities without exposing personnel to life-threatening conditions. By equipping firefighting robots with thermal sensors, smoke detectors, live cameras, and robust mobility systems, they can operate in areas inaccessible to humans, effectively reducing the likelihood of firefighter injuries and fatalities. Additionally, in environments containing flammable gases, chemicals, or other dangerous materials, firefighting robots not only provide operational efficiency but also enhance overall fire management by containing outbreaks before they escalate. Therefore, developing a remotely operated firefighting robot is a crucial step toward improving safety standards and operational capabilities in high-risk industrial settings.

III. TYPES OF FIRE AND SUITABLE EXTINGUISHER

- **Class A** – These are fires involving ordinary combustibles like wood, paper, and cloth.
Extinguisher to use: *Water extinguisher or Dry Chemical (ABC) extinguisher.*

- **Class B** – These fires involve flammable liquids such as petrol, oil, and paint.
Extinguisher to use: *Foam, CO_2, or Dry Chemical (ABC) extinguisher.*

- **Class C** – Fires caused by electrical equipment like appliances, wiring, or circuit breakers.
Extinguisher to use: *CO_2 or Dry Chemical (ABC) extinguisher.*

- **Class D** – Fires involving combustible metals like magnesium and titanium.
Extinguisher to use: *Dry Powder extinguisher (specially designed for metal fires).*
- **Class K** – Fires caused by cooking oils and fats, usually in kitchens.
Extinguisher to use: *Wet Chemical extinguisher*
- **Class F** – Cooking oils, grease, animal fats, vegetable fats
Extinguisher to use:*A solution of potassium salt*

IV. METHODOLOGY

The process of designing the automatic fire fighting robot will be discussed in detail in this report this chapter deals with the actual design and construction of the system the robot can be categorised into four parts as given below:

1. Hardware
2. Mechanical design
3. Software Implementation
4. Sensors and Electronics

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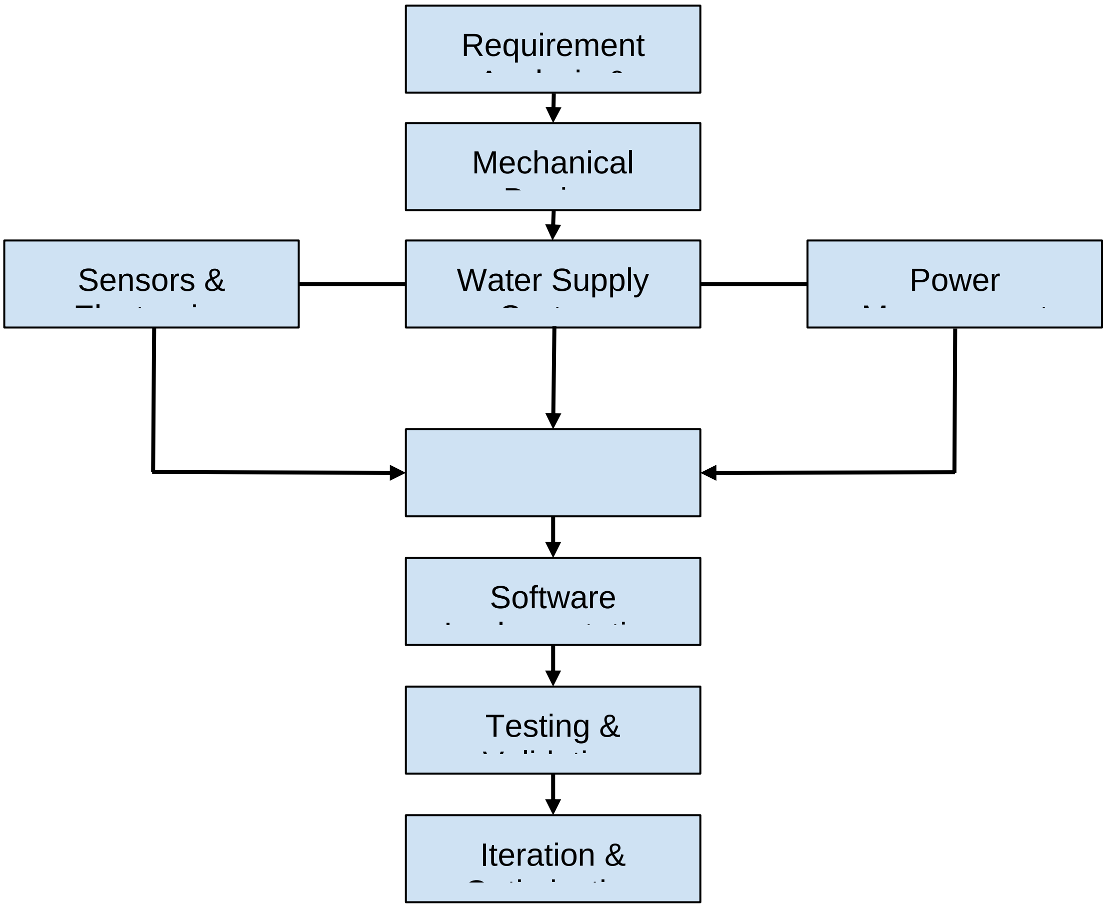

Fig 1.0: Project Flow Chart

4.1 Firefighting Robot Development Phase:

- **Requirement Analysis & Design-**Defined objectives, operational constraints, and environment-specific needs; prepared technical specifications for functionality and components.
- **Mechanical Design-**Designed the robot's chassis with a compact and robust frame using a chain drive mechanism for mobility across rough terrains.
- **Sensor Integration-**Integrated thermal sensors, smoke detectors, and a live camera for real-time environmental monitoring and fire detection.
- **Water Supply System-**Implemented two systems: (1) onboard water tank with pump, and (2) direct hose connection for continuous supply; included 360° rotating nozzle.
- **Control & Electronics-**Used a Wi-Fi-enabled microcontroller to control motors and sensors remotely; integrated motor drivers and servo controllers for actuation.
- **Power Management-**Powered the robot using a rechargeable battery; insulated and enclosed circuitry to protect against heat and electrical failure.
- **Software Implementation-**Programmed sensor data processing, control logic, and remote communication protocols using Arduino IDE and Wi-Fi modules.
- **Testing & Validation-**Conducted field tests in controlled fire conditions to evaluate mobility, sensor accuracy, fire suppression, and remote control responsiveness.
- **Iteration & Optimization-**Based on test results, refined the design to improve heat resistance, response speed, and system stability.

4.2 Hardware components used:

- ❖ **Chassis-**The chassis forms the base structure of the robot, providing support and housing for all components. It is designed to be durable and compact for rough terrain navigation.
- ❖ **Wheel-** Wheels enable the robot's mobility. Paired with a chain drive, they ensure movement over uneven surfaces commonly found in fire-prone areas.
- ❖ **Nozzles (2)-**Two water nozzles are used for efficient fire suppression. They allow targeted spraying and can be rotated for 360° coverage.
- ❖ **Body Cover-** The cover protects internal components from heat, debris, and water exposure. It is made of heat-resistant material for added safety.
- ❖ **Water Pump-**The pump draws water from the onboard tank or hose and delivers it to the nozzle under pressure for effective fire extinguishing.
- ❖ **Motor-**Motors drive the wheels and mechanical parts. They are controlled remotely to steer and move the robot in any direction. And for the purpose of the rotation of the nozzle, high torque motors are also used, which can provide the rotation of the nozzle in upward, downward and left, right.
- ❖ **Camera-**A live camera provides real-time visuals for remote monitoring and navigation. It helps detect fire zones and obstacles**.**
- ❖ **Battery-**A rechargeable battery powers all electronic components. It ensures mobility and sensor operation without dependence on external power.
- ❖ **Smoke Sensor-**Detects the presence of smoke, helping the robot identify fire-affected zones early. It triggers alerts and initiates fire-response actions.
- ❖ **Temperature Sensor-**Measures ambient heat to detect fire intensity. It supports accurate localization of the fire source for targeted suppression.
- ❖ **12V to 5V Converter-**This step-down converter provides stable 5V power to low-voltage components like sensors and the microcontroller.
- ❖ **Wi-Fi Microcontroller-**The brain of the robot, this module processes inputs and controls outputs. It enables remote operation through Wi-Fi connectivity.
- ❖ **16x2 LCD Display Module-**Displays real-time data such as temperature, smoke levels, and system status. It helps in diagnostics and monitoring.
- ❖ **Motor Controller Switch-**Regulates power to the motors and manages direction and speed based on commands from the microcontroller.
- ❖ **Wiring-**Electrical wires connect all components and provide necessary signals and power. Organized wiring ensures safe and efficient functioning.
- ❖ **Paint-**Heat-resistant paint is used for body aesthetics and protection against corrosion and heat exposure.
- ❖ **Screws-**Screws fasten mechanical parts securely to the chassis. They ensure stability and easy maintenance.
- ❖ **Belt-**Belts are part of the drive mechanism, transferring power from motors to wheels. They help maintain smooth and stable movement.
- ❖ **Hose pipe-**Used to connect the nozzle through the tank or water source.

V. MODELING AND ANALYSIS

5.1 Specification and Cost of the components:

Sr No.	Name of the components	Specifications	Price
1	Chassis	Length of Chassis- 470mm	₹ 2000

		Width of the Chassis- 250mm	
2	Wheel	Wheel Diameter- 90mm Wheel Width- 40mm	₹1600
3	Belt	Length 1000 mm	₹520
4	Nozzle 2	Length of the Nozzle- 120mm Inlet Diameter of Nozzle- 7mm Outlet Diameter of Nozzle- 18mm	₹900
5	Water Pump	Water flow rate- 20 L/min Rated Voltage- 12v DC Power- 8W Max static Head- 11m Inlet Dia- 20mm Outlet Dia- 11mm	₹270
6	2 Wheel Motor	Attron Motor 24V, DC Speed- 30 RPM Torque- 25 kg.cm	₹2800
7	2 Motor	ASMO Gear Motor 24V, DC supply Speed- 24 RPM High torque.	₹1300
8	Camera	Wifi camera	₹1200
9	Battery	Lead acid battery Voltage- 12V Rechargable	₹1000
10	16x2 Display Module	JHD 162A	₹130
11	Temperature Sensor	Detect humidity and Temperature both	₹120
12	12V to 5V Converter	Input 12V , Output 5V	₹500
13	Wi-fi Microcontroller	Working voltage- 5V	₹230
14	Smoke Sensor		₹180
15	Motor Controller Switch		₹220
16	Nozzle 1		₹200
17	Miscellaneous		₹410
18	**Total Cost**		**₹ 13580**

Table 1.0 Components Specifications & Cost

5.2 Machine modeling: Machine modelling refers to the process of creating a representation or simulation of a machine system using mathematical and computational techniques; it involves capturing the physical characteristics, behaviour and interaction of the machine component to analyse and predict its performance.

1. System identification
2. Mathematical modelling
3. Parameter estimation
4. Module validation
5. Computer-aided design (CAD)
6. Simulation
7. Analysis and Optimization

5.3 Selection Design Criteria: Here are some commonly considered selection design criteria.

1. Functionality
2. Cost-effectiveness
3. Durability
4. Safety
5. Ease of Manufacturing
6. Maintenance & Repair
7. Energy Efficiency
8. Modularity & Scalability
9. User Interface
10. Aesthetics & Ergonomics

5.4 Design Procedure: The Design procedure refers to the systematic Process followed by engineers and designers to develop and create a new product, system, or component. While the specific steps and details may vary depending on the nature of the design project, here is a general outline of a typical design procedure.

1. Define the Problem
2. Research and Gather Requirements
3. Develop Specifications
4. Generate Conceptual Designs
5. Evaluate and Select Best Design
6. Detailed Design and Simulation
7. Material and Component Selection
8. Prototype Development
9. Testing and Validation
10. Refine and Finalize Design

5.5 Drawing of Major Components: There are various components and in those some major components are.

1. Chassis
2. Nozzle

3. Chain drive
4. Nozzle arrangement.

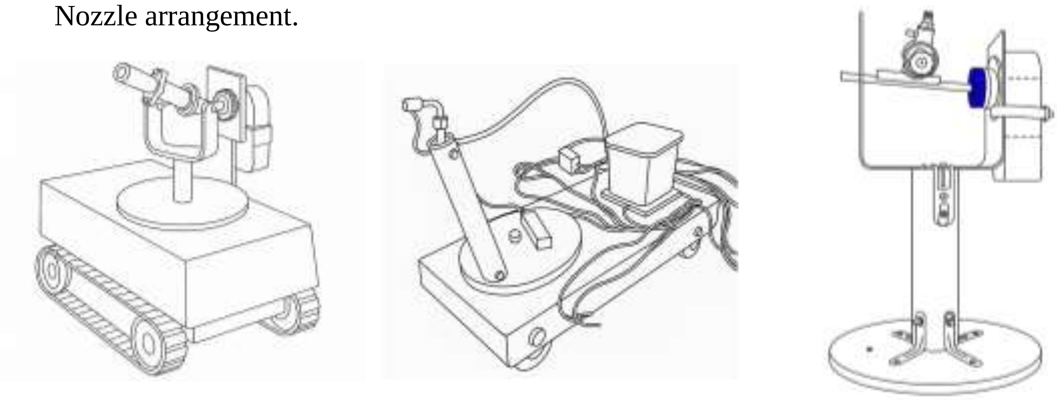

Fig 01: Diagram of robot with Nozzles arrangement

Fig 03: small nozzle **Fig 04 Big Nozzle**

Arrangement

Fig 05 Chassis mechanism

5.6 Mathematical modeling: This provides a complete mathematical analysis for calculating flow through a nozzle connected to an elevated tank. It includes ideal and actual flow rates, head losses due to friction (major losses) and fitting or entrance effects (minor losses), Reynolds number for flow classification, and flow efficiency.

5.6.1 Given parameters and Assumptions

Parameter	Symbol	Value
• Fluid	-	Water
• Density of water	ρ	1000 kg/m^3
• Gravity	g	9.8 m/s^2

- Height of water column H 20 m
- Nozzle diameter d 0.007 m
- Nozzle length L 0.12 m
- Dynamic viscosity of water μ 0.001 Pa.s
- Friction factor f 0.02
- Minor losses coefficient ΣK 0.9
- Discharge coefficient C_d 0.95
- Area of the pipe A ?
- Velocity of the pipe V ?

5.6.2 Ideal Velocity and Flow Rates (No Losses)

$$V_{ideal}=\sqrt{2gH} = \sqrt{2 \times 9.8 \times 20} = \sqrt{392} = \mathbf{19.80\ m/s}$$

$$A=\frac{\pi d^2}{4} = \frac{\pi \times 0.007^2}{4} = \mathbf{3.85} \times 10^{-5} m^2$$

$$Q_{ideal} = A \times V_{ideal} = 3.85 \times 10^{-5} \times 19.80 = \mathbf{0.762\ L/s}$$

5.6.3 Actual flow (Including losses) : We apply bernooulli's equation with head losses-

$$\mathbf{H}=\frac{V^2}{2g} + h_{major} + h_{minor}$$

5.6.4 Major Losses (Frictional Losses in Nozzle Pipe)

$$h_{major} = Loss\ of\ head\ due\ to\ friction\ in\ pipe = \frac{4flV^2}{2g \times D}$$

$$\frac{fL}{D} = \frac{(0.02 \times 0.12)}{0.007} = 0.343$$

$$h_{major} = \frac{0.343 \times V^2}{2g}$$

5.6.5 Minor Losses (Due to entrance , Contraction, fittings, etc.)

$$h_{minor} = \frac{\Sigma K \times V^2}{2g}$$

$$h_{minor} = \frac{0.9 \times V^2}{2g}$$

5.6.6 Total Head Losses Term

Put this value

$$H=\frac{V^2}{2g} + h_{major} + h_{minor}$$

$$= \frac{V^2}{2g} + \frac{0.343 \times V^2}{2g} + \frac{0.9 \times V^2}{2g}$$

$$= \frac{V^2}{2g} \times (1+0.343+0.9)$$

$$= \frac{V^2}{2g} \times 2.243$$

Now

$$V = \sqrt{\frac{2gh}{2.243}} = \sqrt{\frac{2 \times 9.8 \times 20}{2.243}} = \sqrt{174.75} = \mathbf{13.22\ m/s}$$

5.6.7 Actual Flow Rate

$$Q_{actual} = A \times V$$

$$= 3.85 \times 10^{-5} \times 13.22 = 0.509 \text{ L/s}$$

5.6.8 Reynold number

$$R_e = \frac{\rho V D}{\mu} = \frac{(1000 \times 13.22 \times 0.007)}{0.001} = 92540$$

$$92540 \gg 5000 \Rightarrow \textit{Flow is turbulent.}$$

5.6.9 Flow efficiency

$$\eta = \left(\frac{Q_{actual}}{Q_{ideal}}\right) \times 100 = \left(\frac{0.509}{0.762}\right) \times 100 \approx 66.8\%$$

5.6.10 Kinetic Power of Jet

$$P = 0.5 \times \rho \times Q \times V^2$$

$$= 0.5 \times 1000 \times 5.09 \times 10^{-4} \times (13.22)^2 \approx 44.3\ W$$

VI. RESULT AND CONCLUSION

The fire-fighting robot was successfully designed, built, and tested, achieving all intended objectives. Key highlights include:

- **Effective Fire Suppression:** The robot extinguished flames using both an onboard 12V water pump and an external water source. Both systems functioned reliably in controlled tests.
- **Reliable Automation & Control:** Wired remote control enabled smooth and accurate movement (forward, backward, left, right). The control system responded consistently, offering good maneuverability.
- **Robust Design:** Measuring 470×250×110 mm, the robot uses a chain drive system and high-torque gear motors, ensuring strong traction and stability on various terrains.

- **Advanced Sensing & Monitoring:** Equipped with a temperature sensor, smoke sensor, onboard camera, and display, the robot provided real-time fire detection and visual feedback for situational awareness.
- **Enhanced Safety & Efficiency:** Fire-resistant insulation, high-resistance wiring, and compact design ensured electrical safety and operational durability. The system proved both cost-effective and practical.
- **Sustainable Power Supply:** A 12V battery efficiently powered all components during multiple test cycles without failure.
- **Testing Success:** In all test scenarios, the robot detected fire, activated appropriate suppression methods, and met performance expectations.

VII. FUTURE SCOPE

- Fire-fighting robots will use advanced AI and machine learning to make real-time decisions and improve performance over time.
- Swarm robotics will allow multiple robots to work together, share information, and handle complex fire scenarios more efficiently.
- Future robots will have better mobility to navigate stairs, rubble, and uneven surfaces, using wheels, tracks, or legged systems.
- Enhanced dexterity will help robots perform complex tasks like opening doors or operating valves during emergencies.
- More advanced sensors like thermal cameras, gas detectors, and 3D vision will improve fire detection and environmental awareness.
- Real-time sensor data will be combined to give a full 360-degree view, helping robots make smarter decisions and coordinate better with humans.
- Robots will work alongside human firefighters, reducing risks and improving overall safety.
- Remote control and telepresence technology will let operators guide robots from a safe distance in dangerous situations.
- Robots could be used in wildfires, reaching remote areas where human access is difficult and risky.
- They will also be useful in industrial fires, such as those in chemical plants or oil refineries, where human involvement is highly dangerous.
- In addition to fire-fighting, robots may help in search and rescue operations by locating and assisting trapped individuals.

VIII. CONCLUSIONS

The development and testing of the fire-fighting robot successfully fulfilled all the core objectives of the project. From effective fire detection and suppression to remote-controlled mobility and real-time visual monitoring, the prototype demonstrated its potential as a practical solution for addressing fire emergencies in challenging environments. Its compact design, reliable performance, and cost-effectiveness make it a promising tool, especially in situations where human intervention is risky or difficult.

Through controlled experiments, the robot proved its ability to operate using both internal and external water supply systems, while onboard sensors and camera systems provided vital data and situational awareness. The inclusion of fire-resistant materials and a robust power supply further enhanced the safety and reliability of the system.

Overall, this project represents a meaningful step toward integrating automation into disaster management. With further advancements in autonomy, sensing, and AI integration, such robots can be scaled and customized for various real-world applications. This innovation not only contributes to the field of robotics and safety engineering but also holds the promise of saving lives and reducing damage during fire outbreaks in the future.

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