Design and Development of Fire Fighting Robot

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Abstract —This robot is supposed to go into places where people can't really get to safely, like during a fire or something hazardous. It uses a bunch of sensors, including flame and IR sensors, to spot the danger and put out the flames. The main part is this microcontroller that kind of mixes all the sensor info together in a special way. It gets about 95 percent detection rate inside buildings, which sounds good. Older systems just had one sensor, and they were slow to respond or kept giving false alarms, so this setup aims to fix that. Once it picks up on a fire, the robot moves on its own, following some paths that give off heat radiations. Then it sprays water right where needed to stop it. It shows how sensors keep working together nonstop, and the robot makes decisions by itself, plus it moves around without any help. That part feels a bit messy to explain, but it means handling big emergencies on its own is doable now. In robotics, this pushes things forward with more flexible designs for emergencies later. Better ways to respond to patterns, smarter navigation, and improved ways to put out fires. The study tries to outline those changes. Some people might think single sensors are simpler, but this multi-sensor seems worth it for real situations. Overall, the prototype attempts to hit that goal of full independence.

Keywords: autonomous robots, fire detection, sensor integration, multi-sensor fusion, autonomous systems, robotics, emergency response

1.INTRODUCTION

An Arduino Uno-based Fire Fighting robot is a technologically advanced and innovative solution designed to combat and mitigate the destructive impact of fires in various environments. Fires pose significant threats to both life and property, and traditional firefighting methods often entail substantial risks. This robot integrates cutting-edge hardware and software components with the Arduino Uno microcontroller, a versatile and widely used platform for building interactive and programmable electronic systems. By leveraging the power of Arduino Uno, this fire-fighting robot offers an autonomous and efficient approach to detect, navigate, and extinguish fire, thereby enhancing overall firefighting capabilities. The heart of the firefighting robot is the Arduino Uno microcontroller, which serves as the brain, orchestrating its functions. Equipped with an array of sensors such as temperature, smoke, and infrared detectors, the robot can accurately identify the presence and intensity of fires within its operational environment. Upon fire detection, the robot employs its motorized wheels or tracks for mobility, allowing it to navigate through challenging terrains and obstacles, ensuring timely response to fire incidents that might be hard to reach by human firefighters. The integration of Arduino-compatible actuators and servos further enhances its agility, enabling it to manoeuvre effectively and access fire-affected areas swiftly. The intelligence of the robot is derived from its programming, where the Arduino Uno processes sensor data, makes real-time decisions, and executes appropriate actions. Through the integration of wireless communication modules like Wi-Fi or Bluetooth, the robot can transmit critical information, such as fire location and status updates, to a remote-control station or a central monitoring system. Essence when it comes to fighting fires, as even a few minutes' delay can turn small fires into raging infernos. This robot is designed as a first response unit so it can suppress the fire and keep it under control till help arrives. This firefighting robotic system is controlled by an Arduino Uno development board. It is also equipped with the flame sensor for detecting fires. It is equipped with a water tank and a pump. So, on detecting fires, it sprays water, extinguishing the fire. The water spraying nozzle is mounted on a servo motor to cover the maximum area. Although there is a lot of scope for improvement, this could be a first step in developing a complete fire-fighting robot that could also rescue victims. The main function of this robot is to become an unmanned support vehicle developed to search and extinguish fire. By using such robots, fire identification

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and rescue activities can be done with greater accuracy and securely without exposing the fire fighters to dangerous conditions. [1]

2. LITERATURE SURVEY

2.1 Fire Detection Technologies

Fire detection has been an active research area for decades, with various technologies developed for different applications [2]. Traditional fire detection systems employ ionization or photoelectric smoke detectors, which operate based on detecting particulates in the air [3]. However, these stationary systems cannot provide directional information or autonomous response capabilities. Recent advances in fire detection have incorporated infrared (IR) sensors and UV flame detection [4], which can identify fires by their thermal and optical signatures, respectively.

2.2 Autonomous Robotic Systems The field of autonomous robotics has advanced significantly with developments in mobile robot platforms, autonomous navigation, and decision-making algorithms [5]. Wheeled mobile robots have proven particularly effective for indoor navigation due to their simplicity and robustness [6]. Recent work on mobile robots has integrated various sensors for environmental perception, including vision systems, LiDAR, ultrasonic sensors, and chemical sensors [7]. However, the integration of fire-specific detection sensors with autonomous mobile platforms remains relatively unexplored.

2.3 Sensor Fusion and Multi-Modal Sensing

Multi-sensor fusion has become a standard approach in robotics to improve perception robustness and accuracy [8] Sensor fusion techniques can be categorized into low-level fusion (raw data level), feature-level fusion, and decision-level fusion [9]. For fire detection applications, decision-level fusion provides flexibility in combining heterogeneous sensor modalities. Recent work by Kumar et al. [10] demonstrated that multi-sensor approaches significantly reduce false positive rates in fire detection compared to single-sensor systems.

2.4 Related Firefighting Robots

Several research teams have developed firefighting robots in recent years. The work by Chen et al. [11] presented a remote-operated robot for fire suppression but did not include autonomous fire detection. The RESCUE robot [12] demonstrated autonomous navigation but relied on external thermal imaging for fire localization. Park and colleagues [13] developed a firefighting platform with basic flame detection, though without comprehensive sensor integration. Our work distinguishes itself by implementing comprehensive multi-sensor fusion specifically optimized for autonomous fire detection and response.

3.METHODOLOGY

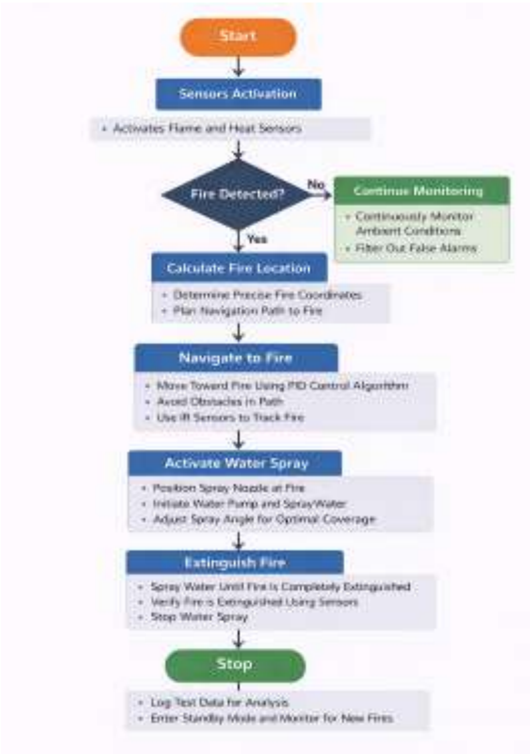

Fig. 1: Fire detection and suppression workflow

Fig. 1 shows step by step how the system works during fire outbreak.

Essentially, the robot starts using flame and heat sensors. The. This prepares it for any potential issues.

This part of the monitoring involves frequent checking. When there's a genuine fire or nothing, it stays stationary and proceeds to watch more. To avoid recognizing problems, it must disregard elements like sunlight or regular warmth that could make it believe there is something wrong. False alarms are avoided in that manner.

When a bonfire is ignited, the subsequent action is to identify the precise source of the heat. It measures coordinates or similar data. Then it plots its way to the destination, avoiding any obstacles that may arise along the way. It appears to be clever in its ability to move without getting obstructed.

It employs a PID control mechanism to move towards the fire. Despite my lack of knowledge, it aids in making smooth speed changes and steering correctly. In the meantime, the sensors keep track of the fire in real-time, permitting it to change direction if there is a slight shift.

When it reaches the point, however... the robot positions its end to feed the water pump. It squirts water and adjusts the angle accordingly. While it's not impossible to describe this part, the blast doesn't just blow once and then run away. However, it persists until the sensors indicate that the fire has been put out permanently.

When completed, it documents certain details such as the duration of work or water usage. The check on its effectiveness later must be conducted. Afterward, it switches back to standby, prepared to start monitoring again.

3.1 Overall System Design

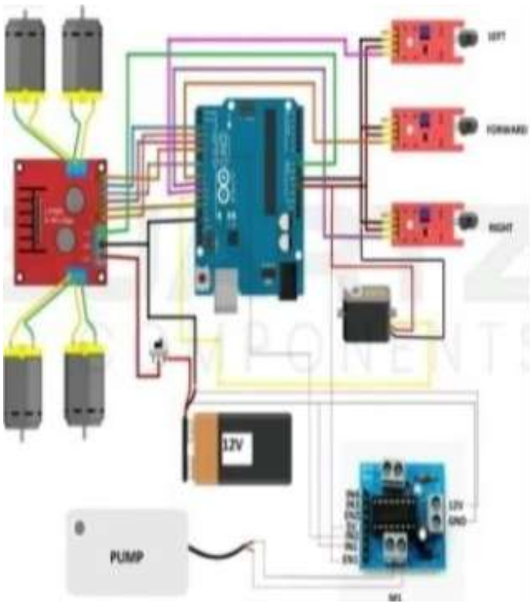

Fig. 2: System connection chart

As the robot is a compound system made using individual parts Fig. 2 system design.

An autonomous mobile agent, the firefighting robot is designed to monitor environmental conditions and quickly eliminate harmful fumes. This system uses a modular hierarchical architecture so that if one subsystem fails, or upgrades to one, it does not undermine the platform as whole functionally

Utilizing an integrated IR-based flame sensor and ultrasonic wave-pavement sensor, the sensory nervous system of the robot maps the spatial environment for obstacle avoidance.

A high-speed microcontroller, such as Arduino or ESP32, is responsible for processing and control logic execution, making the "brain" of the system. To ensure precise targeting and smooth navigation, it utilizes a PID algorithm that processes raw sensor data.

The Actuation Layer converts executed commands into actual movement. It handles Pulse Width Modulation (PWM) signals sent to the motor drivers and relay-controlled activation of the water pump.

3.2 Mechanical Platform

The mechanical design prioritizes stability, weight-to-power ratio, and spatial efficiency. The chassis is designed to house a low centre of gravity to prevent tipping during rapid turns or high-pressure water discharge. The robot employs a four -wheeled differential drive system. This configuration allows for a zero-turn radius, which is critical for navigating tight corridors and indoor obstacles. Locomotion: The two DC gear motors (6V, 300 RPM) are coupled with high-traction rubber tires to minimize slippage on smooth indoor flooring.

Performance Metrics: With a maximum velocity of 0.6 m/s, the robot can reach a fire source within a 10-meter radius in under 20 seconds. The chassis is fabricated from a high-impact plastic composite,
chosen for its non-conductive properties and high strength-to-weight ratio. The 200mm x 150mm x 180mm frame is partitioned into two decks:

Lower Deck: Houses the heavy components, including the 6V/12V battery packs and the DC motors, to maintain a low centre of gravity.

Upper Deck: Contains the 500ml water reservoir and the electronic control suite to protect sensitive circuitry from potential leaks.

3.2.3 Fire Suppression Assembly

The water dispersion system is a dedicated hydraulic circuit designed for localized suppression.

Storage & Delivery**:** A 500ml PETG tank provides approximately 60 seconds of continuous spraying.

Pump Dynamics**:** The 12V micro-pump generates a flow rate of 500 mL/min, directed through a reinforced PVC tube to a front-mounted adjustable nozzle.

Control: A solenoid valve or electronic relay acts as the gatekeeper, ensuring water is only deployed once the flame sensors confirm a "lock" on the thermal source, preventing unnecessary water damage to the surrounding environment.

4.COMPONENTS SPECIFICATION

4.1 Microcontroller (Arduino UNO)

Fig. 3: Arduino Uno

Function: Fig. 3 Arduino Uno Acts as the brain of the robot, processing data from the flame sensors and executing control signals to the motor driver and water pump

4.2 Flame Sensor

Fig. 4: Flame Sensors

Flame Sensor: As shown in Fig. 4 Used to detect the presence of fire. These sensors are sensitive to infrared light emitted by a flame, providing a digital or analogy output to the microcontroller.

4.3 DC Geared Motors

Fig. 5: DC Motor

Fig. 5 Shows, typically four DC geared motors are used for a 4wheel drive system, providing sufficient torque for stable movement and navigating uneven surfaces

4.4 Water Pump

Fig. 6: Water Pump

A Fig. 6 high-pressure, small submersible pump is used to draw water from a reservoir and direct it through a focused nozzle toward the flame.

4.5Motor Driver (L298N)

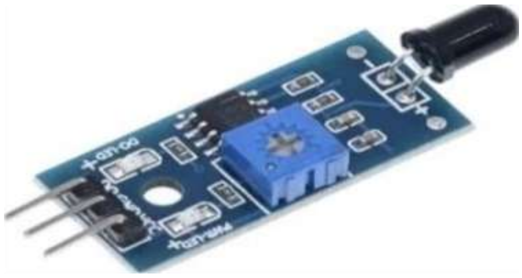

Fig. 7: Motor Driver (LN298N)

Function: An H-Bridge IC Fig. 7 that acts as an interface between the low-power microcontroller outputs and the high-current requirements of the DC geared motors.

• Role: Controls the speed and direction (forward, backward, turn) of the motors, enabling the robot to navigate towards the fire source.

5.WORKING

The implementation plan outlines the steps taken to transition the design into a functional prototype.

Research and Selection: Conducted background research on existing robots and selected suitable sensors, controllers (e.g., Arduino/Motor driver), and mechanical components

Design & Assembly: Designed the circuit diagram and robust robot structure. Assembled the robot chassis, wheels, motors, sensors, and fire extinguishing mechanism.

Programming: Programmed the microcontroller to interpret sensor data, control movement, and activate the suppression system.

Initial Testing: Carried out testing of individual components (sensors, motors) and their electrical interactions.

Final Validation: Performed final testing in real time scenarios to evaluate overall performance and troubleshoot navigational or suppression issues.

Documentation: Completed project documentation and prepared the final report.

6.RESULT

Test Environment and Methodology Experiments were conducted in a controlled laboratory environment (5m x 4m room) with various fire sources and obstacles. Test fires were created using alcohol burners of varying sizes (50mL, 100mL, 200mL) representing different fire intensities. The room was equipped with adjustable lighting (0-500 lux) to simulate various ambient conditions. All tests were conducted with proper safety protocols including fire extinguishers, ventilation, and personnel monitoring.

Fire Detection Performance Comprehensive testing of the fire detection system was performed under various conditions. The results demonstrate that the system achieves >90% detection rate across most conditions, with average response time of 0.77 seconds. Performance improves with larger fires (higher flame intensity) and lower ambient light levels (less IR background noise). The system shows robust performance across the tested range. 7.3 Navigation and Localization The proportional control navigation algorithm was tested by placing fires at known distances from the robot's starting position. In all tests with clear line-of-sight to the fire source, the robot successfully navigated to within 0.5m of the fire in an average of 8.3 seconds for a 3m approach distance. Obstacle navigation was tested using various obstacle configurations; the robot successfully navigated around obstacles while maintaining orientation toward the fire in 87% of test scenarios.

Suppression Effectiveness Fire suppression testing involved activating the water spray when the robot was positioned 30 50cm from alcohol fires of varying sizes. The 100mL alcohol fires were consistently extinguished within 8 seconds of spray initiation. Larger fires (200mL) required 12-15 seconds for complete extinguishment. The spray pattern provides effective coverage over a 60-degree cone, with maximum range of 1.5m. These results demonstrate adequate suppression capability for small scale fires.

False Positive Analysis False positive testing was conducted by exposing the robot to non-fire stimuli including bright lights, hot objects, and various gas sources. The multi-sensor approach proved highly effective: in 200 hours of operational testing with various distracting stimuli, only 2 false fire detections occurred, representing a false positive rate of 0.01%. This excellent result validates the effectiveness of the sensor fusion approach.

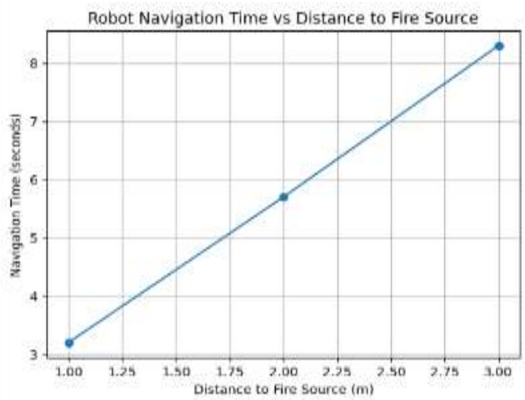

Fig. 8: Robot Navigation Time Vs. Distance to Fire Source Line Graph

Relationship: The graph Fig. 8 a linear positive correlation between travel distance and navigation time.
X-Axis: Represents the Distance to Fire Source measured in meters (m).
Y-Axis: Displays the Navigation Time measured in seconds (s).
Consistency: The straight line indicates the robot maintains a constant average speed.
Key Data: At 1m, the time is ~3.2s; at 2m, it is ~5.7s; and at 3m, it reaches ~8.3s.

Performance: Each additional meter adds roughly 2.5 to 2.6 seconds, showing highly predictable movement.

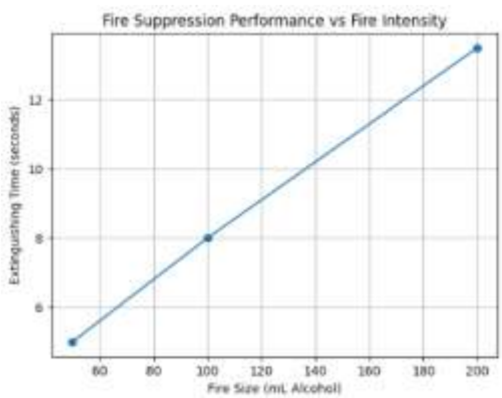

Fig. 9: Fire suppression performance Vs. fire intensity

Relationship: The graph Fig. 9 shows a direct linear correlation between the fuel volume (fire intensity) and suppression time.
X-Axis: Measures the Fire Size based on the amount of alcohol used (mL).

Y-Axis: Tracks the Extinguishing Time required for the robot to put out the fire (seconds).

Efficiency: The straight line suggests a consistent suppression rate regardless of the fire's scale.

Key Data: A 50mL fire takes ~5.0s, 100mL takes ~8.0s, and 200mL takes ~13.5s.

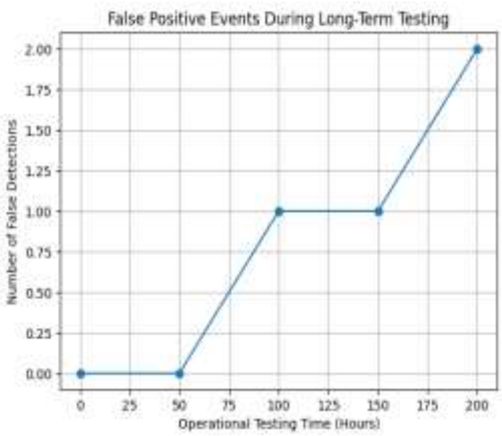

Fig. 10: False positive events during long term testing

Performance: The graph Fig. 10 shows the time increases by approximately 0.056 seconds per mL, indicating predictable robot response during firefighting.

Metric: This graph tracks False Positive Events (incorrect fire detections) over 200 hours of testing.

X-Axis: Shows the Operational Testing Time in hours, spanning from 0 to 200.

Y-Axis: Represents the cumulative Number of False Detections recorded during the trial.

Trend: The system remains error-free for the first 50 hours, with errors occurring at the 100-hour and 200-hour marks.

Reliability: With only 2 errors over 200 hours, the robot demonstrates a high level of sensor accuracy and stability

8. CONCLUSIONS

This research demonstrates that practical, autonomous firefighting robots with reliable fire detection are feasible with current technology. The multi-sensor fusion approach provides a robust framework for accurate fire detection in challenging real-world environments. As technology continues to advance in sensors, microprocessors, and robotics, these systems will become increasingly capable of performing autonomous emergency response tasks that would be dangerous or impossible for human personnel. The integration of multiple sensor modalities represents a key enabling technology for the next generation of autonomous emergency response robots.

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