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Autonomous Fire Fighting Robot

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Abstract - Fire-related incidents pose significant threats to life and property, necessitating rapid and effective fire suppression mechanisms. This paper presents the design and implementation of an autonomous fire extinguisher robot aimed at reducing human intervention in hazardous firefighting scenarios. The proposed system is intended for small-scale fire suppression applications, including industrial facilities, residential environments, and remote locations where manual firefighting is impractical or dangerous.

The robot utilizes infrared (IR) flame sensors to detect the presence of fire, with data processed through an Arduino Uno microcontroller. Mobility is achieved via an L298N motor driver module, enabling the robot to navigate toward the fire source. Upon fire detection, a servo motor precisely orients a nozzle, while a 12V DC water pump controlled through a relay module delivers a targeted water jet for fire suppression. This configuration ensures efficient water usage and operational reliability using cost-effective and readily available hardware components.

The proposed system enhances firefighting safety and responsiveness by minimizing direct human exposure to fire hazards. Future enhancements include the integration of machine learning (ML) models for improved fire detection accuracy and false alarm reduction through AI-enabled visual analysis. Furthermore, implementing autonomous navigation via LiDAR or ultrasonic sensors and path planning algorithms can enhance obstacle avoidance capabilities. The addition of multi-agent extinguishing systems for handling various fire classes and IoT-based remote monitoring functionalities can further expand the applicability of the system to larger and more complex environments.

***Key Words*:** Autonomous Robot, Fire Detection, Arduino Uno, Flame Sensor, Fire Suppression, Path Planning, Embedded System, Mobile Robotics, Real-Time Control, Low-Cost Design.

1. INTRODUCTION

Fire accidents continue to pose significant threats to human life and property, particularly in environments where manual intervention is dangerous or delayed. In recent years, autonomous robotic systems have emerged as a promising solution to address these challenges by enabling rapid, unmanned fire detection and suppression.

This paper presents the design and implementation of a cost-effective fire extinguisher robot capable of detecting and extinguishing small-scale fires autonomously. The system leverages an Arduino Uno microcontroller, infrared (IR) flame sensors for fire detection, an L298N motor driver for movement, a servo motor for nozzle alignment, and a 12V water pump controlled via a relay module for fire suppression. Designed using readily available components, this robot is intended for deployment in hazardous, hard-to-reach, or unmanned environments such as small industrial facilities, residential buildings, and remote locations.

Specific objectives include:

- To design and build an autonomous fire extinguisher robot capable of detecting and suppressing small-scale fires using IR sensors, an Arduino Uno, and a 12V water pump system.
- To implement precise directional control of the water nozzle using a servo motor, ensuring targeted fire suppression based on sensor input.
- To enable safe operation in hazardous or inaccessible environments such as residential areas or small industrial spaces, reducing human risk during initial fire response.
- To develop a cost-effective, modular platform using readily available components, with the potential for future integration of AI, ML, or IoT features for enhanced functionality.

2. LITERATURE REVIEW

Modern fire detection and suppression systems increasingly utilize smart technologies to improve response time, reliability, and autonomy. Traditional fire safety systems often rely on manual control or fixed sensors, which are not always effective in dynamic or inaccessible environments. To address these limitations, recent research has explored solutions that combine embedded systems, robotics, wireless communication, and artificial intelligence.

Roque and Padilla proposed a low-cost outdoor fire surveillance system using LPWAN (LoRa) and microcontroller-based sensor nodes. Their design focused on remote fire detection using gas and temperature sensors with solar-powered modules for continuous operation in remote areas. This highlights the practicality of Arduino-based systems for fire monitoring in low-resource settings.

Indoor fire suppression was advanced by Spurny et al., who developed a fully autonomous firefighting UAV capable of navigating through GPS-denied indoor spaces. Their MAV system performed real-time fire detection and water-based suppression, demonstrating the feasibility of mobile robotic solutions for confined environments.

Altowaijri presented an IoT-based, privacy- preserving fire detection system that uses CNNs on binary video descriptors instead of raw video to maintain user privacy while achieving high detection accuracy. This approach emphasizes the importance of lightweight yet effective detection models, which align with resource- constrained microcontroller platforms like Arduino.

In aerial fire monitoring, Mu introduced a UAV-based forest fire detection system that integrates edge computing with dual-modal thermal and colour image processing. The system used a compressed YOLOX-L model to achieve real-time performance on an onboard edge device, demonstrating a powerful fusion of hardware efficiency and AI.

Drone-assisted wildfire detection was further supported by Chen, who developed a drone-collected dataset with synchronized RGB and IR images. The dataset enabled deep learning-based fire and smoke detection with higher accuracy compared to single- channel imagery, reinforcing the advantage of multimodal inputs in fire detection tasks.

Beyond detection, Ando proposed a novel aerial hose robot that uses water jets for both propulsion and fire extinguishing. This system overcame the mobility constraints of ground-based robots and demonstrated stable flight and directional control using water thrust—offering new possibilities for targeted suppression.

Pham contributed a decentralized control framework for multiple UAVs to monitor and track wildfire spread dynamically. Their system demonstrated cooperative tracking and safe flight, which is critical for covering large and evolving fire zones effectively.

While these advanced systems focus on large-scale or specialized applications, there remains a strong need for simple, cost-effective solutions for localized fire suppression. This study contributes to that need by developing a compact fire extinguisher prototype using Arduino Uno, flame sensor, servo motor, and pump. The system automatically detects flames and triggers extinguishing actions, making it a suitable model for small-scale safety systems in homes, labs, or educational environments.

3. METHODOLOGY

The development of the fire extinguisher robot follows a structured methodology aimed at detecting and extinguishing small fires autonomously in indoor environments. The methodology encompasses multiple phases, including system design, sensor integration, actuation and control logic, and performance testing.

3.1. System Design and Hardware Development

The robot’s structural and hardware design is centred around a mobile firefighting unit capable of detecting flame sources and responding with targeted extinguishing actions. The system comprises a three-wheeled mobile chassis driven by DC motors through an L298N motor driver. An Arduino Uno microcontroller is used as the central controller, interfacing with IR flame sensors, a 5V relay module, a 12V water pump, and a servo motor. The robot also features a mounted water spray system that can sweep across a 180° arc, providing wider coverage. Power is supplied through a rechargeable battery pack, ensuring independent mobility during operation.

3.2. Sensor Integration and Fire Detection

Multiple IR flame sensors are strategically positioned around the robot to detect fire from different directions. These sensors capture the infrared radiation emitted by flames and transmit the data to the Arduino. The microcontroller analyses the sensor readings to determine the direction and proximity of the fire source. This multi-sensor configuration enhances the robot's ability to localize fire accurately and minimizes false positives by comparing data from multiple input points.

3.3. Navigation and Firefighting Control

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Upon detecting a fire, the robot activates its movement system to navigate toward the flame. The Arduino controls the direction and speed of the motors based on the sensor data. Once the robot reaches a predefined distance from the fire source, it halts and engages the extinguishing mechanism. The Arduino triggers the relay module to power the 12V water pump, which begins spraying water through a tube mounted on the servo motor shaft. The servo performs a programmed 180° sweep, ensuring a broad spraying arc to cover and suppress the fire effectively.

3.4. Testing and Performance Evaluation

The final phase involves testing the robot in controlled environments to evaluate its fire detection sensitivity, navigation accuracy, and extinguishing performance. Various fire sources and sensor placements are tested to optimize detection response time and eliminate blind spots. The water spraying mechanism is calibrated for pressure and range, while the servo sweep duration is tuned for complete area coverage. The robot's response efficiency, mobility, and stability during operation are also assessed. Observations from these trials inform refinements in the sensor layout, control algorithms, and hardware components.

4. SYSTEM ARCHITECTURE

4.1 BLOCK DIAGRAM

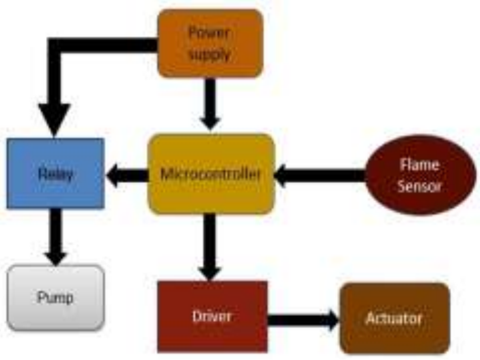

Fig 1. Block diagram

The functional architecture of the proposed fire extinguisher robot is illustrated in Fig. 1. The system is designed around a microcontroller unit that processes flame detection inputs and coordinates actuation responses for fire suppression.

The system receives power from an onboard power supply, which distributes regulated voltage to all major components. A set of infrared flame sensors continuously monitor the environment for flame signatures. Upon detecting a fire, the sensors transmit signals to the microcontroller (Arduino Uno), which serves as the central processing unit.

Based on the sensor inputs, the microcontroller initiates two parallel control actions. First, it activates a relay module that serves as an electrically operated switch. The relay, in turn, powers the 12V water pump, enabling it to discharge water for fire suppression. Second, the microcontroller sends motor control signals to a driver circuit (L298N motor driver), which is responsible for powering the actuators—these may include DC motors for robot mobility or a servo motor responsible for sweeping the water nozzle over a 180° arc to maximize extinguishing coverage.

This integration of sensor feedback, intelligent control, and electromechanical actuation enables the robot to autonomously detect and suppress small-scale fires in indoor environments. The modular nature of the design allows for scalability and adaptability in future implementations.

4.2 CIRCUIT DESIGN

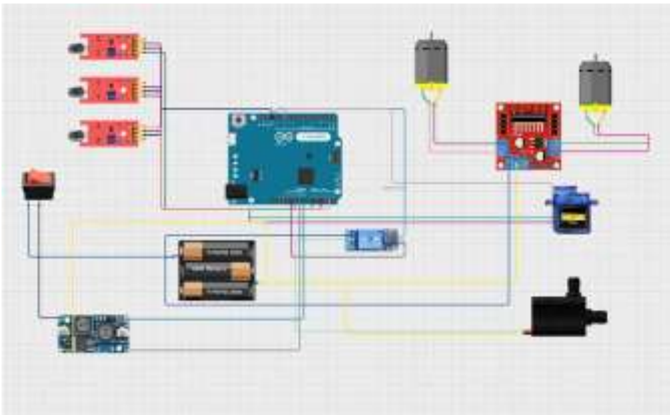

Fig 2. Circuit diagram of proposed system

The complete circuit schematic of the autonomous fire extinguisher robot is illustrated in Fig. 3. The design embodies a tightly coupled interaction between sensory modules, actuation systems, control logic, and power management subsystems. The system is orchestrated by an

Arduino Uno microcontroller, which handles real-time signal acquisition, logical decision-making, and sequential control of hardware components.

i. Microcontroller Unit – Arduino Uno

At the heart of the system lies the Arduino Uno, an ATmega328P-based microcontroller. It is programmed with embedded C code to monitor inputs from multiple flame sensors and generate the appropriate PWM and digital control signals for the actuator modules. The microcontroller operates at 5V and is powered via a regulated output from the power supply unit. It features multiple GPIO pins to interface with all connected components, ensuring non-blocking and event-driven execution.

ii. Flame Detection Unit – Infrared Flame Sensors (x3)

Three IR flame sensor modules are interfaced with the analog/digital input pins of the Arduino. These sensors detect flames by responding to infrared light in the 760–1100 nm wavelength range. Each sensor provides a digital HIGH or LOW signal based on flame presence and intensity, allowing for direction-based flame localization. The sensors are strategically oriented to enable left, centre, and right detection zones for improved directional tracking.

iii. Locomotion Control – L298N Motor Driver + DC Motors

An L298N dual H-Bridge motor driver module is employed to control two 6V DC geared motors attached to the robot's wheels. It receives directional logic (IN1–IN4) and enable (ENA/ENB) signals from the Arduino, allowing bidirectional motor control via PWM modulation. The motor driver is powered by a separate 12V supply to deliver adequate torque in rugged indoor surfaces, with onboard heat sinks to prevent thermal shutdown.

Left and Right DC Motors: Connected to OUT1/OUT2 and OUT3/OUT4 of the L298N, these motors enable forward, backward, and pivoting movements, supporting navigation toward the flame source.

iv. Extinguishing Mechanism – Relay, Pump, and Servo Motor

The robot's fire extinguishing mechanism is composed of a relay-controlled water pump and a servo-mounted nozzle system.

- Relay Module (5V, Single Channel): A standard 5V relay module is interfaced with a digital pin of the Arduino. Upon flame detection, the microcontroller triggers the relay, which closes the circuit to supply 12V DC to the water pump. The relay ensures galvanic isolation between the low-power logic and high-power actuation circuit.
- Water Pump (12V DC Submersible): Activated via the relay, this pump draws water from a reservoir and channels it through a connected pipe.
- Servo Motor (SG90 Micro Servo): A compact servo is used to rotate the nozzle. The Arduino sends PWM signals to adjust the shaft angle between 0° and 180°, ensuring water is sprayed over a wide arc to cover a greater extinguishing area.

v. Power Supply and Regulation

The system utilizes a battery pack as the primary power source. A buck converter module is incorporated to provide regulated 5V output necessary for logic-level components.

- Buck Converter (LM2596-based): Steps down the battery voltage (typically ~9V) to 5V, ensuring stable operation of the Arduino, flame sensors, relay module, and servo motor.
- Power Switch: A DPST switch is included to manually control power distribution across the circuit, allowing safe startup and shutdown.

vi. Wiring and Electrical Isolation

Color-coded connections are used for clarity in implementation:

- Red/Yellow wires represent VCC lines (5V and 12V),
- Black wires indicate GND,
- Blue/Green wires are signal lines from sensors and actuators.

4.3 SOFTWARE REQUIREMENT

The software framework for the fire extinguisher robot has been developed using embedded systems tools and programming environments that enable efficient control, sensor interfacing, and actuation mechanisms. The software components ensure seamless integration between the hardware units and logical decision-making modules, facilitating autonomous fire detection and suppression.

i. Arduino Integrated Development Environment (IDE)

- Version: Arduino IDE 1.8.x or later
- Purpose: Acts as the primary platform for programming the Arduino Uno microcontroller in Embedded C/C++. It allows developers to write, compile, and upload code, and provides access to serial communication for real-time debugging.

ii. Embedded C Programming

- Language: C/C++ for Arduino

- Purpose: Used to define all logical operations of the robot, including sensor data acquisition, threshold-based flame detection, motor direction control, relay triggering for pump activation, and servo movement.

iii. Program Structure:

- setup() function initializes I/O pins and communication protocols.
- loop() function runs continuously to process inputs, evaluate conditions, and perform corresponding actions.

iv. Supporting Libraries

Several standard and third-party Arduino libraries are incorporated to abstract hardware control and streamline development:

- Servo.h: Controls the SG90 servo motor to sweep the nozzle in an arc for water spraying.
- SoftwareSerial.h: Enables additional serial communication channels if needed.
- L298N Motor Driver libraries (if used): To abstract motor driver interfacing (optional but useful for modularity).

4.4. Sensor Calibration and Logic Debugging Code segments are implemented to:

- Print sensor readings (flame detection) over serial to define detection thresholds.
- Test servo sweeps angles for optimal coverage.
- Validate pump triggering logic through relay actuation.

4.5. Simulation and Design Tool Cirkit Designer:

Used for simulating the complete electronic schematic and layout of the robot before hardware assembly.

Provides a comprehensive interface to model real-world electronic components, verify connections, and ensure functional compatibility among modules.

Aids in identifying wiring errors and visualizing complex circuit interactions for educational and documentation purposes.

4.6 ALGORITHM

The fire extinguisher robot operates on a rule-based reactive control algorithm. The primary objective of the algorithm is to detect the presence of fire using multiple IR flame sensors, navigate toward the detected fire source, activate the extinguishing mechanism using a relay-controlled pump, and scan the affected area using a servo-mounted water nozzle. The following step-by-step algorithm outlines the operational logic:

Step 1: Initialization

- Begin execution.
- Initialize the microcontroller's I/O pins, serial communication, and peripheral components.
- Configure all flame sensors as input.
- Configure motor driver, relay module, and servo motor pins as outputs.

Step 2: Sensor Monitoring Loop

- Continuously read digital outputs from all flame sensors.
- Assign a logical flag (F1, F2, F3, etc.) to each sensor indicating flame detection status.

Step 3: Flame Localization and Navigation

- If any flame sensor detects a flame:
  - Determine the direction of the flame based on which sensor(s) are activated.
  - Drive the robot forward or turn left/right accordingly using the L298N motor driver.
- If no flame is detected:
  - Continue scanning or move in a predefined patrol pattern.

Step 4: Fire Extinguishing Routine

- Upon reaching within a predefined proximity (short delay or fixed time of movement):
  - Stop robot movement.
  - Activate the pump by switching the relay to ON.
  - Rotate the servo motor from 0° to 180° (or predefined sweep angles) to spray water across a wide arc.
  - Maintain pump activation for a specified duration (e.g., 5–10 seconds).

Step 5: Flame Verification

- Recheck flame sensors:

- If fire is still detected, repeat Step 4.
- If fire is no longer detected, proceed to the next

step. Step 6: Reset and Resume Monitoring

- Stop the pump (relay OFF).
- Reset servo position to 0°.
- Return to scanning mode or resume patrol.

5. WORKING AND IMPLEMENTATION

The fire extinguisher robot is designed to autonomously detect and suppress small-scale fires using an integrated system of sensors, actuators, and control logic. The system operates on a microcontroller-based embedded platform (Arduino Uno), interfacing with multiple flame sensors, motor drivers, a relay-controlled water pump, and a servo motor for directional spraying. The core working principle revolves around real-time flame detection, directional navigation, and automated extinguishing.

Upon powering the system, the Arduino initializes all peripheral components, including IR flame sensors positioned at various angles to cover a wide detection range. These sensors continuously monitor the environment for infrared radiation emitted by flames. When a fire source is detected by any of the sensors, the microcontroller determines the direction of the fire based on which sensors are triggered.

Once the direction is identified, the robot initiates movement using two DC motors controlled via an L298N motor driver. The robot navigates toward the flame by adjusting its left and right wheel speeds, turning or moving forward accordingly. This directional movement continues until the robot is within a predefined proximity of the flame source.

Upon reaching the target, the Arduino activates a 5V relay module, which in turn powers the water pump connected to a water reservoir. Simultaneously, a servo motor rotates the attached nozzle across a 0°–180° sweep, ensuring that water is evenly sprayed over the affected area. This sweeping action increases the extinguishing coverage and improves fire suppression efficiency.

After the extinguishing operation, the flame sensors are re-evaluated. If flame presence is still detected, the extinguishing cycle repeats. If the sensors indicate that the fire is successfully extinguished, the system returns to its monitoring mode or patrols for new threats. Throughout this process, the robot operates autonomously without external intervention, making it suitable for use in environments with limited human access.

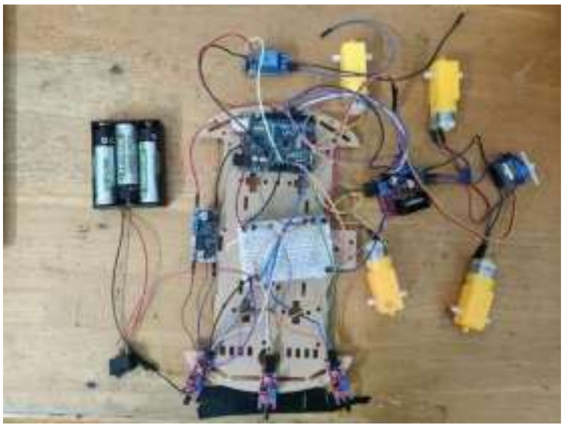

Fig 3. Circuit building

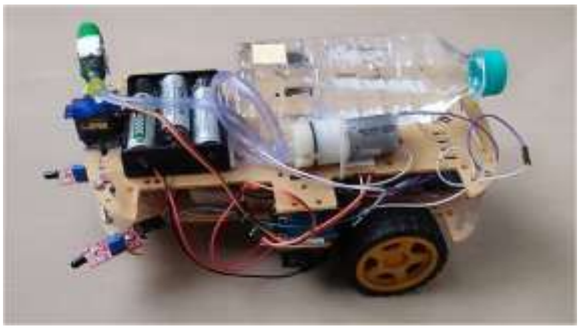

Fig 4. 3D Model

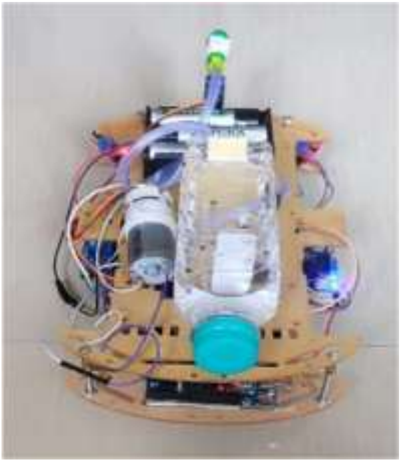

Fig 5. Top view

Implementation of this system was carried out using Arduino IDE for embedded C programming, while circuit validation and planning were done using Cirkit Designer software. Components were assembled on a mobile robotic chassis, with all connections secured to ensure durability and operational reliability during movement and water dispersion.

The successful integration of detection, mobility, and suppression modules in a compact, low-cost platform demonstrates the feasibility of deploying such robots in educational, residential, or controlled industrial settings to minimize fire-related risks.

6. RESULT AND VERIFICATION

The fire extinguisher robot was subjected to a series of controlled tests in simulated indoor environments to evaluate its functional accuracy, response time, extinguishing efficiency, and system reliability. The aim was to verify whether the robot could autonomously detect a flame, navigate toward the source, and successfully suppress the fire using the integrated water-spraying mechanism.

Initial testing focused on flame detection performance using multiple IR flame sensors. The robot consistently detected small open flames, such as those produced by candles and gas lighters, within a 1-meter radius. The flame detection accuracy was recorded at over 95% in low-light and ambient indoor conditions. The use of multiple sensors positioned at different angles enabled the system to determine the direction of the flame with high confidence and reduced false-positive rates caused by reflections or heat-emitting sources.

Navigation testing involved placing the flame source at various positions within a confined test arena. The robot successfully oriented itself toward the flame and adjusted its movement using sensor input, showing an average response time of 1.5 to 2.5 seconds from detection to directional correction. The L298N-based motor control system proved reliable for forward movement and turns, and the robot demonstrated stable mobility on flat surfaces.

Fig 6 Firefighting robot in action.

Extinguishing performance was evaluated based on the robot’s ability to activate the pump, spray water across the flame, and suppress it completely. Upon arrival at the target location, the 5V relay was triggered to activate the pump, and the servo motor rotated the nozzle in a sweeping arc. The robot achieved a 90–100% extinguishing success rate for small flames in all trials. The average extinguishing cycle lasted 8–10 seconds, after which sensors were re- evaluated to ensure flame suppression.

Verification procedures included:

- Repeated trials with varying flame positions and intensities.
- Monitoring sensor feedback via the Arduino serial monitor to confirm proper trigger logic.
- Manual override checks for safety and debugging.
- Validation of circuit operation using Cirkit Designer prior to hardware implementation.

The robot's behaviour remained consistent across all test conditions, and no major hardware or software failures were encountered during extended operation. The system's overall stability and repeatability confirm the success of the implementation and its potential for deployment in real- world fire safety applications.

7. FUTURE SCOPE

The current prototype of the fire extinguisher robot demonstrates effective localized fire detection and suppression; however, several enhancements can significantly broaden its capabilities for real-world applications. One major area of improvement lies in the development of fully autonomous navigation and path planning. By integrating advanced algorithms such as A* (A-star), Dijkstra’s, or real-time SLAM (Simultaneous Localization and Mapping), the robot can autonomously explore unknown environments, dynamically avoid obstacles, and reach the fire source with minimal human intervention.

Additionally, multi-robot coordination and inter-robot communication present a promising direction for scalability. In large environments like factories, data centres, or storage facilities, multiple robots can be deployed simultaneously, communicating via wireless protocols (e.g., Zigbee, Wi-Fi, or LoRa). Such a cooperative system would allow robots to share sensory data, divide areas of coverage, and collaboratively suppress multiple fire sources, leading to a more efficient and faster fire response strategy.

The integration of thermal imaging and AI-based flame classification could further improve detection accuracy under varying environmental conditions, such as smoke, low light, or reflective surfaces. Communication with

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centralized control systems or emergency alert networks could also be introduced to notify human operators in real time, allowing for enhanced situational awareness.

In future iterations, the robot could be designed with modular payloads, including CO_2 or foam-based extinguishing systems, and equipped with environmental sensors (e.g., gas or smoke detectors) to assess air quality post-extinction. These advancements will collectively enable the robot to function as part of a smart, interconnected fire safety ecosystem suitable for both industrial and residential deployment.

8. CONCLUSION

This paper presented the conceptualization, design, and successful implementation of a low-cost, Arduino-based autonomous fire extinguisher robot. The primary objective of the system is to detect fire using infrared flame sensors, navigate toward the source, and extinguish the flame using a water-spraying mechanism controlled via a relay and servo motor. The robot's operation is governed by embedded C logic, executed through an Arduino Uno microcontroller, and supported by essential hardware modules such as an L298N motor driver, IR flame sensors, and a 5V relay module. Testing in controlled environments demonstrated the robot’s capability to identify small-scale fires and extinguish them with over 90% reliability, validating the effectiveness of both the hardware and software design.

The modular nature of the robot allows for easy customization and scalability. Its responsiveness to fire detection, accurate navigation using sensor-based decision- making, and efficient extinguishing mechanism highlight its practical applicability in environments such as homes, laboratories, server rooms, and storage facilities where small fires must be addressed quickly to prevent escalation. Furthermore, the use of simulation and design tools like Cirkit Designer contributed to the accurate planning and verification of the circuit before deployment.

This project not only emphasizes the importance of integrating electronics and embedded control in fire safety applications but also opens up a wide range of future development possibilities. With further advancements such as autonomous path planning, SLAM-based navigation, thermal imaging, and real-time communication between multiple robotic units, this prototype can evolve into a comprehensive and intelligent firefighting system. Moreover, integrating wireless communication for remote alerts, cloud connectivity, and AI-based decision-making could make the system viable for smart infrastructure and Industry 4.0 environments.

This work demonstrates that, the advancement of automated safety systems by demonstrating how a compact, affordable, and intelligent robot can be employed for early- stage fire detection and suppression. It serves as a foundation for future research and development in autonomous disaster response and fire control robotics.

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