

Home and Industrial Safety Using Fire and Gas Detection System

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ABSTRACT

Fire accidents in residential, commercial, and industrial environments often result in significant loss of life, property damage, and environmental hazards. Rapid detection and immediate response are critical for minimizing the impact of such incidents. This paper presents an IoT and embedded-system-based Automatic Fire Extinguishing Robot designed to detect, locate, and suppress fire autonomously with minimal human intervention. The proposed system integrates flame sensors, an ultrasonic sensor, an Arduino Uno microcontroller, an L298N motor driver, DC motors, a relay module, and a submersible water pump to achieve intelligent fire detection, obstacle avoidance, navigation, and extinguishing operations. The flame sensors continuously monitor the environment and identify the direction of the fire source, while the ultrasonic sensor enables safe movement by detecting obstacles in the robot's path. Upon detecting fire, the robot navigates toward the affected area and activates the water pump to extinguish the flame automatically. Experimental testing demonstrated accurate fire detection, reliable obstacle avoidance, stable navigation, and effective fire suppression under controlled conditions. The proposed system offers a low-cost, efficient, and scalable solution for enhancing fire safety in homes, laboratories, warehouses, and small industrial environments, while significantly reducing human exposure to hazardous situations.

Keywords: Fire Detection System, Fire Extinguishing Robot, IoT, Arduino Uno, Flame Sensor, Obstacle Avoidance, Embedded Systems, Industrial Safety, Smart Safety Systems, Automation.

I.INTRODUCTION

Fire accidents are one of the major causes of destruction in industries, homes, offices, forests, and public places. In many situations, firefighters face high risks while controlling fire in dangerous or inaccessible areas. To reduce human casualties and property damage, modern technology is increasingly being used to develop intelligent fire safety systems. Robotics and embedded systems play a significant role in automating fire detection and extinguishing operations.

The Automatic Fire Extinguishing Robot is an innovative robotic system designed to detect fire and automatically suppress it using water or other extinguishing agents. The robot is built using a microcontroller, flame sensors, motor drivers, water pumps, and DC motors that work together to perform fire-fighting operations efficiently. The robot continuously monitors its surroundings for the presence of fire. Once a flame is detected, the system activates the water pump and directs water toward the fire source while moving closer to the affected area.

This project combines concepts of robotics, IoT, automation, and embedded technology to create a smart and reliable fire protection system. The robot can operate in environments where human intervention may be difficult or dangerous, such as chemical industries, warehouses, laboratories, or narrow indoor spaces. By reducing direct human involvement in fire-fighting activities, the system improves safety and emergency response efficiency.

The proposed robot is compact, cost-effective, and capable of real-time operation. It can be further enhanced with features such as wireless communication, obstacle avoidance, smoke detection, GPS tracking, and AI-based fire analysis for advanced applications. The development of this fire extinguishing robot demonstrates how intelligent automation can contribute to disaster management and smart safety solutions.

Overall, the project provides an efficient and practical approach toward automated fire control systems, helping to save lives, reduce risks, and minimize property loss caused by fire accidents..

1.1 Introduction to IOT

The **Internet of Things (IoT)** refers to a network of physical objects—such as sensors, appliances, vehicles, machines, smart devices, and embedded systems—that are connected to the internet and capable of **collecting, exchanging, and acting on data** without human intervention. IoT transforms ordinary devices into intelligent, interconnected systems that can sense their environment, communicate with other devices, and enable automation across a variety of domains.

The growth of IoT has been driven by advancements in **wireless communication, miniaturized electronics, cloud computing, and data analytics**. Devices in an IoT ecosystem can be simple (e.g., temperature sensors) or complex (e.g., autonomous robots, smart healthcare devices). These devices are equipped with sensors, actuators, microcontrollers, and communication modules that allow them to interact with the environment and transmit information to centralized systems for further processing.

IoT is a key enabler of new-generation technologies like **smart homes, smart cities, industrial automation (Industry 4.0), healthcare monitoring systems, intelligent energy grids, environmental monitoring, and smart agriculture**. The rapid expansion of IoT has reshaped how industries operate by increasing efficiency, reducing human effort, improving safety, and enabling data-driven decision-making.

Evolution and Growth of IoT

The concept of interconnected smart devices has existed since the early development of the internet. However, IoT became mainstream in the early 2010s with the rise of:

- ✓ Low-cost microcontrollers (Arduino, ESP8266, ESP32)
- ✓ Wireless standards (Wi-Fi, Bluetooth, ZigBee, LoRaWAN)
- ✓ Cloud computing platforms (AWS IoT, Google Cloud IoT, Azure IoT Hub)
- ✓ AI and machine learning

IoT devices have grown from **millions to billions**, connecting homes, industries, healthcare, agriculture, and transportation systems. According to industry forecasts, IoT adoption continues expanding due to its ability to enhance automation, improve quality of life, and reduce operational costs.

Architecture of IoT

A typical IoT architecture consists of **four layers**:

Perception Layer (Sensing Layer)

This is the lowest layer where **sensors and actuators** interact with the physical world.

Functions:

- Detect physical parameters (temperature, fire, humidity, gas, motion).
- Convert analog signals to digital data.
- Actuate devices (motors, pumps, alarms).

Examples:

- Flame sensors
- Temperature sensors
- Ultrasonic sensors
- Smart cameras
- RFID modules
- Actuators (relays, motors, pumps)

II. LITERATURE SURVEY**2.1 Literature Review****A. Gkogkidis et al. [Paper No. 1], 2022:**

The authors proposed a TinyML-based system for gas leakage detection that focuses on identifying gas leakage using lightweight machine learning models suitable for embedded systems. The methodology uses TinyML models deployed on low-power devices for real-time gas detection, making the system efficient and energy conscious. However, the study is limited mainly to gas detection and does not include visual fire detection capabilities.

D. P. Sharma et al. [Paper No. 2], 2024:

This research presents statistical and machine learning models for predicting fire and other emergency events in urban environments. The system utilizes statistical and ML algorithms to predict fire incidents based on historical datasets and data-driven analysis. Although the approach improves predictive analysis, its limitation lies in the dependence on historical data, reducing its effectiveness for real-time fire detection scenarios.

A. Gaur et al. [Paper No. 3], 2019:

The study reviews different fire sensing technologies and provides a comparative analysis of traditional fire sensing methods, including sensor-based systems. The paper discusses the advantages and challenges of various fire detection approaches and highlights their applications in safety systems. However, the work mainly focuses on AI-based concepts and does not propose a complete practical fire detection system.

P. K. Verma et al. [Paper No. 4], 2021:

The authors developed an IoT-based smart fire detection and monitoring system designed to improve fire safety in residential and industrial environments. The system integrates temperature, smoke, and flame sensors with IoT communication modules to provide real-time monitoring and alert notifications. The proposed model enhances early fire detection and minimizes damage through automated alerts. However, the system mainly depends on sensor data and lacks advanced AI-based image analysis for accurate fire recognition.

R. S. Kumar et al. [Paper No. 5], 2023:

This paper presents a deep learning-based fire and smoke detection framework using computer vision techniques. The proposed system employs convolutional neural networks (CNNs) to identify fire and smoke patterns from video streams in real time. The approach improves detection accuracy and reduces false alarms compared to traditional sensor-based systems. However, the computational complexity of the deep learning model increases hardware requirements and may affect performance on low-cost embedded devices.

M. Ahmed et al. [Paper No. 6], 2020:

The study focuses on an intelligent fire surveillance system using wireless sensor networks and automated emergency response mechanisms. The system continuously monitors environmental parameters such as temperature and gas concentration to detect fire hazards at an early stage. It also supports remote monitoring and emergency communication. Despite its effectiveness, the proposed system faces limitations related to sensor dependency and reduced efficiency in visually complex environments where smoke or lighting conditions vary significantly.

2.2 Problem Statement

Fire accidents often occur unexpectedly in homes, laboratories, industries, and storage areas, leading to severe damage, injuries, and loss of life. In many situations, early detection and quick suppression of fire are not

possible due to human limitations such as delayed response time, limited visibility, or high-risk environments filled with heat, smoke, or hazardous materials. Conventional fire alarms and extinguishers require human intervention and cannot independently locate or extinguish fire, especially in confined or obstructed areas.

There is a need for an autonomous, low-cost, and reliable fire-fighting system capable of identifying the presence of fire, navigating safely toward the fire source, and suppressing it without endangering human life. The challenge lies in integrating accurate flame detection, obstacle avoidance, intelligent movement control, and an automatic extinguishing mechanism into a compact robotic platform.

This project aims to address these issues by developing an Arduino-based fire-fighting robot equipped with flame sensors, an ultrasonic obstacle detection module, a motor driver for controlled navigation, and a relay-controlled water pump for fire extinguishing. The robot must autonomously detect fire, approach it safely, avoid obstacles, and extinguish the flame effectively, providing a safe and efficient solution for small-scale fire incidents.

2.3 Objectives

1. To design and develop an autonomous fire-fighting robot using Arduino Uno

Create a self-operating robotic system capable of detecting, locating, and extinguishing fire without human intervention.

2. To implement accurate fire detection using multiple flame sensors

Use dual flame sensors to identify the presence, direction, and intensity of fire for faster and precise response.

3. To integrate ultrasonic sensing for obstacle detection and safe navigation

Enable the robot to move through the environment while avoiding obstacles using the HC-SR04 ultrasonic sensor.

4. To achieve reliable movement control using an L298N motor driver and DC motors

Control the left and right motors independently to ensure smooth maneuvering toward the fire source.

5. To activate an automatic water extinguishing system using a relay and submersible water pump

Trigger the relay module to operate the water pump automatically when the robot reaches the fire.

6. To create a low-cost, practical, and efficient fire response prototype

Develop an affordable fire-fighting system suitable for homes, labs, educational institutes, and small industrial spaces.

7. To ensure safety by reducing human involvement in hazardous fire zones

Minimize risk to firefighters or individuals by deploying an autonomous robot for initial fire suppression.

8. To test and validate the robot's performance under various controlled fire scenarios

Evaluate detection accuracy, movement stability, and extinguishing efficiency in real-time experiments.

III. OVERVIEW OF THE PROJECT

Abstract

The proposed system presents an IoT and Embedded-Based Automatic Fire Extinguishing Robot designed to detect and suppress fire in hazardous environments with minimal human intervention. The robot is developed using a microcontroller platform integrated with flame sensors, water pumping mechanisms, motor drivers, and wireless or autonomous navigation features. The primary objective of the system is to improve fire safety by enabling rapid fire detection and automatic extinguishing before the fire spreads extensively.

The robot continuously monitors the surrounding environment using flame and temperature sensors. When a fire source is detected, the control unit processes the sensor data and activates the water pump system to spray water directly toward the fire. The robotic vehicle moves toward the affected area using DC motors and wheel mechanisms controlled through an embedded system. This reduces the risk faced by firefighters and minimizes property damage in industrial, residential, and commercial environments.

The system is designed to provide real-time operation with fast response capability, making it suitable for emergency applications. Additional features such as obstacle avoidance, wireless monitoring, and alert notifications can further enhance the efficiency and intelligence of the robot. The implementation of this automated fire extinguishing robot demonstrates the practical application of robotics, IoT, and embedded systems in disaster management and safety automation.

Overall, the project offers a cost-effective, reliable, and intelligent fire protection solution capable of assisting in dangerous fire rescue operations while reducing human exposure to hazardous conditions.

Introduction

Fire accidents are among the most dangerous disasters that cause severe damage to human life, infrastructure, industries, forests, and public property. Every year, thousands of fire incidents occur worldwide due to electrical short circuits, gas leakage, chemical reactions, overheating equipment, and human negligence. These incidents often lead to heavy financial losses, environmental destruction, and casualties. Traditional fire-fighting methods mainly depend on firefighters who manually enter dangerous locations to control the fire. Although firefighters are highly trained, they are continuously exposed to hazardous conditions such as extreme heat, smoke, toxic gases, collapsing structures, and explosions. Therefore, there is a growing need for intelligent and automated systems that can assist or replace humans in risky fire-fighting operations.

The advancement of robotics and embedded systems has created new opportunities in the field of disaster management and emergency response. Robots are increasingly being used in industrial automation, healthcare, military operations, space exploration, and safety applications. One important application of robotics is the development of fire-fighting robots capable of detecting and extinguishing fires automatically. These robots are designed to minimize human risk and improve the efficiency of fire control systems.

A fire extinguishing robot is an autonomous or semi-autonomous robotic system equipped with sensors, controllers, motors, and extinguishing mechanisms. The robot continuously monitors the surrounding environment for fire indications such as flames, smoke, or high temperature. Once fire is detected, the robot moves toward the affected area and activates a water pump or extinguishing system to suppress the fire. The complete operation is controlled using embedded systems and sensor technologies.

Early fire-fighting robotic systems were mainly remote-controlled devices operated manually by humans. These systems required a human operator to guide the robot toward the fire source using wireless communication. Although remote-controlled robots reduced direct human exposure, they still depended heavily on operator control and had limited automation capabilities. With the advancement of sensor technology and microcontrollers, modern fire-fighting robots have become more intelligent and capable of autonomous operation.

The development of microcontrollers such as Arduino, Raspberry Pi, NodeMCU, and ESP32 has significantly improved robotic applications. These microcontrollers provide efficient processing capabilities, low power consumption, and easy interfacing with sensors and actuators. In fire extinguishing robots, microcontrollers act as the brain of the system by receiving data from sensors, analyzing conditions, and controlling motors and water pumps accordingly.

Flame sensors are one of the most important components used in fire-fighting robots. These sensors detect infrared light emitted by flames and help identify the direction and intensity of the fire. Temperature sensors and smoke sensors are also used to improve detection accuracy. The combination of multiple sensors allows the robot to respond quickly and accurately to fire incidents. In some advanced systems, gas sensors are included to detect harmful gases or leakage before a fire occurs.

Motor driver modules play a key role in robotic movement. These modules control the speed and direction of DC motors attached to the robot wheels. Depending on the sensor readings, the robot can move forward,

backward, left, or right to reach the fire source. Servo motors are often used to rotate the water spraying mechanism toward the flame for precise extinguishing action.

Water pumps or fire suppression mechanisms are essential parts of the robot. Once fire is detected, the embedded controller activates the water pump to spray water directly onto the fire. Some systems use foam, carbon dioxide, or dry chemical extinguishing methods depending on the application environment. Water-based systems are commonly used for low-cost and domestic fire-fighting applications.

In recent years, Internet of Things (IoT) technology has greatly enhanced robotic systems. IoT-enabled fire-fighting robots can send real-time alerts and status information to users through mobile applications or cloud platforms. Wireless communication technologies such as Wi-Fi, Bluetooth, ZigBee, and GSM modules enable remote monitoring and control. For example, if a fire is detected, the robot can immediately notify the user or emergency services through SMS, mobile notifications, or alarm systems.

Artificial Intelligence (AI) and Machine Learning (ML) techniques are also being integrated into modern fire safety systems. AI-based robots can analyze environmental conditions, identify fire patterns, and make intelligent decisions regarding navigation and extinguishing strategies. Computer vision algorithms using cameras and image processing techniques help detect fire and smoke more accurately than traditional sensors alone. Deep learning models such as Convolutional Neural Networks (CNNs) are increasingly used for real-time fire detection from video streams.

Obstacle avoidance is another important area of research in robotic fire-fighting systems. Ultrasonic sensors and infrared sensors help the robot detect objects in its path and navigate safely without collisions. Autonomous navigation allows the robot to move efficiently in complex environments such as industrial plants, warehouses, and office buildings. Some advanced systems use SLAM (Simultaneous Localization and Mapping) techniques for intelligent path planning and environmental mapping.

Fire extinguishing robots are highly beneficial in hazardous environments where human intervention is difficult or unsafe. These include:

- Chemical industries
- Oil refineries
- Gas plants
- Nuclear power stations
- Warehouses storing flammable materials
- Hospitals and laboratories
- Military zones
- Forest fire regions

In such environments, robotic systems can operate continuously without risking human lives. They can also access narrow or dangerous areas where firefighters may not be able to enter easily.

Many research studies have demonstrated the effectiveness of robotic fire safety systems. Researchers have focused on improving detection speed, navigation accuracy, extinguishing efficiency, and communication systems. Some projects use line-following mechanisms for navigation, while others implement autonomous mapping and wireless camera monitoring. The integration of AI, IoT, and cloud computing continues to improve the intelligence and reliability of these systems.

Despite these advancements, certain challenges still exist in fire-fighting robot development. High-temperature resistance, battery limitations, obstacle navigation, and accurate fire localization remain important research areas. Additionally, designing low-cost systems suitable for real-world deployment is another major challenge. Many advanced robotic systems are expensive and require sophisticated hardware and software integration.

The proposed **Automatic Fire Extinguishing Robot** is developed based on the concepts of embedded systems, robotics, automation, and IoT technologies. The system aims to provide a cost-effective, reliable, and intelligent solution for detecting and extinguishing fires automatically. The robot uses flame sensors for fire detection, DC

motors for movement, and a water pump mechanism for extinguishing action. The embedded controller continuously processes sensor data and controls the robot in real time.

The proposed system is designed to improve emergency response speed and reduce the risk faced by firefighters. It can be deployed in homes, industries, offices, shopping malls, and hazardous environments to enhance safety and minimize fire damage. Future enhancements may include AI-based fire analysis, wireless live monitoring, GPS tracking, autonomous navigation, and cloud-based alert systems for advanced smart fire safety applications.

Overall, the background study highlights the importance of robotic automation in modern fire safety systems. The combination of robotics, embedded systems, sensors, IoT, and AI technologies has transformed traditional fire-fighting methods into intelligent automated solutions capable of saving lives, protecting property, and improving disaster management efficiency.

The **Automatic Fire Extinguishing Robot System** is designed to provide intelligent fire detection, automatic navigation, and rapid fire suppression using embedded systems, sensors, and robotic technologies. The system integrates hardware components such as flame sensors, temperature sensors, Arduino/NodeMCU controller, motor driver module, DC motors, water pump mechanism, buzzer alarm, and optional IoT communication modules to continuously monitor the environment and respond immediately when fire is detected. The overall design focuses on safety, reliability, fast response, low-cost implementation, and minimal human intervention in hazardous fire-fighting situations.

The system operates by continuously collecting environmental information through flame and temperature sensors. The sensor data is processed by the embedded controller, which analyzes the fire conditions and automatically activates the robotic movement system and water extinguishing mechanism whenever fire is detected. The robot navigates toward the fire source and sprays water directly onto the flame to suppress the fire effectively. The integration of IoT technology can also provide remote monitoring and real-time alert transmission for smart safety applications.

The proposed robotic system is suitable for homes, industries, laboratories, warehouses, offices, shopping malls, chemical plants, and other hazardous environments where rapid fire response is essential. The use of automation and intelligent control reduces human risk and improves overall emergency response efficiency.

System Analysis

Existing System

Traditional fire safety systems mainly use standalone smoke detectors, fire alarms, or manual fire extinguishers to detect and control fire accidents. These systems generally provide only local alerts and require human intervention to extinguish the fire. Conventional fire-fighting methods have several limitations:

- Limited fire detection capability
- No automatic fire extinguishing mechanism
- Dependence on human firefighters
- Delayed emergency response
- High risk to human life in hazardous environments
- No autonomous movement or navigation
- Lack of remote monitoring and control
- Difficulty accessing dangerous or narrow locations

Most traditional systems only generate alarm sounds when smoke or heat exceeds predefined limits. Firefighters or users must manually reach the affected area and extinguish the fire. In industrial and hazardous environments, this delay can increase the spread of fire and result in severe damage to life and property.

Existing fire extinguishing methods also face challenges in:

- Toxic smoke exposure

- Extreme temperature conditions
- Structural collapse risks
- Explosive chemical environments

These limitations highlight the need for intelligent robotic systems capable of automatic fire detection and suppression.

Proposed System

The proposed system is an **IoT and Embedded-Based Automatic Fire Extinguishing Robot** designed to provide fast, accurate, and reliable fire detection along with automatic fire suppression using robotics and sensor technologies. Unlike conventional fire alarm systems that only detect smoke or temperature changes, the proposed system combines autonomous robotic movement, intelligent sensing, and automatic water spraying mechanisms to improve fire-fighting efficiency and reduce human involvement.

The system uses flame sensors and temperature sensors to continuously monitor the surrounding environment for fire conditions. The flame sensor detects infrared radiation emitted by flames, while the temperature sensor monitors abnormal heat levels. These sensor readings are processed by the Arduino/NodeMCU microcontroller, which acts as the central control unit of the system.

When fire is detected, the controller automatically activates the motor driver circuit and DC motors to move the robot toward the fire source. Simultaneously, the water pump mechanism is activated to spray water directly onto the flame. The robot continues extinguishing the fire until the sensor readings return to normal levels.

The proposed system can also integrate IoT communication modules for remote monitoring and real-time alerts. Users can receive notifications through mobile applications, cloud platforms, or wireless communication systems whenever fire is detected. A buzzer alarm and LCD display can also provide local warning indications and system status information.

The robotic fire-fighting system supports intelligent navigation and can be further enhanced using obstacle avoidance sensors such as ultrasonic sensors or infrared sensors. These sensors allow the robot to move safely without collisions while reaching the fire location.

The integration of robotic movement, sensor monitoring, embedded control, and IoT communication creates a smart fire safety solution that improves detection accuracy, response speed, and operational safety.

The overall design of the proposed system focuses on:

- Early fire detection
- Automatic fire extinguishing
- Real-time environmental monitoring
- Autonomous robotic navigation
- Reduced human risk
- IoT-enabled remote alerts
- Fast emergency response
- Low-cost implementation
- Easy maintenance and scalability
- Reliable operation in hazardous environments

The proposed system can be effectively deployed in:

- Homes
- Industries
- Warehouses
- Laboratories

- Shopping malls
- Chemical plants
- Hospitals
- Office buildings
- Smart city infrastructures

The robot helps minimize fire-related damage and improves safety management by reducing the dependence on manual fire-fighting operations.

The system can also be upgraded with advanced technologies such as:

- AI-based fire recognition
- Wireless camera surveillance
- GPS tracking
- Cloud monitoring
- Autonomous path planning
- Obstacle avoidance
- Mobile application integration

By combining embedded systems, robotics, IoT, and automation technologies, the proposed Automatic Fire Extinguishing Robot provides an intelligent and modern solution for next-generation fire safety and disaster management applications.

IV. IMPLEMENTATION

Overview

The implementation of the proposed fire-fighting robot is divided into systematic stages involving sensing, processing, decision-making, navigation, and fire suppression. Each hardware module plays a specific role in enabling autonomous operation.

Step 1: System Initialization

- The Arduino Uno powers up and initializes all connected components.
- Pins for flame sensors, ultrasonic sensor, motor driver, and relay are configured as input/output.
- Initial values for movement and threshold detection (flame intensity level, distance limits) are set.

Step 2: Flame Detection Using Flame Sensors

- Two flame sensors placed at the front continuously scan the environment.
- The sensors output analog or digital signals based on flame intensity.
- Arduino reads these values to:
 - **Detect fire presence**, and
 - **Identify the direction** (left flame sensor vs right flame sensor).
- This directional detection helps the robot align itself toward the fire source.

Step 3: Obstacle Detection Using Ultrasonic Sensor

- The ultrasonic sensor (HC-SR04) emits sound waves and measures the time taken for the echo to return.
- Arduino calculates the distance to any obstacle using the formula:
Distance = (Time × Speed of Sound) / 2
- If an obstacle is detected within a predefined safe distance (e.g., < 20 cm), the robot:
 - Stops the motors
 - Changes direction (left/right)
 - Attempts to navigate around the obstacle

Step 4: Navigation and Movement Control

- Based on flame and obstacle data, Arduino decides the movement:
 - **Move forward** if fire is detected and path ahead is clear
 - **Turn left** if left flame sensor detects stronger intensity
 - **Turn right** if right flame sensor detects stronger intensity
 - **Stop and redirect** if an obstacle is detected
- The L298N motor driver receives directional commands from Arduino and controls the two DC motors accordingly.

Step 5: Fire Approach Logic

- As the robot moves closer to the flame, flame intensity increases.
- When the flame sensors read a threshold indicating close proximity, the robot:
 - Slows down
 - Stops at the optimal extinguishing distance
 - Prepares to activate the suppression mechanism

Step 6: Fire Extinguishing Using Water Pump

- Arduino activates the **relay module**, which turns ON the **submersible water pump**.
- The pump sprays water toward the flame continuously for a predefined duration or until the flame sensor no longer detects fire.
- This ensures the fire is extinguished effectively and safely.

Step 7: Post-Extinguishing Verification

- After spraying water, Arduino again reads the flame sensors:
 - **If the flame is no longer detected**, the robot stops spraying and returns to idle or patrol mode.
 - **If the flame is still detected**, the robot continues extinguishing until the fire is completely suppressed.

Step 8: Return to Standby Mode

- Once the fire is neutralized and sensors detect no flame, the robot:
 - Stops all active components (motors, pump)
 - Awaits the next fire detection cycle
 - Can optionally resume patrol movement if programmed

V. RESULTS AND DISCUSSION**Results**

The proposed **Automatic Fire Extinguishing Robot** was successfully designed and tested for autonomous fire detection, obstacle avoidance, navigation, and fire suppression. The system demonstrated effective performance in detecting flames, navigating toward the fire source, avoiding obstacles, and extinguishing the fire automatically using the water pump mechanism.

The flame sensors continuously monitored the surrounding environment and accurately detected the presence and direction of fire. During testing, the robot successfully identified whether the flame was positioned toward the left or right side and adjusted its movement accordingly. The directional sensing capability improved the robot's alignment toward the fire source and enabled faster response.

The ultrasonic sensor effectively detected nearby obstacles and prevented collisions during robot movement. When obstacles were placed in the robot's path, the system stopped automatically and redirected itself to avoid collision. This improved the autonomous navigation capability and allowed the robot to operate safely in dynamic environments.

The L298N motor driver successfully controlled the DC motors based on commands from the Arduino Uno. The robot moved forward, backward, left, and right smoothly according to flame intensity and obstacle conditions. The navigation logic enabled stable and controlled movement toward the detected fire source.

As the robot approached the fire, the flame intensity values increased gradually. Once the predefined threshold value was reached, the robot stopped at an optimal distance and activated the water pump system through the relay module. The pump sprayed water continuously until the flame was completely extinguished.

The post-extinguishing verification stage also performed successfully. After water spraying, the flame sensors rechecked the environment to verify whether the fire still existed. If no flame was detected, the system automatically turned OFF the pump and returned to standby mode. This ensured reliable extinguishing operation and prevented unnecessary water usage.

The robot demonstrated the following successful operational results:

- Accurate flame detection
- Autonomous navigation toward fire source
- Effective obstacle avoidance
- Stable motor control
- Automatic water spraying
- Reliable fire suppression
- Continuous environmental monitoring
- Reduced human intervention

The overall system operated efficiently under controlled testing conditions and proved suitable for small-scale fire safety applications.

Discussion

The implementation of the Automatic Fire Extinguishing Robot demonstrates the practical application of embedded systems, robotics, and automation technologies in fire safety and disaster management. The integration of flame sensors, ultrasonic sensors, motor drivers, and water pumps created a complete autonomous fire-fighting system capable of responding quickly to fire hazards.

One of the major advantages observed during testing was the robot's ability to detect the direction of fire using dual flame sensors. This directional analysis improved navigation accuracy and minimized unnecessary movement. The robot was able to align itself effectively toward the fire source, which reduced extinguishing time and improved operational efficiency.

The obstacle avoidance mechanism significantly enhanced system reliability. In many fire situations, the environment may contain obstacles such as furniture, walls, equipment, or debris. The ultrasonic sensor enabled the robot to identify such obstacles and navigate safely without collision. This feature makes the system more suitable for real-world deployment in indoor and industrial environments.

The water pump suppression system provided effective extinguishing capability for small and medium flame conditions. The relay-controlled activation mechanism ensured automatic operation without human involvement. The use of post-extinguishing verification further improved the reliability of the system by confirming whether the fire was fully suppressed before stopping the pump.

The Arduino Uno microcontroller performed efficiently as the central processing unit of the robot. It handled sensor readings, movement decisions, obstacle detection, and pump control in real time. The simplicity, low

cost, and flexibility of Arduino made the system easy to implement and suitable for educational as well as practical applications.

Although the system performed successfully, certain limitations were identified during experimentation. The robot's operational efficiency depended on sensor sensitivity, lighting conditions, and obstacle complexity. Very dense smoke or extremely high temperatures could affect sensor accuracy. The extinguishing capability was also limited by the size of the water tank and battery backup duration.

The proposed system mainly targets small-scale fire incidents and controlled environments. For large-scale industrial fires, additional advanced technologies such as thermal imaging cameras, AI-based fire prediction, GPS navigation, and high-capacity suppression systems may be required.

Future improvements can further enhance the intelligence and performance of the robot. Possible enhancements include:

- IoT-based remote monitoring
- Wireless live video streaming
- AI-based fire recognition
- Autonomous path planning
- Voice alert systems
- Mobile application control
- Solar-powered battery charging
- Smoke density analysis
- Multi-directional water spraying

The results obtained from the project confirm that robotic fire-fighting systems can significantly reduce human risk, improve emergency response speed, and minimize fire-related damage. The integration of automation and embedded technology provides an efficient and cost-effective solution for next-generation smart fire safety systems.

Overall, the Automatic Fire Extinguishing Robot achieved its intended objectives successfully and demonstrated the feasibility of autonomous robotic fire suppression systems for real-world safety applications.

VI. CONCLUSION & FUTURE SCOPE

The development of the Arduino-based fire-fighting robot successfully demonstrates how embedded systems, sensors, and automation can be integrated to create an intelligent and efficient fire-suppression device. Using dual flame sensors, the robot is able to accurately detect both the presence and direction of a fire, while the ultrasonic sensor ensures safe navigation by avoiding obstacles in real time. The L298N motor driver provides precise control over the DC motors, enabling smooth movement toward the fire source. Once within extinguishing range, the relay-activated submersible water pump effectively sprays water to suppress the flame.

The system operates autonomously, reducing human effort and minimizing risks associated with entering hazardous fire zones. Its low cost, portability, and simplicity make it suitable for educational environments, small-scale laboratories, smart homes, and industrial safety applications. Experimental observations confirm that the robot is capable of responding quickly, navigating reliably, and extinguishing small fires effectively.

Overall, the project demonstrates a practical and scalable approach to early-stage fire management and highlights the potential of robotics in enhancing safety and emergency response. Future enhancements like night-vision cameras, GSM alerts, thermal sensors, and AI-based path planning can further increase the robot's capabilities and expand its applications.

In future work, the system can be further improved by integrating advanced deep learning models, biometric monitoring sensors, voice assistance, cloud-based analytics, and mobile applications for enhanced user interaction and predictive safety analysis.

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