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Fire Fighting Robot with 360° Water Spray

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Abstract: *Fire is one of the most hazardous and destructive forces of nature. Many accidents caused by fire lead to severe loss of life and property. In such conditions, human firefighters face life-threatening risks. This project aims to develop an autonomous Fire Fighting Robot with a 360° Water Spray Mechanism that can detect, approach, and extinguish fire automatically, thereby minimizing human risk. The robot is powered by a microcontroller (ESP32 or Arduino Uno) and integrates flame sensors, DC motors, servo motors, and a water pump system to extinguish fire efficiently. It is equipped with IoT-based manual override functionality through a mobile app (Blynk), enabling wireless monitoring and control. This dual- mode robot (manual + autonomous) detects fire using sensors, determines the f ire's direction, moves toward the source, and activates a 360° water-spraying mechanism to extinguish the fire effectively. The expected outcome of this project is a low-cost, efficient, and smart firefighting robot suitable for homes, industries, laboratories, and hazardous areas where human intervention is risky.*

Keywords: Fire detection, ESP32, IoT, Servo Motor, Flame Sensor, 360° Spray, Robotics

I. INTRODUCTION

Fire accidents are among the most dangerous hazards faced by industries, residential buildings, laboratories, and public infrastructures. Traditional firefighting operations often expose firefighters to extreme heat, toxic gases, smoke, and structural collapse risks, making emergency response highly dangerous [1]. As urbanization and industrialization continue to increase, there is a growing demand for intelligent and automated fire safety systems capable of reducing human intervention and improving emergency response efficiency [2].

Recent advancements in embedded systems, robotics, and Internet of Things (IoT) technologies have enabled the development of autonomous robotic systems for hazardous environments. Firefighting robots are designed to detect flames, navigate toward the fire source, and extinguish fires without directly risking human life [3]. These systems use sensors, microcontrollers, actuators, and communication technologies to perform firefighting operations with higher speed and accuracy compared to manual methods [4].

The proposed project, "IoT-Based Autonomous Fire Fighting Robot with 360° Water Spray System," focuses on developing a smart robotic platform capable of automatic fire detection and suppression. The robot integrates flame sensors, temperature sensors, ESP32 microcontroller, DC motors, servo motors, and a water pump mechanism to create an intelligent firefighting solution [5]. The ESP32 controller acts as the central processing unit, continuously analyzing sensor data and controlling the robot's movement and extinguishing operations in real time [6].

One of the major innovations of the proposed system is the implementation of a 360° rotating water spray mechanism. Unlike traditional firefighting robots that spray water in only one direction, the rotating nozzle ensures complete fire coverage and eliminates blind spots during operation [7].

In addition to autonomous operation, the robot incorporates IoT-based monitoring and manual control using the Blynk cloud platform. Through Wi-Fi communication, users can remotely monitor fire conditions, receive alerts, and manually operate the robot during emergency situations [8]. The integration of cloud connectivity and real-time monitoring improves situational awareness and allows quick decision-making in hazardous conditions.

The system is designed using cost-effective and easily available components, making it suitable for educational, domestic, and small-scale industrial applications [9]. Its compact structure, portability, and low power consumption further enhance its practical usability. The project also demonstrates how embedded systems and automation technologies can be combined to create safer and smarter disaster management solutions [10].

II. PROBLEM STATEMENT

Fire accidents in homes, industries, laboratories, and commercial buildings often result in severe damage to human life, infrastructure, and valuable resources. Traditional firefighting methods require direct human involvement, exposing firefighters to dangerous conditions such as extreme heat, toxic smoke, and poor visibility. In many situations, delayed response and limited accessibility further increase the risk of fire spreading uncontrollably. Existing firefighting systems are often expensive, partially automated, or limited in extinguishing coverage. Therefore, there is a need for a low-cost, intelligent, and autonomous firefighting system capable of detecting fire in real time, navigating toward the affected area, and extinguishing flames efficiently with minimal human intervention. The proposed IoT-based Fire Fighting Robot with 360° Water Spray is designed to address these challenges by integrating embedded systems, sensor-based fire detection, autonomous movement, and remote IoT monitoring to provide a safer, faster, and more reliable firefighting solution.

III. OBJECTIVES

1. To detect fire accurately using flame and temperature sensors for quick emergency response.
2. To develop an autonomous robotic system that can move toward the fire source without human intervention.
3. To implement a 360° water spray mechanism for efficient and complete fire extinguishing coverage.
4. To integrate IoT-based monitoring and control using ESP32 and Blynk for real-time alerts and remote operation.
5. To design a low-cost, reliable, and energy-efficient firefighting robot suitable for domestic and small industrial applications.

IV. LITERATURE SURVEY

Sharma and Mehta (2021) presented the design and development of an autonomous fire extinguishing robot using flame sensors, Arduino microcontroller, DC motors, and a water pump mechanism. The authors focused on reducing human involvement in hazardous firefighting environments by enabling automatic fire detection and suppression. Their study concluded that autonomous robotic systems can improve firefighting safety and response speed, although the system lacked multi-directional water spraying and IoT-based monitoring features.

Chen and Gupta (2022) developed an IoT-based fire detection and control system for smart buildings using ESP8266, temperature sensors, smoke detectors, and cloud communication platforms. The study emphasized real-time fire monitoring and instant alert generation through mobile applications. The authors concluded that IoT integration improves emergency response efficiency and remote accessibility, but the system did not include autonomous fire extinguishing capabilities.

Lee and Park (2022) proposed a vision-based fire detection robot using Raspberry Pi, OpenCV, and Convolutional Neural Networks (CNN) for accurate flame and smoke recognition. The research focused on improving fire detection reliability through artificial intelligence and image processing techniques. Their findings showed that computer vision-based systems provide high detection accuracy, but increased computational complexity and system cost limited practical low-cost implementation.

Patil and Chavan (2023) designed a flame tracking robot using NodeMCU ESP8266, multiple flame sensors, and IoT communication modules. The system was capable of detecting fire direction, moving toward the flame source, and sending real-time updates to users through a mobile application. The authors concluded that IoT-enabled firefighting robots improve remote monitoring and safety, though the extinguishing coverage and movement speed required further enhancement.

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Kumar and Singh (2023) introduced an IoT-based fire fighting robot using ESP32, motor drivers, and automated water spraying mechanisms for intelligent fire suppression. The study focused on integrating wireless communication, autonomous navigation, and sensor-based decision-making to improve firefighting efficiency. The research concluded that combining IoT and robotics provides a reliable and low- cost solution for domestic and industrial fire safety applications.

Jindal et al. (2021) presented the design and deployment of an autonomous unmanned ground vehicle for urban firefighting scenarios using LiDAR sensors, thermal cameras, and robotic navigation systems. The authors focused on enabling robots to operate in dangerous environments with minimal human intervention. Their work concluded that autonomous firefighting robots significantly improve operational safety and precision, although the system required expensive hardware and complex computational algorithms.

IV. WORKING OF SYSTEM

The proposed IoT-Based Autonomous Fire Fighting Robot with 360° Water Spray System operates through the integration of sensors, embedded controllers, motor drivers, and a water spraying mechanism to detect and extinguish fire automatically. The overall system architecture and circuit implementation are shown in Figure 1 and Figure 2 respectively.

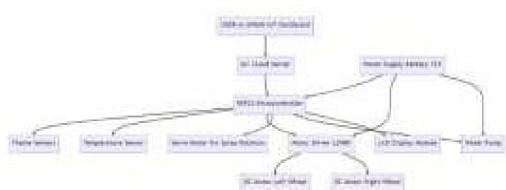

Figure 1: System Architecture of Fire Fighting Robot

The system architecture of the proposed IoT-Based Autonomous Fire Fighting Robot with 360° Water Spray System represents the overall interaction and communication between the hardware and software components used in the firefighting process.

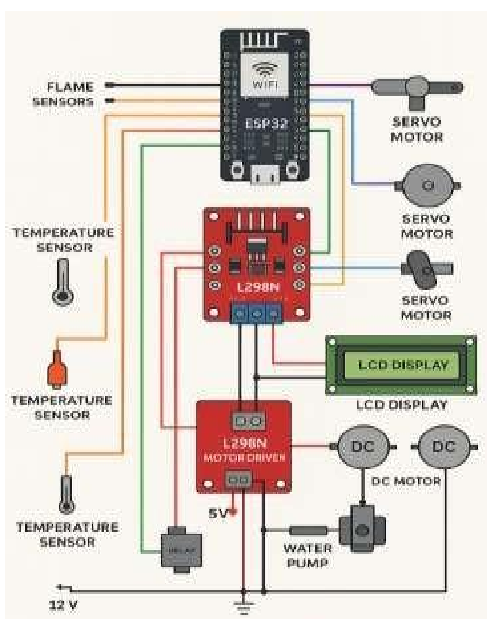

Fig 2: Circuit Diagram of Fire Fighting Robot

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The ESP32 microcontroller acts as the central control unit of the system and coordinates all operations including fire detection, robot movement, water spraying, and IoT communication. The flame sensors and temperature sensor continuously monitor the surroundings to identify the presence of fire or abnormal heat conditions. These sensors send analog or digital signals to the ESP32, where the sensor data is processed in real time to determine the intensity and direction of the fire source.

The circuit diagram shows the practical hardware connections of the Arduino/ESP32 board with flame sensors, L298N motor driver, DC motors, servo motor, water pump, and battery supply. The sensors continuously monitor the surroundings for fire detection and send signals to the controller for processing.

System Working

1. Fire Detection:

Flame sensors and temperature sensors continuously scan the environment to identify the presence of fire or abnormal heat conditions. When fire is detected, sensor data is transmitted to the ESP32 microcontroller.

2. Signal Processing and Decision Making:

The ESP32 analyzes the sensor inputs and determines the direction of the fire source based on sensor intensity values. The controller then generates control signals for robot movement and extinguishing operations.

3. Robot Navigation:

The L298N motor driver controls the DC motors attached to the wheels of the robot. Based on the fire direction, the robot moves toward the affected area automatically without human intervention.

4. Activation of Water Spray Mechanism:

Once the robot reaches the fire source, the water pump gets activated. Simultaneously, the servo motor rotates the nozzle through 360°, ensuring complete water coverage and eliminating blind spots during extinguishing.

5. IoT Monitoring and Control:

The ESP32 connects to the IoT cloud server through Wi-Fi communication. Real-time fire alerts, system status, and sensor readings are transmitted to the Blynk mobile application, allowing users to monitor and manually control the robot remotely if required.

6. Fire Extinguishing and System Reset:

The robot continuously sprays water until the flame sensors detect that the fire has been extinguished. After successful suppression, the system stops the pump and motors and returns to standby mode for further monitoring.

V. SYSTEM DESIGN

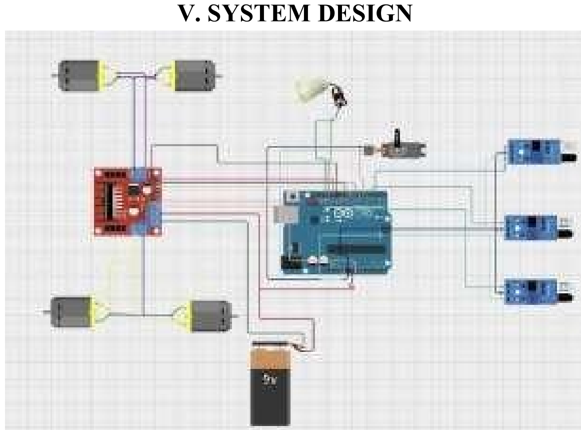

Fig 3. System Design

1. System Overview

The proposed IoT-Based Autonomous Fire Fighting Robot with 360° Water Spray System is designed to detect fire automatically and extinguish it using a rotating water spray mechanism. The system integrates flame sensors, Arduino/ESP32 controller, L298N motor driver, DC motors, servo motor, water pump, and battery supply to perform autonomous firefighting operations. The robot continuously monitors the surroundings for fire using multiple flame sensors and moves toward the detected fire source using motor-controlled wheels. Once the fire is detected, the water pump and rotating nozzle mechanism are activated to spray water over the affected area.

The circuit design shown in the figure consists of an Arduino Uno controller connected with three flame sensors for multi-directional fire detection. The L298N motor driver controls four DC motors responsible for robot movement. A servo motor is attached to the water nozzle to achieve 360° rotational spraying coverage. The entire system is powered using a 9V battery supply, while embedded programming controls sensor processing, movement logic, and extinguishing operations.

2. Hardware Design

a) Arduino Uno Microcontroller

The Arduino Uno acts as the central processing unit of the system. It receives input signals from flame sensors, processes the sensor data, and controls the movement of motors, servo rotation, and water pump activation. The controller executes programmed logic to perform autonomous firefighting tasks.

b) Flame Sensors

Three flame sensors are mounted on the robot to detect fire from different directions. These sensors continuously monitor infrared radiation emitted by flames and send signals to the Arduino controller whenever fire is detected.

c) L298N Motor Driver

The L298N dual H-bridge motor driver module controls the movement of DC motors. It receives control signals from the Arduino and regulates the speed and direction of the robot wheels for forward, backward, left, and right movement.

d) DC Motors

Four DC geared motors are connected to the wheels of the robot chassis. These motors provide mobility to the robot and allow it to move toward the detected fire source automatically.

e) Servo Motor

A servo motor is connected to the water spray nozzle. It rotates the nozzle through different angles to provide 360° water spraying coverage for efficient extinguishing.

f) Water Pump

The DC water pump is responsible for pumping water from the tank to the nozzle. Once the fire is detected, the controller activates the pump to spray water on the fire.

g) Power Supply

The entire system is powered using a 9V battery supply. The battery provides electrical power to the Arduino board, motor driver, sensors, and water pump.

3. Software Design

The software of the system is developed using Embedded C/C++ in the Arduino IDE. The program continuously reads data from flame sensors and processes the signals to determine the direction of fire. Based on the sensor inputs, the controller generates commands for motor movement and water spray activation.

The software algorithm performs the following operations:

- Initialize sensors and motors
- Continuously monitor flame sensors
- Detect fire location
- Move robot toward fire source
- Activate water pump
- Rotate servo motor for water spraying
- Stop operation after fire extinguishing

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4. System Working Flow

1. The robot starts and initializes all sensors and motors.
2. Flame sensors continuously monitor the environment for fire.
3. When fire is detected, the Arduino controller identifies the fire direction.
4. The motor driver activates DC motors to move the robot toward the fire source.
5. The water pump is switched ON automatically.
6. The servo motor rotates the nozzle for complete water spray coverage.
7. After extinguishing the fire, the system stops the pump and returns to standby mode.

VI. RESULTS

Fig 4. Prototype model

The developed prototype of the IoT-Based Autonomous Fire Fighting Robot with 360° Water Spray System was successfully designed and tested under controlled fire conditions. The prototype model consists of a mobile robotic chassis equipped with DC motors, rechargeable lithium-ion battery pack, water pump mechanism, servo- controlled nozzle, controller circuit, and flame detection sensors. The robot demonstrated stable movement, efficient fire detection, and reliable extinguishing performance during testing.

The flame sensors were able to detect fire within an approximate range of 1–2 meters and transmitted signals to the microcontroller for processing. After detecting the fire source, the robot autonomously moved toward the flame using the motor driver-controlled wheel mechanism. The servo motor successfully rotated the nozzle, enabling 360° water spraying coverage and ensuring effective extinguishing without leaving blind spots. The water pump generated continuous water flow through the nozzle, which helped suppress small-scale fires rapidly and efficiently.

The prototype also showed good mechanical stability and smooth navigation on flat indoor surfaces. The rechargeable lithium-ion battery pack provided sufficient power backup for continuous operation during testing. The compact design of the robot made it lightweight, portable, and easy to operate in small environments such as laboratories, classrooms, homes, and industrial workspaces.

During experimental analysis, the robot achieved quick response time and efficient firefighting performance. The overall fire detection and extinguishing process was completed within a few seconds under normal operating conditions. The integration of embedded control and automation significantly reduced the need for human intervention in hazardous situations. The prototype successfully validated the practical implementation of autonomous firefighting technology using low-cost electronic components and embedded systems.

The final prototype demonstrates that the proposed system is capable of providing an intelligent, efficient, and economical firefighting solution for small-scale fire safety applications. The successful operation of the robot confirms the feasibility of integrating robotics, IoT, and automation technologies for modern fire disaster management systems.

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VII. CONCLUSION

The IoT-Based Autonomous Fire Fighting Robot with 360° Water Spray System was successfully designed, developed, and tested as an intelligent solution for automated fire detection and suppression. The system effectively integrates embedded systems, robotics, sensor technology, and IoT communication to create a reliable firefighting mechanism capable of minimizing human involvement in hazardous environments. The robot was able to detect fire accurately using flame sensors, navigate toward the fire source autonomously, and extinguish the flame efficiently through a rotating 360° water spray mechanism.

The implemented prototype demonstrated stable movement, fast response time, and effective firefighting performance during experimental testing. The integration of motor drivers, servo-controlled nozzle rotation, rechargeable battery supply, and water pump system ensured smooth and continuous operation. Additionally, the use of IoT technology enhanced system functionality by enabling remote monitoring and control, making the robot more practical for real-time emergency applications.

VIII. FUTURE SCOPE

The proposed IoT-Based Autonomous Fire Fighting Robot with 360° Water Spray System provides a strong foundation for future advancements in intelligent firefighting and safety automation. Although the current prototype performs efficiently for small-scale fire detection and suppression, several improvements can be implemented to enhance its performance, intelligence, and real-world applicability.

In future developments, the system can be integrated with artificial intelligence and computer vision technologies such as OpenCV, YOLO, or TensorFlow for more accurate flame and smoke detection using camera modules. AI-based image processing can help the robot identify different types of fires and improve decision-making capabilities under complex environmental conditions.

The robot can also be upgraded with ultrasonic sensors, LiDAR, GPS, and autonomous navigation algorithms to enable obstacle avoidance, path planning, and operation in large indoor or outdoor environments. This enhancement would improve mobility and allow the robot to function effectively in industrial plants, warehouses, and disaster- prone areas.

Another important improvement is the implementation of multi-robot coordination and wireless communication protocols such as MQTT or Zigbee. Multiple firefighting robots could work together in large-scale emergency situations to improve firefighting efficiency and coverage. Cloud-based analytics and IoT data storage can also be integrated for monitoring historical fire events and predictive maintenance.

Future versions may include larger water tanks, automatic water refill systems, solar charging mechanisms, and all-terrain chassis designs for extended operational capability and outdoor deployment. The addition of thermal cameras, gas sensors, and voice alert systems would further improve safety and reliability.

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