IJEAST

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE
AND TECHNOLOGY

VOLUME : 10 ISSUE : 12 Print / Issue Publication Date: April 2026

ISSN : 2455-2143

DOI : 10.33564/IJEAST.2026.v10i12.015

Indexed In

Google SCHOLAR OPEN ACCESS doi Crossref

WWW.IJEAST.COM

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International Journal of Engineering Applied Sciences and Technology, 2026
Vol. 10, Issue 12, ISSN No. 2455-2143, Pages 108-111
Published Online April 2026 in IJEAST (http://www.ijeast.com)

DEVELOPMENT & CONSTRUCTION OF SEMI-AUTOMATED FIREFIGHTING ROBOT

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Abstract: **Fire accidents in industrial and residential environments pose serious threats to human life and property, often requiring rapid response in hazardous conditions. To reduce human risk and improve early fire suppression, this project focuses on the development and construction of a semi-automated fire-fighting robot using an ESP32 microcontroller. The robot is designed to detect, approach, and extinguish small-scale fires with minimal human intervention while allowing manual control when required.**

Key Words: **Fire-Fighting Robot, ESP32, Semi-Automated System, Flame Sensor, Wireless Control, Industrial and Residential Safety**

I. INTRODUCTION

Fire accidents in industrial and residential areas are becoming increasingly common due to electrical faults, chemical storage, machinery overheating, and human negligence. These incidents pose serious threat to life, property, and the environment. Traditional fire-fighting methods require humans to enter hazardous zones filled with extreme heat, toxic smoke, or unstable structures, makes the process highly risky. Therefore, there is a growing need for automated systems that can respond quickly and operate safely in dangerous conditions. With advancements in robotics, sensor technology, and embedded systems, fire-fighting robots have emerged as a reliable solution for assisting in fire detection and suppression. These robots are capable of navigating through hazardous environments, locating fire sources, and extinguishing flames using built-in suppression mechanisms. Semi-automated robots, in particular, offer an ideal balance between autonomous operation and manual control, ensuring flexibility and greater safety during operation.

II. LITRATURE SURVEY

Fire-fighting robotics has been an active field of research as engineers seek to reduce human risk during emergency responses. Researchers have explored various sensing techniques, control strategies, and robotic platforms to improve early fire detection and suppression. The following
1. Kim et al. (2004): Sensor-Integrated Fire-Fighting Robot Kim and colleagues developed an early autonomous fire-fighting robot that used temperature and gas sensors to detect potential fire sources in smoke-filled environments. Their system combined these sensors with simple navigation and path finding algorithms, enabling the robot to move toward heat and gas signatures indicating fire.
2. Tanaka et al. (2006): Vision-Based Fire Detection Tanaka and coworkers implemented a robot using stereo vision and image processing to detect flame patterns. The system employed real-time image analysis to locate fire sources and navigate around obstacles.

III. METHODOLOGY

Problem Definition.
The problem addressed in the research paper is the increasing severity of fires in various environments, which pose significant risks and challenges to human firefighters. The proposed solution is a firefighting robot based on the ESP32 platform, designed to navigate manually, detect fires, and extinguish them using a water pump. The robot can be automatically work, reducing the risks faced by human firefighters. The proposed robot is intended to be efficient, effective, safe, and feasible, providing a valuable tool for fire fighters to combat fires in various environments.
Problem planning and Designing the Robot
Design conceptualization of robot: The robot design involves the creation and assembly of a sturdy and highly maneuverable hardware chassis. For our prototype, we have opted to use a polycarbonate Sheet, which provides a solid foundation for the robot's structure. Please refer to Figure1 below for an illustration of the robot's design with the polycarbonate Sheet.

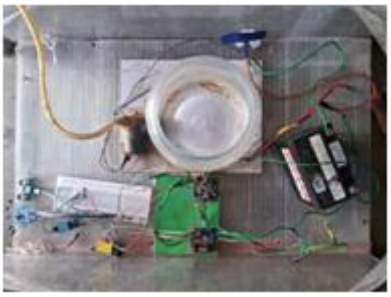

Fig-1: Robot's Schematic Picture

International Journal of Engineering Applied Sciences and Technology, 2026
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In this project, the robot operates autonomously without the use of any remote control or external control devices. All the robot functions are controlled directly by the onboard microcontroller based on sensor inputs. The sensors continuously monitor the surrounding environment, and the microcontroller processes this data to make real-time decisions for robot movement and operation. Since no Bluetooth module, mobile application, or remote controller is used, the system remains simple, reliable, and independent of human intervention. This autonomous approach enhances operational safety and makes the robot suitable for continuous and unattended operation in real-time applications.

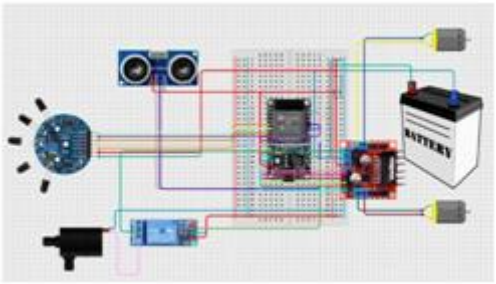

Fig-2: Fire Detection System

The semi-automated fire-fighting robot operates by continuously monitoring its surroundings using fire-detecting sensors such as flame sensors, temperature sensors, and smoke or gas sensors. These sensors detect the presence of fire or abnormal heat levels and send signals to the microcontroller, which acts as the brain of the system.
Once a fire is detected, the microcontroller processes the sensor data and determines the direction and intensity of the fire. Based on this information, the robot either moves automatically toward the fire source or waits for manual control commands from the operator through a remote control or wireless interface, making it semi-automated in nature.
The movement of the robot is controlled by DC motors driven through a motor driver module. This allows the robot to navigate safely through narrow or hazardous areas in industrial plants or residential buildings, reducing the risk to human firefighters. When the robot reaches a safe distance from the fire source, the control unit activates the fire-extinguishing mechanism. A water pump or fire-retardant spray system is switched ON using a relay module, directing water or extinguishing agent through a nozzle toward the fire.
The robot continues spraying until the fire is suppressed or until the sensor readings indicate that the temperature and flame intensity have reduced to safe levels. During this process, the operator can manually override the system if required to improve accuracy or safety.
After extinguishing the fire, the robot stops the pump and either returns to its initial position or remains in standby mode for further instructions. This working principle makes the semi-automated fire-fighting robot efficient, safe, and suitable for early fire detection and response in both industrial and residential environments.
Test the robot in simulated scenarios: Conduct simulated firefighting scenarios to test the robot's performance in navigation, fire detection, and fire extinguishing tasks.
Components used: Below are the components we have used in our prototype robot.

Table-1: Components Specification

Components (Sensor/Actuator)	
Sensor/Actuator	**Working Voltage**
ESP32	5V
Motor Drive (l298N)	12V
Ultrasonic	5V
5 Channel Flame Sensor	5V
Relay Module	12V
Water Pump	12V
Dc Motor	12V

IV. WORKING

The semi-automated fire-fighting robot consists of a microcontroller, which acts as the main control unit of the system. It receives signals from different sensors and controls the movement, fire detection, and fire-extinguishing operations. Flame sensors, temperature sensors, and smoke sensors are used to detect the presence of fire and abnormal heat conditions. A rechargeable battery supplies power to all electronic and mechanical components.

The robot is designed with DC motors, wheels, and a sturdy chassis to allow smooth movement in industrial and residential environments. A motor driver module is used to control the speed and direction of the motors based on commands from the microcontroller. The robot can be operated automatically or manually using a remote or wireless control, which provides flexibility and improves safety.

When a fire occurs, the sensors continuously monitor the surroundings and send data to the microcontroller. Once fire is detected, the control unit analyzes the sensor signals to identify the location of the fire. The robot then moves toward the fire source either automatically or with manual assistance from the operator, making the system semi-automated.

After reaching a safe distance from the fire, the microcontroller activates the fire-extinguishing system. A water pump connected through a relay module is switched ON to spray water or fire-retardant liquid through a nozzle toward the fire. This helps in controlling and extinguishing the fire without human intervention in dangerous areas.

Once the fire is extinguished, the sensors confirm the reduction in flame and temperature levels. The microcontroller then turns OFF the pump and stops the robot or moves it back to a standby position. This semi-automated fire-fighting robot improves safety, reduces risk to human life, and provides an effective solution for early fire control in both industrial and residential applications.

V. ESULTS

The development and construction of a semi-automated fire-fighting robot focus on enhancing safety in industrial and residential environments by reducing human involvement in dangerous fire situations. The robot is built around a microcontroller that acts as the main control unit, receiving inputs from flame, temperature, and smoke sensors to detect fire and abnormal heat conditions. It is mounted on a sturdy chassis with DC motors and wheels, allowing smooth movement across different surfaces. A rechargeable battery supplies power to all electronic and mechanical components, while a motor driver controls the speed and direction of the robot. The system can operate in both automatic and manual modes, giving flexibility to the user.

Fig-04: Fire Detection Output

During operation, the sensors continuously monitor the surroundings and send real-time data to the microcontroller. When a fire is detected, the robot moves toward the fire source either autonomously or with operator assistance, making it semi-automated.

After reaching a safe distance, the control unit activates a water pump through a relay module to spray water or fire-retardant liquid through a nozzle, helping to extinguish the fire.

Once the fire is controlled, the sensors confirm the reduction in flame and temperature, and the robot returns to standby mode. This semi-automated fire-fighting robot provides an effective, reliable, and safer solution for early fire detection and suppression in both industrial and residential applications.

V. FUTURE SCOPE

Future Scope of the Semi-Automated Fire-Fighting Robot for Industrial and Residential Fire Safety Applications

The future scope of a semi-automated fire-fighting robot is broad and promising as advancements in robotics, sensors, and artificial intelligence continue to evolve. In the coming years, the robot can be upgraded with advanced fire-detection systems such as infrared cameras, thermal imaging sensors, and gas sensors to identify fire sources more accurately and at an early stage. These improvements will allow faster response times and better decision-making in complex fire environments, especially in large industrial plants and multi-storey residential buildings.

Integration of artificial intelligence (AI) and machine learning algorithms can significantly enhance the autonomy of the robot. With AI-based navigation and obstacle-avoidance capabilities, the robot can learn building layouts, predict fire spread patterns, and choose the safest and most efficient paths to reach the fire source. This will reduce the dependence on human operators and improve performance in low-visibility or smoke-filled environments where manual control becomes difficult.

In the future, the robot can be connected to the Internet of Things (IoT) for real-time monitoring and remote control. By linking the robot to fire alarm systems, surveillance cameras, and cloud-based dashboards, emergency responders can receive live data such as temperature levels, fire intensity, and structural conditions. This connectivity will enable coordinated fire-fighting operations and quicker evacuation planning in both industrial and residential settings.

VI. CONCLUSIONS

The development and construction of a semi-automated fire-fighting robot for industrial and residential fire safety applications demonstrate an effective and practical approach to enhancing fire emergency response while reducing risks to human life. By integrating sensors such as flame, smoke, and temperature detectors with a microcontroller-based control system, the robot is capable of identifying fire hazards at an

early stage and responding quickly with appropriate fire-extinguishing actions. And reliability in different fire scenarios.

Overall, the proposed system proves that semi-automated fire-fighting robots can significantly improve safety standards, minimize property damage, and serve as a foundation for future advancements in intelligent fire protection systems. images peak signal to noise ratio has a better performance than others.

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