Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 5, No.1, May : 2025

FIRE-FIGHTER ROBOT USING TEENSY 4.1

Mr. Ritik Raj, Student, Dept. of Electronics and Telecommunication, Xavier Institute of Engineering, Mumbai, India
Prof. Nitin Ahire, Assistant Professor, Dept. of Electronics and Telecommunication, Xavier Institute of Engineering, Mumbai, India

ABSTRACT :
The Fire-Fighter Robot Using Teensy 4.1 is an advanced IoT-enabled autonomous system designed to detect, navigate, and extinguish fires efficiently in real-time. Central to its architecture is the Teensy 4.1 microcontroller, powered by an ARM Cortex-M7 processor running at 600 MHz, ensuring high-speed processing and real-time responsiveness. The robot is composed of four key modules: Fire Detection, Navigation, Fire Suppression, and Wireless Monitoring, all seamlessly integrated for autonomous operation.
The Fire Detection module utilizes a combination of IR flame sensors and a DHT11 temperature sensor to accurately identify the presence and intensity of fire hazards. These sensors allow the robot to detect even small-scale fire events promptly. The Navigation System employs ultrasonic and infrared sensors to enable dynamic obstacle detection and avoidance, allowing the robot to manoeuvre through complex environments without collisions.
Upon fire detection, the Fire Suppression unit is activated automatically. This unit comprises a relay-controlled water pump capable of targeting and extinguishing the fire source with precision. For enhanced situational awareness and remote control, the system includes an ESP32 module that connects to Firebase cloud services, enabling real-time monitoring and alert generation via the internet. The entire software stack is developed using VS Code with PlatformIO, ensuring modularity, scalability, and efficient code management. Designed for use in industrial settings, smart homes, and hazardous area**s**, the robot minimizes human risk. Future upgrades include AI-driven fire intensity analysis**,** intrusion detection system integration, and machine learning-based route optimization to improve autonomous decision-making and system performance.
Keywords - Fire-Fighting Robot, Teensy 4.1, IoT, ESP32, Real-Time Monitoring, Autonomous Navigation, Flame Sensor, Water Pump, Firebase, ARM Cortex-M7

INTRODUCTION :

Fire accidents remain one of the most dangerous hazards in industrial, commercial, and residential environments. These emergencies often demand immediate action, but human intervention may be delayed, difficult, or life-threatening. To address this problem, the **Fire-Fighter Robot Using Teensy 4.1** project introduces an intelligent, autonomous solution responsive, navigating, and extinguishing fires in real time.

The robot is built around the high-performance Teensy 4.1 microcontroller (ARM Cortex-M7), which ensures fast processing and efficient control of all operations. The system is divided into four primary modules Fire Management and Wireless Monitoring. It uses IR flame sensors and a DHT11 temperature sensor to identify the presence of fire based on heat and infrared radiation. The Navigation Module incorporates ultrasonic and IR sensors to detect obstacles and plan paths in dynamic environments. The Fire Suppression Module employs a relay-controlled water pump to extinguish fire once detected. Finally, the Wireless Monitoring Module, using ESP32, sends real-time data to the Firebase cloud, enabling remote access to temperature readings, fire alerts, and robot activity.

Development was carried out using Visual Studio Code with PlatformIO, ensuring a flexible and open-source development environment. The robot's modular architecture supports easy upgrades and customization, allowing the integration of future enhancements such as camera modules, smoke sensors, and voice alerts. This system is highly applicable in areas such as factories, warehouses, data centres, and smart buildings, where fire risks are high and rapid response is essential. In future iterations, features like machine learning-based fire pattern recognition, AI-powered path optimization, and Intrusion Detection System (IDS) integration can further enhance its performance and autonomy.By combining embedded systems, IoT technologies, and automation, this project demonstrates the potential of robotics to deliver real-time, life-saving solutions. It also aligns with the growing need for smart safety systems in modern infrastructure.

RELATED WORKS:

The authors [1] present a study on an autonomous fire-fighting robot equipped with infrared flame sensors, Arduino UNO, and a submersible water pump. The system autonomously detects fire direction using three strategically placed sensors and navigates using BO motors and a motor driver. Upon detection, it activates a water pump to extinguish the fire. The robot operates effectively in high-temperature, rugged environments and is capable of real-time monitoring. The integration of IoT and autonomous navigation improves fire response times. The design reduces human involvement and enhances safety during fire incidents. The system is proposed for both industrial and domestic applications. The study highlights the potential for scalable fire-safety solutions through embedded systems.

The paper [2] present a semi-autonomous IoT-based fire-fighting robot designed to increase fire safety in homes and industries. The robot alerts users remotely via an IoT server in case of gas leaks or fire. It can be controlled through the internet and is equipped with flame and gas sensors along with a fan to extinguish fire. The system provides early warnings and allows users to send commands from any location. It offers a safer alternative to human intervention in dangerous situations. The design is aimed at being a smart, cost-effective solution. It minimizes the risk to life and property. The paper underscores the growing role of remote fire safety systems.

The paper [3] present a comprehensive study on an Arduino Uno-controlled fire-fighting robot built for enclosed space operations. The robot uses infrared flame and temperature sensors to detect fire and autonomously navigate to the source. A water pump is deployed for suppression once fire is confirmed. The robot can communicate wirelessly for remote control and monitoring. Designed for tight and hard-to-reach environments, the robot efficiently bypasses obstacles while staying responsive. This setup improves safety and provides an alternative to manual intervention. The study focuses on real-time detection and IoT-driven monitoring. It enhances fire response speed and system reliability. The robot serves as a model for smart emergency robotics.

The authors [4] present an IoT-enabled firefighting robot equipped with fire and obstacle sensors, water level detection, and remote monitoring via Wi-Fi. It uses Arduino and NodeMCU for system control and real-time communication. A submersible pump, IR flame sensors, and ultrasonic modules enable the robot to navigate and suppress fires efficiently. The L298D motor driver ensures reliable locomotion. Programming is handled in the Arduino IDE, with remote access via a hosted web interface. The robot adapts to various terrains and operates under different temperature conditions. It is designed for long-term use with a durable battery. This robot supports efficient, unmanned fire response in dangerous areas.

The paper [5] present a fire-fighting robot that operates in autonomous and manual modes, utilizing NodeMCU (ESP8266), flame and gas sensors, a mini water pump, and a wireless camera. IoT integration through platforms like Ubidots enables cloud-based monitoring and control. In autonomous mode, the robot detects fire and gas leaks and responds without human input. In manual mode, users can control it remotely through a dashboard. The system is coded using the Arduino IDE and streams live video. It is suitable for hazardous zones like petrochemical plants. The robot enhances safety by reducing the need for human presence in dangerous environments. Its flexibility supports both emergency automation and human-assisted control.

The authors [6] present the design of an autonomous industrial fire-fighting mobile robot using an Atmega 32 microcontroller. The robot utilizes infrared sensors to detect fire and movement, while DC geared motors provide mobility. Once fire is detected, it halts and activates a DC water pump. The system processes analog sensor data and converts it into digital signals to guide navigation and extinguishing. The robot follows a fixed path in industrial settings. Future improvements include adding temperature and smoke sensors and integrating wireless tracking. Use of CO_2 instead of water is suggested for certain fires. The study envisions applying neural networks for advanced motion planning. It's geared toward high-risk industrial environments.

The authors [7] present the design and development of a manually operated fire-fighting robot using the Arduino microcontroller platform. The robot integrates flame sensors, a water pump, and motor control for fire suppression. It employs Bluetooth communication for remote operation and uses OpenCV to enhance fire detection through visual processing. The system allows users to navigate the robot and activate the extinguisher manually. Its simple architecture supports real-time user feedback. The study demonstrates how low-cost hardware and open-source tools can produce functional firefighting systems. It is intended for use in small-scale fire response scenarios. The paper emphasizes its educational and prototyping value.

The authors [8] present a low-cost firefighting robot powered by Arduino Uno and designed to handle small domestic fires. The robot detects fire using flame sensors up to 1 meter and sprays water via an onboard system. It navigates autonomously and avoids obstacles, functioning as a first-response unit in unsafe environments. Its compact build allows access to confined spaces before professionals arrive. The system focuses on early fire control to minimize damage and risk. It provides a practical safety tool for homes and small buildings. The robot is designed for ease of use and reliability. It offers a baseline model for future enhancements in domestic fire safety.

The paper [9] present a fire-fighting robot powered by Arduino UNO and designed to extinguish fire autonomously. Three flame sensors are strategically placed for directional fire detection. The robot uses BO motors and L293D motor drivers for navigation, while a submersible water pump suppresses the flames. A servo motor directs the water accurately at the fire. The robot operates independently, monitoring for fire and reacting instantly. The system is low-cost and easy to replicate. It suits both domestic and industrial use. The methodology includes structural design, hardware assembly, and software integration via Arduino IDE. The study underlines the robot's quick response and surveillance capabilities.

The paper [10] present a wirelessly controlled firefighting robot that integrates RF communication, flame sensors, and a spraying system. The robot operates within an 8-meter range, executing fire detection and suppression based on remote commands. A microcontroller processes inputs from sensors and controls the motors accordingly. Water is sprayed upon fire detection using a pump mechanism. The paper explores enhancing fire detection using machine learning models like Haar Cascades and YOLOv3. It provides a comparison of detection accuracy and real-time performance. The system bridges basic robotics with AI for improved response. It is intended for small indoor fire scenarios with manual or semi-automated control.

The authors [11] present a fire-fighting robot controlled via a web application and supported by real-time IoT data transmission. Built with an ESP-32 microcontroller, the robot uses flame, PIR, and ultrasonic sensors to detect fire, human presence, and obstacles. It navigates toward the fire and activates a water pump for suppression. The system supports both manual and automated control, offering flexibility in emergency scenarios. Obstacle avoidance enhances its operational safety. The robot's web-controlled interface allows for remote deployment in hazardous areas. Its design is intended for improving fire response times in both industrial and residential settings. The study concludes that IoT connectivity significantly enhances operational reliability and efficiency.

The paer [12] present an IoT-based autonomous fire suppression system for public transport vehicles. The robot detects fires, monitors environmental parameters, and triggers safety mechanisms like window opening and fire alerts. It uses OpenCV for face detection, GPS for location tracking, and Thingspeak for cloud communication. The Haversine formula helps calculate the nearest fire station's distance. This system prioritizes passenger safety and rapid response in emergencies. It enables proactive actions and real-time updates. Designed for buses, trains, and ships, it improves safety in high-occupancy vehicles. The integration of smart monitoring tools makes it a valuable addition to transport fire safety infrastructure

The authors [13] present a study focused on deep learning techniques for early fire detection using image processing. The system uses convolutional neural networks (CNNs) to identify flames in images by recognizing specific visual patterns. It enhances fire detection accuracy and speed, enabling earlier response. The paper discusses other AI models like restricted Boltzmann machines (RBM) and recurrent neural networks (RNN) for improving detection efficiency. Cloud computing and large datasets are used for model training. Image pre-processing is critical for removing visual noise and improving recognition. The proposed AI system is adaptable for indoor and outdoor use. It offers a modern solution for real-time fire safety.

The authors [14] propose a fire-fighting robot system using an STM32 microcontroller and a two-wheeled, self-balancing design. A JY-901 attitude sensor ensures stability through PID control. It includes flame sensors for fire detection, ultrasonic sensors for obstacle avoidance, and photoelectric sensors for path tracking. The robot can detect fire wavelengths from 760–1100 nm. Power is managed through LM2596 and XL6019 modules for efficient voltage control. The robot processes real-time sensor data to manage fires autonomously. The design enables the robot to operate in complex, cluttered environments. It's targeted for use in emergency rescue and hazardous zones. Experimental results confirm the system's high precision and environmental adaptability

The authors [15] present an IoT-based fire hazard prevention system specifically designed for industrial safety. The system integrates sensors that monitor temperature, gas levels, and chemical presence, transmitting data via Zigbee to a central control unit. Wearable sensors track workers' exposure to hazardous substances. Unlike traditional reactive systems, this setup aims to detect risks before ignition. It is particularly suited for high-risk sectors such as firecracker production. The proactive system enables timely alerts and preventive actions. It safeguards both human health and property. The paper emphasizes real-time data collection and pre-emptive fire mitigation. This IoT model enhances overall industrial fire safety protocols.

The authors [16] present a smart fire prevention system leveraging IoT technologies for industrial safety. The architecture includes sensors for smoke, gas, and temperature detection, all connected to microcontrollers. Data is processed and triggers autonomous alarms and suppression mechanisms. Allows remote management with real-time visibility through wireless communication. It is designed to improve emergency responsiveness and reduce manual intervention. The authors highlight cost-effectiveness and scalability as major benefits. However, challenges such as internet dependency and sensor calibration are noted. The study promotes the integration of predictive analytics and automation in future fire safety frameworks.

The authors [17] present a remotely controlled firefighting robot utilizing a Raspberry Pi as the core processor. The robot features flame and temperature sensors for real-time fire detection and cloud-based monitoring. The system is internet-enabled, allowing users to manage operations from mobile devices. It is suitable for environments requiring remote surveillance and early fire detection. Cloud connectivity offers seamless data transmission, although reliability depends on stable internet access. The robot is effective for small- to medium-scale fire safety operations. Its compact design and use of widely available hardware support scalability. The system enhances safety in inaccessible or risky environments through real-time alerts and control.

The authors [18] present an Arduino-based fire-fighting robot using a multi-sensor detection system and PID control. Built from locally sourced water-resistant materials, the robot includes flame and LM35 temperature sensors for fire identification. It uses a centrifugal water pump and a water spreader for safe and effective suppression. The robot halts near the fire and reverses before spraying, ensuring operator safety. Sensor accuracy is tested under different lighting and distances. Results show IR detection is affected by ambient light, particularly sunlight. The system is suited for both homes and industrial settings. Its low cost and adaptability highlight its practical application in real-world fire safety.

The authors [19] present an autonomous fire-fighting robot using image processing and sensor fusion. A Raspberry Pi handles video processing via HSV colour detection, while an Arduino manages sensor inputs and actuators. The robot detects fire visually and confirms it using a pyro sensor. A robotic arm presses a fire extinguisher lever after navigating obstacles using sonar. The robot uses servo motors to adjust direction and maintain accuracy. The system achieves a fire detection accuracy of 93.89% during testing. It performs well on different surfaces and under variable lighting. The robot is ideal for indoor industrial environments. This approach combines vision and robotics for precise fire control.

The authors [20] present a fire-fighting robot designed for indoor environments, featuring flame and temperature sensors, obstacle avoidance, and a CO_2-based extinguisher. Intelligent path-planning allows autonomous navigation to the fire source. The system supports wireless communication for real-time monitoring and remote override. Upon detecting fire, the robot maneuvers safely and activates suppression mechanisms. Experiments show high accuracy in confined, hazardous conditions. The modular design makes it easy to scale or upgrade. Future plans include integrating computer vision and expanding IoT capabilities. The study demonstrates a promising approach to improving fire response efficiency and automation in indoor spaces.

DESIGN METHODOLOGY:

The project aims on the development of an autonomous fire management system that operates autonomously. The approach is divided into three key sections: the design structure, hardware components, and programming framework. These components were integrated and tested through various experiments to create an effective fire-fighting robot.

Design Structure

Following are the details of the fire-fighting robot, which incorporates several essential components. & its basic design is illustrated in Fig. 1.

The robot performs four primary functions:

1. **Initialization:** Upon receiving power, the robot activates and calibrates its sensors.
2. **Environmental Sensing:** It monitors the surrounding environment to detect temperature variations and identify the presence of a fire.
3. **Navigation:** Once a fire is detected, the robot processes the navigation data to move towards the fire source.
4. **Fire Suppression:** The robot uses servo motors and a submersible water pump to extinguish the fire effectively.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 5, No.1, May : 2025

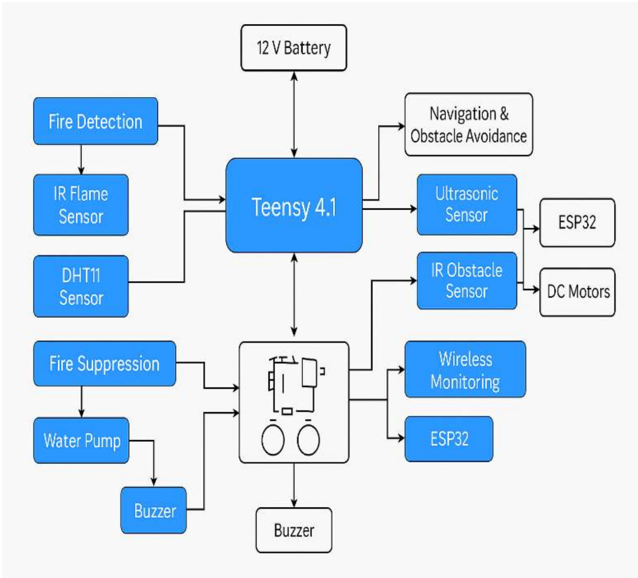

Fig.1. Block Diagram of Proposed Methodology

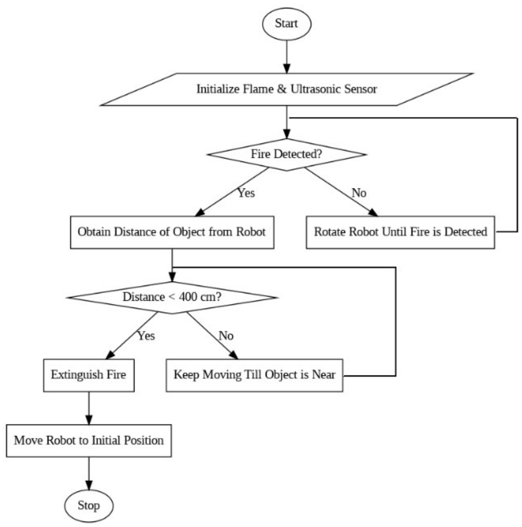

Figure 2. Flowchart of robot

HARDWARE IMPLEMENTATION:

The hardware components play a pivotal role in the construction of the firefighting robot. This section outlines the key hardware elements.

As depicted in Fig. 3, the diagram illustrates the overall setup of the model. The system receives input from three IR flame sensors, which detect the presence of fire. The Teensy 4.1 serves as the central controller, coordinating and connecting various components to ensure seamless operation.

For wheel movement, the L293D motor driver is employed. This driver is capable of simultaneously operating two DC motors—designated as the left and right DC motors—enabling efficient and responsive navigation.

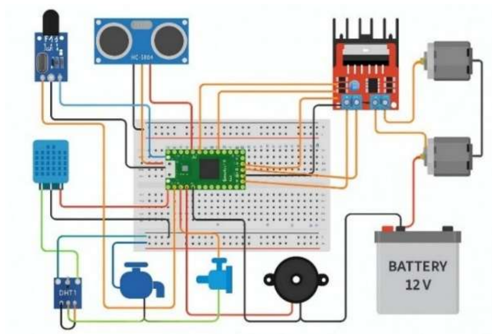

Fig.3 Architecture/ Block diagram of Fire Fighting Robot

HARDWARE USED

Teensy 4.1 Microcontroller :

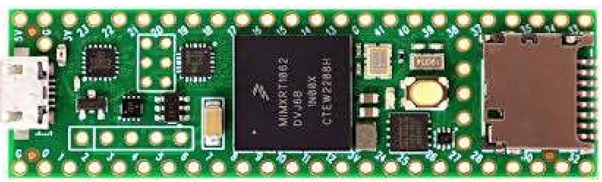

Figure 4: Teensy 4.1 Microcontroller

It is a powerful microcontroller (600MHz ARM Cortex-M7) used as the brain of the robot. It handles processing tasks, sensor data acquisition, and decision-making for the robot.

Specifications:

- Microcontroller: ARM Cortex-M7 @ 600 MHz
- Flash Memory: 8MB
- RAM: 1024 KB
- I/O: 55 digital, 18 analog
- Operating Voltage: 3.3

DHT11 Temperature and Humidity Sensor

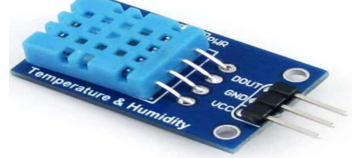

Figure 5: DHT11 Temperature and Humidity Sensor.

It measure both temperature and humidity in the surrounding. It helps confirm the presence of fire based on temperature variations.

Specifications:

- Temperature Range: 0–50°C
- Humidity Range: 20–90% RH
- Accuracy: ±2°C, ±5% RH
- Output: Digital Signal

OLED Display :

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 5, No.1, May : 2025

Figure 6: OLED Display

It serves as a visual interface, providing crucial data such as sensor readings and fire detection status, helping users monitor the robot's operations in real-time.

Specifications:

- Resolution: 128×64
- Interface: I2C
- Voltage: 3.3–5V

DC Motor :


Figure 7: DC Motor

It is crucial for the robot's mobility, allowing it to move and navigate its environment to reach the fire source and perform its firefighting task.

SPECIFICATIONS:

- Voltage: 6–12V
- Speed: 60–300 RPM
- Torque: Depends on motor model

Servo Motor (S90)


Figure 8: Servo Motor S90

It enables precise rotational movement of sensors, which is essential for scanning and detecting fire from multiple angles, improving the robot's effectiveness in real-time fire detection

Motor Driver Module (L298N)

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 5, No.1, May : 2025

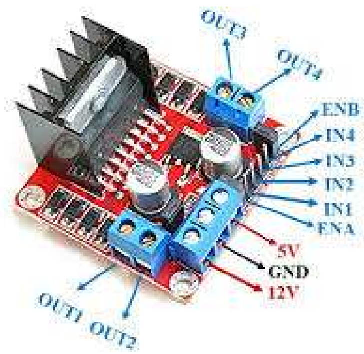

Figure 9: L298N Motor Driver Module

It is essential for controlling the DC motors, allowing the robot to move in different directions and control its speed, ensuring smooth and precise navigation in fire-fighting tasks.

Specifications:

- Motor Voltage: 5–35V
- Logic Voltage: 5V
- Dual H-Bridge: 2 DC Motors

Single Channel Relay Module

Figure 10: Relay Module

It allows the control of high-voltage devices like the water pump in the Fire-Fighter Robot. It acts as an intermediary, enabling the microcontroller to safely switch larger currents and voltages using low-level digital signals.

Specifications:

- Operating Voltage: 5V
- Load Capacity: 10A @ 250VAC / 30VDC
- Trigger: Low-Level Signal

Water Pump (12V DC) :

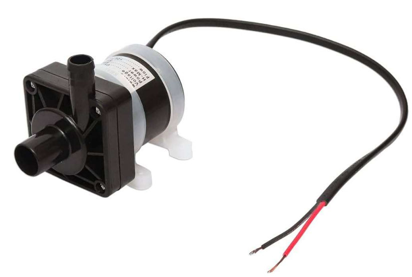

Figure 11: Water Pump DC 12V

It enables the robot to spray water to extinguish the fire. It is powered by the 12V battery and activated via a relay, playing a crucial role in the firefighting functionality of the robot.

Specifications:

- Voltage: 5–12V
- Flow Rate: ~120 L/h

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 5, No.1, May : 2025

- Current: ~0.3–0.6A

IR Flame Sensor:

Figure 12: IR Flame Sensor

It detects infrared radiation emitted by flames. It is used to detect fire in the robot's surroundings, helping the robot identify fire sources.

Specifications:

- Detection Range: 0–80 cm
- Detection Angle: ≤ 60°
- Output: Digital (HIGH/LOW)

IR Obstacle Sensor :

Figure 13: IR Obstacle Sensor

It detects nearby objects and helps the robot avoid obstacles, ensuring smooth navigation during its firefighting mission.

Specifications:

- Range: 2–30 cm
- Output: Digital
- Voltage: 3.3–5V

Ultrasonic Sensor (HC-SR04) :

Figure 14: Ultrasonic Sensor (HC-SR04)

It measure the distance between the robot and obstacles. This helps the robot navigate around obstacles and avoid collisions while moving toward the fire.

Specifications:

- Range: 2cm – 400cm
- Accuracy: ±3mm
- Output: Echo & Trigger Pins

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 5, No.1, May : 2025

ESP32 :

Figure 15: ESP32 for wireless communication.

With embedded Wi-Fi and Bluetooth, the ESP32 delivers advanced wireless functionality. In this project, it enables wireless communication for remote control and monitoring of the Fire-Fighter Robot. Its dual-core processor and low power consumption make it ideal for real-time control and data transmission.

Specifications:

- Dual-core 32-bit processor
- Operating Voltage: 3.3V
- Supports: Wi-Fi & Bluetooth
- GPIOs: 30+

12V DC Battery :

Figure 16: 12V DC Battery

It provides the necessary power to operate the robot's motors, sensors, and other components. It ensures the robot can function autonomously during firefighting operations.

Specifications:

- Type: Li-ion / Lipo / 12V Battery
- Output Voltage: 7.4V – 12V
- Capacity: 2000–5000 mAh
- Rechargeable: Yes

BUZZER FIGURE:

Figure 17: Buzzer for alerting.

The Buzzer is used to alert the operator when a fire is detected or when the robot requires attention. It provides an audible signal, ensuring the operator is immediately aware of the robot's status or any critical events. 4.3 Software Components

Specifications:

- **Type**: Passive Buzzer / Active Buzzer (based on your model)
- **Operating Voltage**: 3.3V – 5V

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 5, No.1, May : 2025

- **Sound Output**: ~85 dB @ 10 cm
- **Frequency Range**: 2–5 kHz
- **Current Consumption**: ~20 mA
- **Interface**: Digital (ON/OFF control via GPIO)

PROGRAMMING/SOFTWARE :

Figure 18: PlatformIO IDE in Visual Studio Code.

The firefighting robot's control logic is implemented using PlatformIO, specifically designed for the Teensy 4.1 microcontroller. The code structure is modular and event-driven, promoting organized programming and efficient management of different tasks.

PlatformIO is a versatile development framework tailored for embedded systems, offering advanced features for coding, debugging, and deployment. The programming is done in C/C++, which ensures high performance, fast responsiveness, and reliability—key factors for real-time robotic applications. This design enables seamless communication between the robot's sensors, motors, and other hardware components, allowing it to detect fires, navigate towards the source, and activate its extinguishing system effectively.

Additionally, PlatformIO IDE integrates with Visual Studio Code, providing a robust environment for embedded development. It supports a wide range of microcontroller platforms, libraries, and debugging tools, making it an excellent choice for developing complex embedded systems.

```
final
C: > Users > RITIK RAJ > Downloads > final
// Fire-Fighting Robot Code (Teensy 4.1)
#include <DHT.h>

// Pin Definitions
#define FLAME_SENSOR A0
#define TRIG_PIN 9
#define ECHO_PIN 10
#define MOTOR_A1 2
#define MOTOR_A2 3
#define MOTOR_B1 4
#define MOTOR_B2 5
#define DHT_PIN 6
#define WATER_PUMP 7
#define BUZZER 8

// Constants
#define FIRE_THRESHOLD 300  // Adjust this based on testing
#define OBSTACLE_DISTANCE 10  // Stop if obstacle is closer than 10 cm

// Sensor & Actuator Setup
DHT dht(DHT_PIN, DHT11);
unsigned long lastDistanceCheck = 0;

// Function to Measure Distance
float getDistance() {
    digitalWrite(TRIG_PIN, LOW);
    delayMicroseconds(2);
    digitalWrite(TRIG_PIN, HIGH);
    delayMicroseconds(10);
    digitalWrite(TRIG_PIN, LOW);
    float duration = pulseIn(ECHO_PIN, HIGH, 30000);  // Timeout in case of no response
    return (duration > 0) ? (duration * 0.0343) / 2 : 999;  // If no response, return large value
}

void moveForward() {
```

Figure 19: IDE Programing.

IMPLEMENTATION:

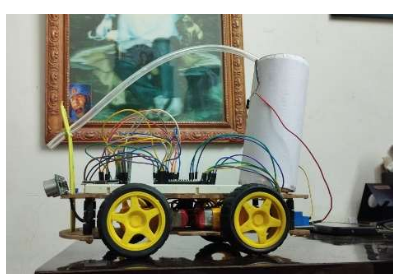

Fig.20. Fire-Fighting Robot

The implementation phase of the "Fire-Fighter Robot Using Teensy 4.1" encompasses the complete integration of hardware components, control logic, and real-time decision-making algorithms. The system is developed to function autonomously—detecting fire, navigating towards its source, extinguishing it, and broadcasting live data. The Teensy 4.1 serves as the main computational hub, managing the real-time coordination between various modules.

SYSTEM INITIALIZATION AND POWER SUPPLY:
The system is powered by a 12V rechargeable Li-ion battery pack, ensuring portability and sufficient runtime for field deployment. Upon activation, the Teensy 4.1 initializes all connected peripherals and performs a self-check to verify the status of sensors, motor drivers, communication modules, and actuators. Initial sensor readings and boot status are displayed on the OLED screen, which serves as a user interface for debugging and monitoring. This ensures that all subsystems are responsive before entering the autonomous operational loop.

FIRE DETECTION SUBSYSTEM:
Accurate fire detection is essential to the robot's operation. To achieve this, the system incorporates multiple infrared flame sensors that respond to IR radiation emitted by flames. Additionally, a DHT11 module monitors ambient temperature and humidity, enabling environmental validation. The combination of thermal and radiation-based sensing improves detection accuracy while minimizing false alarms caused by non-flame heat sources.When the IR flame sensors detect a significant infrared signature within their range and angle of sensitivity, and if the ambient temperature exceeds a predefined threshold (e.g., 45°C), the system confirms the presence of fire. This triggers the robot's transition from monitoring to active mode. The robot also emits an audible alert via the buzzer to notify nearby individuals.

NAVIGATION AND OBSTACLE AVOIDANCE:
Once fire is detected, the robot engages its navigation algorithm to approach the fire source safely. The robot's movement is controlled by BO (Battery Operated) geared motors, which provide torque and stability for motion over indoor terrain. These motors are driven by an L298N motor driver, interfaced with the Teensy 4.1.
The path-planning is assisted by two types of sensors:
1.Ultrasonic Sensors (HC-SR04): Measure the distance to obstacles ahead using the echo time of ultrasonic pulses.
2.IR Obstacle Sensors: Detect proximity to objects using infrared reflection, ideal for short-range side detection.
Based on the feedback from these sensors, the Teensy dynamically calculates the safest and shortest path to the fire. If an obstacle is detected in the robot's intended path, the robot reroutes itself using an avoidance algorithm (e.g., right-hand rule or basic A logic, depending on implementation complexity).

FIRE SUPPRESSION MECHANISM :
After successfully navigating to the fire source, the robot initiates its suppression mechanism. A submersible water pump, mounted on the chassis and connected to a compact water tank, is activated via a relay module controlled by the Teensy. Operates as an electromechanical switching device, providing high current to the pump when triggered.
To direct the water accurately, the nozzle is attached to a servo motor that can sweep across a defined arc. This sweeping action allows the robot to cover a broader area with water, ensuring efficient fire suppression. The robot continues spraying until flame detection sensors register that the infrared radiation and temperature have returned to normal levels, indicating that the fire is extinguished.

WIRELESS MONITORING AND IOT INTEGRATION:
For remote monitoring and future scalability, an ESP32 Wi-Fi module is incorporated into the system. It transmits live sensor data, system status, and real-time alerts to a cloud server or mobile dashboard.

This allows remote supervision, making the robot suitable for applications in hazardous or inaccessible areas. Additionally, logs can be stored for post-event analysis or training machine learning models for predictive fire detection. The OLED display mounted on the robot shows live data such as sensor readings, motor status, and fire detection alerts. This is particularly useful during on-site testing and debugging.

SAFETY AND ALERT SYSTEM:

To enhance situational awareness, a buzzer is used for auditory alerts during critical events such as fire detection, navigation errors, or system failure. This alert system acts as an immediate notification mechanism for human responders near the operating zone

RESULT :

To evaluate its capabilities, the developed fire-fighting robot was examined under controlled conditions, focusing on flame detection, extinguishing effectiveness, autonomous navigation, and hardware functionality. The outcomes were documented through iterative testing and real-time operational analysis.

FIRE DETECTION ACCURACY :

The robot was evaluated across 20 trials using IR flame sensors to detect a controlled flame (candle). The system successfully detected fire in 19 out of 20 trials, achieving a 95% accuracy. The flame was detected at distances ranging from 1 to 1.5 meters, with an average detection time of 1.8 seconds.

FIRE SUPPRESSION EFFICIENCY :

The water pump to extinguish the fire. The suppression mechanism was successful in 17 out of 20 trials**,** giving an 85% success rate. Failures occurred due to misalignment or insufficient water pressure. The average time taken to extinguish the flame was 4.2 seconds**.**

Trial	Fire Detected?	Time to Detect(sec)	Fire Extinguished?	Time to Extinguish (sec)
1	Yes	1.6	Yes	4.0
2	Yes	1.9	Yes	4.3
3	Yes	1.8	Yes	4.2
4	Yes	1.7	Yes	4.1
5	Yes	2.0	No	-
6	Yes	1.8	Yes	4.2
7	Yes	1.6	Yes	4.0
8	Yes	1.7	Yes	4.1
9	Yes	1.9	Yes	4.4
10	Yes	1.8	Yes	4.3
11	Yes	1.7	Yes	4.1
12	Yes	2.1	No	-
13	Yes	1.8	Yes	4.2
14	Yes	1.9	Yes	4.3
15	Yes	1.7	Yes	4.0

Trial	Fire Detected?	Time to Detect(sec)	Fire Extinguished?	Time to Extinguish (sec)
16	Yes	1.6	Yes	4.1
17	Yes	1.8	Yes	4.2
18	Yes	1.9	No	-
19	Yes	1.8	Yes	4.2
20	No	-	No	-

Table 1. Fire Detection & Suppression Data

NAVIGATION AND OBSTACLE AVOIDANCE :

The robot was placed in an arena with multiple obstacles simulating real-world indoor conditions. Using ultrasonic and IR sensors, it navigated successfully in 18 of 20 attempts, achieving a 90% success rate. On average, it reached the flame in 6.5 seconds. Failures were observed due to narrow gaps (<15 cm) between obstacles.

Trial	Navigation Successful?	Time to Reach Flame (sec)
1	Yes	6.5
2	Yes	6.2
3	Yes	6.3
4	Yes	6.4
5	Yes	6.6
6	Yes	6.5
7	Yes	6.2
8	Yes	6.3
9	Yes	6.4
10	Yes	6.5
11	Yes	6.3
12	Yes	6.2
13	Yes	6.4
14	Yes	6.5
15	Yes	6.3
16	Yes	6.2
17	Yes	6.4
18	No	-
19	Yes	6.3
20	No	-

Table 2. Obstacle Navigation Data

GRAPHICAL DATA ANALYSIS :

Average Time Comparison

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 5, No.1, May : 2025

A bar graph shows a comparison between average detection and suppression times across all trials.

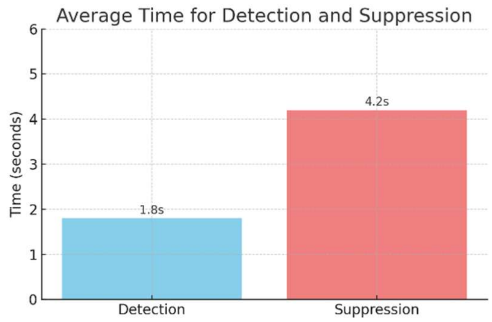

Fig.21. Detection time: 1.8 sec | Suppression time: 4.2 sec.

SUCCESS RATE OVERVIEW:

A pie chart was created to represent the success rates in three critical performance areas: fire detection, suppression, and obstacle navigation.

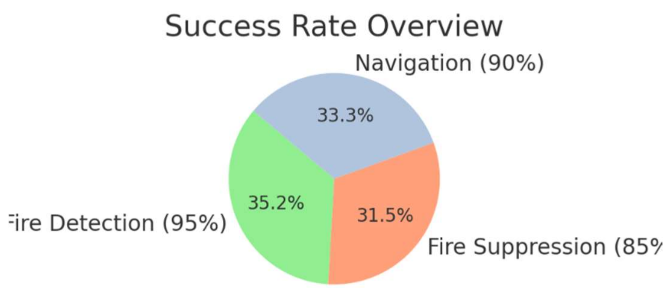

Fig.22. Detection: 95% | Suppression: 85% | Navigation: 90%

OBSERVATIONAL SUMMARY

- **Teensy 4.1** provided stable real-time processing without lags.
- **DHT11** recorded consistent ambient temperatures (25–35°C), but wasn't directly used for suppression logic.
- The **water pump** operated with moderate pressure, suitable for small-scale fires.

CONCLUSION :

The proposed work describes the systematic design, prototyping, and integration fire-fighting robotic system using the Teensy 4.1 microcontroller. The system is aimed at detecting and extinguishing fires in hazardous environments without human intervention. It includes four key modules: fire detection (using IR flame sensors and a DHT11 temperature sensor), autonomous navigation (using ultrasonic and IR sensors with DC motors for movement), fire suppression (via a relay-driven water pump), and wireless monitoring (using an ESP32 for real-time updates over Wi-Fi). The Teensy 4.1 microcontroller manages data acquisition, motor control, and communication, providing efficient operation. Experimental tests demonstrated accurate fire detection, stable navigation, and effective fire suppression. The system offers a scalable, cost-effective solution for early-stage fire mitigation, with future improvements potentially including machine learning, computer vision, and long-range communication features.

FUTURE SCOPE :

 Integration of computer vision for enhanced fire and smoke detection using AI-based image processing.
 Implementation of machine learning algorithms for smart and adaptive decision-making.
 Deployment of swarm robotics for coordinated firefighting in large areas.
 Autonomous mapping and real-time path planning using SLAM and advanced navigation techniques.
 GSM or **LoRa communication** for **long-range alerts**, along with **GPS-based location sharing** to notify emergency responders in real-time

REFERENCES:

[1] C. P. Jain, D. Agarwal, H. Lalawat, J. Pareek, D. Shrimali, and D. Kaithwas, “design of fire fighting robotic system for fire disaster control,” *Int. J. Tech. Res. Sci.*, vol. 2454, no. 2024, pp. 18–23, Apr. 2025, doi: 10.30780/specialissue-ISET-2024/004.

[2] S. Milmile, A. Verma, A. Somkuwar, S. Dhote, K. Bhajgaware, and C. Khandekar, “Design of fire fighting robot using IOT,” *Int. J. Prog. Res. Eng. Manag. Sci. (IJPREMS)*, vol. 4, no. 2, pp. 264–268, 2024, doi: 10.58257/IJPREMS32698.

[3] J. Deore, P. Zalte, D. Waghchaure, P. Shelke, and S. G. Tathe, “Arduino based fire fighting robot,” *Int. J. Innov. Res. Manag. Prof. Sci.*, vol. 12, no. 1, 2024.

[4] K. Vibha, B. Hemalatha, K. Sudha, and M. A. Mohamed Ahnaf, “Fire fighting robot using Internet of Things (IoT) for various temperature levels,” *J. Propuls. Technol.*, vol. 45, no. 2, 2024.

[5] N. K. Choudhari, S. Ponnamanda, G. Deshbhratar, A. Gajbhiye, S. Chaudhari, and S. Harde, “Fire fighting robot,” *Int. J. Sci. Res. Sci. Eng. Technol.*, vol. 10, no. 2, pp. 514–518, 2023, doi: 10.32628/IJSRSET2310287.

[6] H. P. Singh, A. Mahajan, N. Sukavanam, V. Budhraja, S. Singh, A. Kumar, and A. Vashisht, “Control of an autonomous industrial fire fighting mobile robot,” *DU J. Undergrad. Res. Innovat.*, vol. 10, no. 2, pp. 1–10, 2023.

[7] J. Sathe, V. Raut, R. Peddapelli, J. Waghchaure, and V. W. Bembrekar, “Design and development of fire fighting robot,” *Int. Res. J. Eng. Technol. (IRJET)*, vol. 10, no. 5, 2023.

[8] M. P. Suresh, D. K., V. R. Vedha Rhythesh, and J. Manikandan, “An Arduino Uno controlled fire fighting robot for fires in enclosed spaces,” in *Proc. 6th Int. Conf. I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC)*, 2022, pp. 398–402.

[9] A. Sheikh, G. Purohit, V. C. Raut, R. R. Abdul, and C. H. Kidile, “Review paper on Arduino based fire fighting robot,” *Int. J. Res. Appl. Sci. Eng. Technol. (IJRASET)*, vol. 10, no. V, 2022.

[10] R. Karthick, K. Loganathan, H. B. Shankar, M. Chandrustar, and M. Elaiyaguru, “Automatic fire sensing and exhausting robot,” *J. Electron. Inf. Technol. Sci. Manag.*, 2022.

[11] M. Rasheduzzaman, A. H. Gulib, A. Awal, and S. M. G. Mostafa, “Development and implementation of fire fighting robot,” *J. Adv. Res. Dyn. Control Syst.*, vol. 12, no. 07-Special Issue, pp. 818–825, 2020, doi: 10.5373/JARDCS/V12SP7/20202173.

[12] N. Albassam, S. A. Hussain, and J. Khan, “IoT based autonomous fire suppression system for vehicles,” in *Proc. Int. Conf. Emerg. Trends Inf. Technol. Eng. (ic-ETITE)*, 2020, pp. 1–5.

[13] S. S. Al-Ghadani and C. Jayakumari, “Innovating fire detection system fire using artificial intelligence by image processing,” *Int. J. Innov. Technol. Explor. Eng. (IJITEE)*, vol. 9, no. 11, 2020.

[14] Z. Ye, F. Su, Q. Zhang, and L. Wan, “Intelligent fire-fighting robot based on STM32,” in *Proc. IEEE Int. Conf. Mechatronics Autom. (ICMA)*, 2019, pp. 3369–3374.

[15] A. Q. M. S. Sayyed, M. D. T. Hasan, S. Mahmood, and A. R. Hossain, “Autonomous fire fighter robot based on image processing,” in *Proc. IEEE TENSYMP and ASTRO*, 2019, pp. 100–104.

[16] N. Savitha and S. Malathi, “A survey on fire safety measures for industry safety using IoT,” in *Proc. Int. Conf. Commun. Electron. Syst. (ICCES)*, Coimbatore, India, 2018, pp. 1199–1204, doi: 10.1109/CESYS.2018.8723930.
[17] M. Vanitha, M. Selvalakshmi, and R. Selvarasu, “Monitoring and controlling of mobile robot via internet through Raspberry PI board,” in *Proc. 2nd Int. Conf. Sci. Technol. Eng. Manag. (ICONSTEM)*, 2016, pp. 462–466.
[18] T. Rakib and M. A. R. Sarkar, “Design and fabrication of an autonomous fire fighting robot with multisensor fire detection using PID controller,” in *Proc. 2nd Int. Conf. Electr. Comput. Commun. Eng. (ECCE)*, 2016, pp. 1–6.
[19] M. S. Nagesh, T. V. Deepika, S. Michahial, and M. Shivakumar, “Fire extinguishing robot,” *Int. J. Adv. Res. Comput. Commun. Eng.*, vol. 5, no. 12, 2016.
[20] T. L. Chien, H. Guo, K. L. Su, and S. V. Shiau, “Develop a multiple interface based fire fighting robot,” in *Proc. IEEE Int. Conf. Mechatronics*, Kumamoto, 2007, pp. 1–6.amoto, 2007, pp. 1–6.