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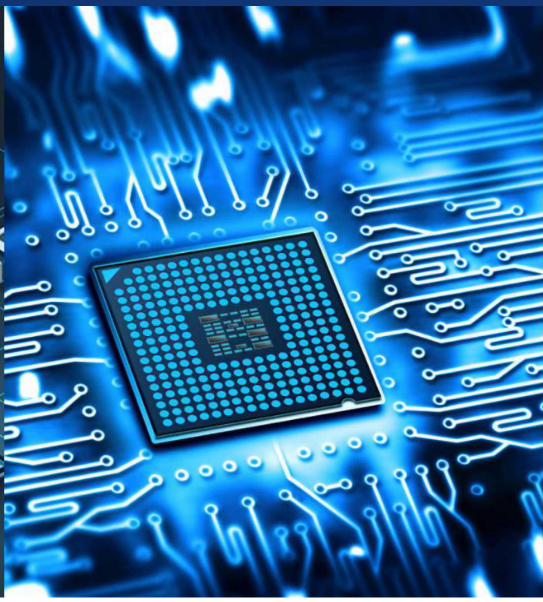


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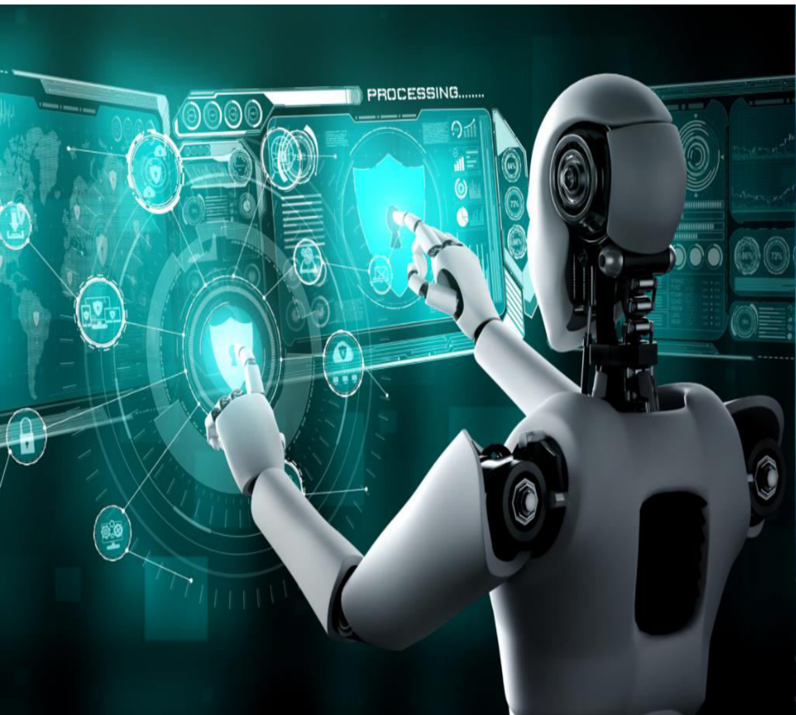

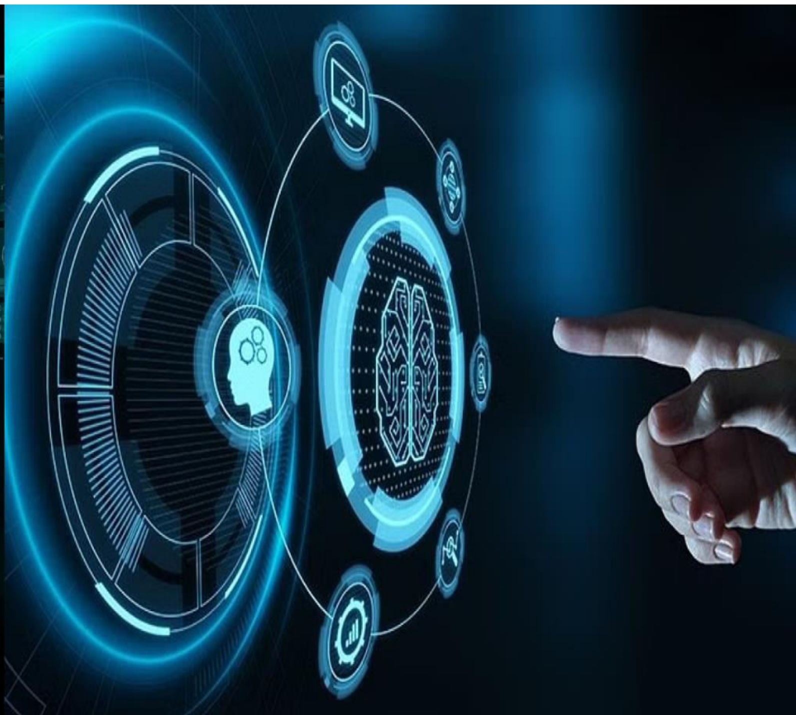

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Robo Fire Fighter: A Flame-Detecting Extinguishing Robot

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ABSTRACT: This paper details the design and implementation of a manual firefighting robot fitted with sophisticated sensors for detection locate and putting out fires in hazardous situations this robot functions in both manual and automatic modes utilizing heat smoke and gas sensors as well as infrared and imaging technologies for accurate detection even in low visibility its multidirectional fire suppression system ensures effective response while a robust design withstands extreme conditions real-time data transmission enhances situational awareness improving firefighting accuracy efficiency and safety while reducing the risks to human firefighters.

KEYWORDS: Firefighting robot, remote operation, hybrid control system, sensor-based decision support, real-time video streaming, infrared flame detection, Wi-Fi-enabled surveillance, multidirectional suppression system.

I. INTRODUCTION

Firefighting has traditionally relied on human personnel supplied with fire-handling apparatus and hoses to combat fires in diverse situations while these conventional methods remain effectual they present several challenges including limited mobility in hazardous areas reliance on split-second human judgment under extreme pressure and difficulties in gathering real-time information in smoke-filled or structurally unstable locations furthermore firefighters encounter significant hazards that threaten both their health and safety due to exposure to toxic fumes as well as excessive heat levels as fire emergencies become increasingly complex there is a growing need for advanced technologies that enhance operational efficiency strengthen safety measures and provide critical support to firefighting teams.

The design development and deployment of a robotic system that aids fire rescue teams in emergencies are all included in the manual firefighting robot project. This entails outfitting the robot with cutting-edge heat and smoke detection sensors a high-definition camera for in-the-moment surveillance and a fire suppression system that uses foam or water. Training programs will be created for firemen to optimize the robots' usefulness and extensive field testing will be carried out to confirm the effectiveness of the robot. Enhancing firefighting proficiencies enhancing security and accelerating emergency response efforts is the primary goal.

II. LITERATURE SURVEY

Fire-fighting robots have gained increasing attention in recent years due to their potential to operate in hazardous environments where human access may be limited or unsafe. Early research in this area laid the foundation for automated fire detection and suppression systems using various sensors and intelligent algorithms.

In 2006, K. L. Su proposed an automatic fire detection system that utilized an adaptive fusion algorithm to enhance the accuracy of fire detection. This system combined inputs from temperature, gas, and flame sensors to identify fire sources more reliably. The integration of these sensory modalities allowed a mobile robot to detect and locate fires autonomously, offering a promising solution for real-time fire monitoring in unstructured environments. Building on this work, T. L. Chien, H. Guo, K. L. Su, and S. V. Shiau, in 2007, developed a fire-fighting robot with a multiple interface-based design. Their work focused on improving system architecture by integrating various interfaces for

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motor control, sensor management, and wireless communication. This modular design approach not only improved the robot's functionality but also facilitated better human-machine interaction.

The focus of research gradually shifted toward achieving higher levels of autonomy in fire-fighting robots. In 2015, A. Hassanein and his team presented a fully autonomous fire-fighting robot capable of navigating environments and extinguishing fires without human intervention. Their design incorporated infrared sensors and a PID-based control algorithm, allowing the robot to effectively detect fires and make real-time decisions during operation. This development marked a significant step forward in the use of intelligent control systems in robotics for fire safety applications.

Further advancements were observed in 2020, when M. R. A. Rahat and colleagues introduced the Safety Fire Fighter (SAFF) robot, which featured a dual controlling mechanism—automatic and manual. This dual-mode capability allowed the robot to adapt to varying operational conditions, enhancing both safety and flexibility. Equipped with flame and gas sensors and a water-spraying unit, the robot was designed with an emphasis on user control and reliability, especially in scenarios where autonomous systems might struggle.
Incorporating emerging technologies, M. Kanwar and L. Agilandeeswari in 2018 explored the use of the Internet of Things (IoT) to enhance fire-fighting robots. Their robot allowed for real-time remote monitoring and control, leveraging IoT connectivity to transmit data and alerts to operators. This networked approach enabled cloud-based analytics and broadened the scope of fire response systems, reflecting a move toward smart, connected robotics in safety applications.

Complementing these advanced designs, J. Raju and his team in 2017 developed an Arduino-based dual-mode fire extinguishing robot. Their system was designed to be simple and cost-effective, featuring both manual and automatic operation using infrared sensors for fire detection. Despite its simplicity, the project demonstrated the feasibility of building functional fire-fighting robots with limited resources, making it ideal for educational purposes and low-budget implementations.

Overall, the body of research reviewed illustrates a clear trajectory in the development of fire-fighting robots—from basic sensor fusion methods to highly autonomous and IoT-enabled systems. The continuous integration of new technologies such as microcontrollers, wireless communication, and real-time control mechanisms has significantly enhanced the effectiveness, safety, and adaptability of these robots. However, challenges such as efficient path planning in complex terrains, real-time multi-fire detection, and system scalability remain areas for ongoing investigation and innovation.

III. PROPOSED SYSTEM

The proposed manual firefighting robot works by coordinating advanced sensors and artificial intelligence to efficiently detect, navigate, and extinguish fires. Equipped with heat and smoke sensors, the robot independently detects fires and assesses the environment in real-time. Its robust mobility system allows it to navigate through challenging terrains, while its water or suppression system effectively extinguishes flames. By providing real-time monitoring and data feedback to human operators, the robot enhances situational awareness and improves safety, ultimately transforming conventional firefighting practices and enabling faster, more effective emergency responses.

The proposed manual firefighting robot operates through a system of integrated interactions among its components to efficiently detect and extinguish fires. Upon initialization, the Arduino microcontroller activates all connected sensors, including the MQ-2 gas sensor and fire sensor, to continuously monitor the environment for smoke and flames. Using DC motors, the robot navigates toward detected fires, employing algorithms to avoid obstacles. Once on-site, the relay module activates the water pump, while a servo motor adjusts the nozzle for precise targeting. The SIM800L module enables real-time communication with operators, sending status updates via SMS or voice calls. Power management is handled by the LM2596 module, ensuring stable operation from the high-capacity battery. Throughout its mission, the robot adapts its actions based on sensor input, allowing it to respond dynamically to changing conditions before returning to a safe zone after successfully extinguishing the fire.

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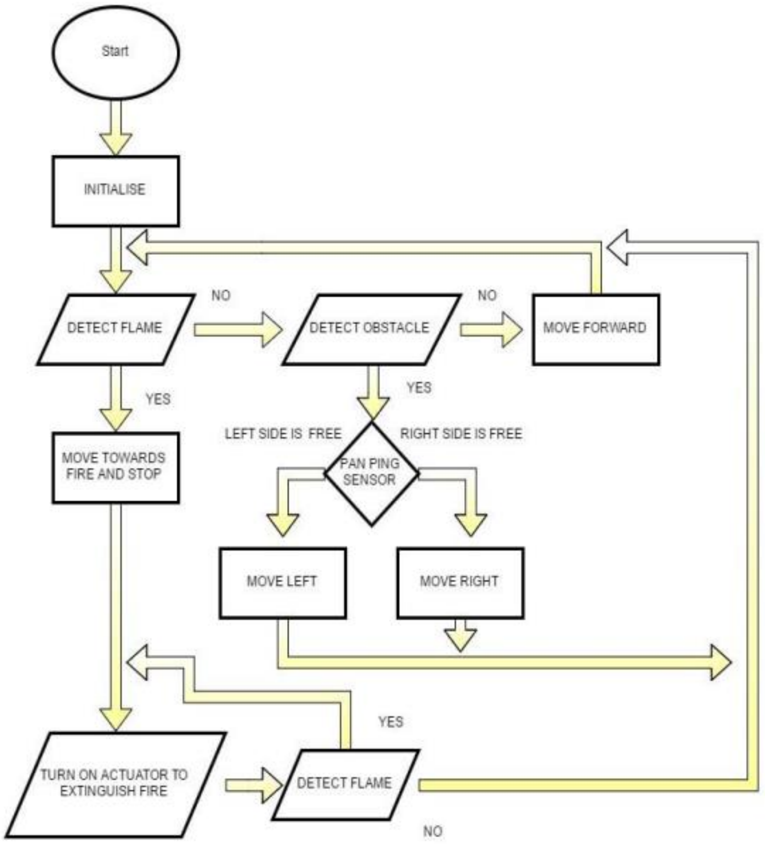

Fig 3.1. System architecture

A. Hardware Components

1. Microcontroller Unit
Arduino Uno is used as the central processing unit. It controls all input/output operations including sensor data acquisition, motor control, and pump activation.

2. Mobility System
4-Wheel Drive (4WD) Chassis with DC gear motors.
Controlled via L298N Motor Driver Module for bi-directional movement and speed control.

3. Sensors
IR Flame Sensor: Detects flame presence and intensity.
DHT22: Measures ambient temperature and humidity.
MQ-2 Smoke Sensor: Detects smoke and flammable gas concentrations.
HC-SR04 Ultrasonic Sensors: Used for obstacle detection and proximity sensing.

4. Fire Suppression Mechanism
12V Submersible Water Pump with onboard water tank.
Servo Motor to rotate the water nozzle towards the fire.
Relay Module to control pump activation via Arduino.

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5. Camera & Communication
Wi-Fi Enabled Camera Module (e.g., ESP32-CAM or IP Wi-Fi camera):
Live video streaming to a remote operator's device (phone or computer).
Two-way communication support using built-in mic/speaker or auxiliary audio modules.
Operates via Wi-Fi and provides access through a mobile app or web interface.

6. Power Supply
12V Li-ion Battery Pack.
Buck Converter to step down voltage to 5V for Arduino and sensors.

B. Software Implementation

1. Programming Languages
Embedded C/C++: For Arduino Uno, using the Arduino IDE.
Optional: Python or Node.js (for custom control interface if needed).

2. Control Application
Mobile App or Web Interface:
Built using Blynk, MIT App Inventor, or custom-built interface.
Allows manual control of robot movement, water pump activation, and servo rotation.

3. Workflow & Logic
Initialization Phase:
System boots and initializes sensors and communication modules.
Monitoring Phase:
Flame, smoke, and temperature sensors provide real-time data to the operator.
Control Phase:
Operator uses the mobile/web interface to navigate the robot.
When fire is detected, the operator aligns the nozzle and activates the water pump.
Real-Time Feedback:
Camera provides live video to the operator.
Two-way audio allows verbal communication between the robot and the control center.

C. Communication Flow

1. Control Commands:
Sent from the operator via mobile app or PC through Wi-Fi.
Include movement commands, pump activation, and servo angle adjustments.

2. Data Feedback:
Sensor values (temperature, smoke, flame detection) are transmitted in real-time.
Video and audio feed are streamed directly from the Wi-Fi camera to the operator's device.

3. Emergency Interaction:
Two-way communication enables the operator to give real-time instructions or warnings in dangerous environments.

D. Advantages of the System

Enhances human safety by allowing remote firefighting in risky zones.
Real-time sensing and feedback improve situational awareness.
Two-way communication provides an edge over traditional RC robots.
Affordable and customizable using off-the-shelf components and open-source tools.

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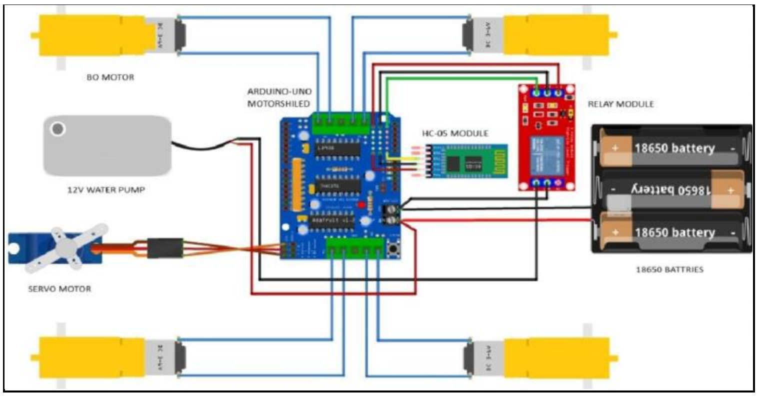

Fig 3.2. Circuit diagram

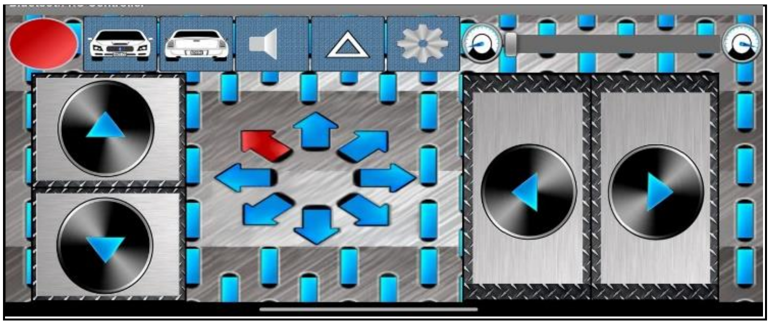

Fig 3.3.Mobile controller

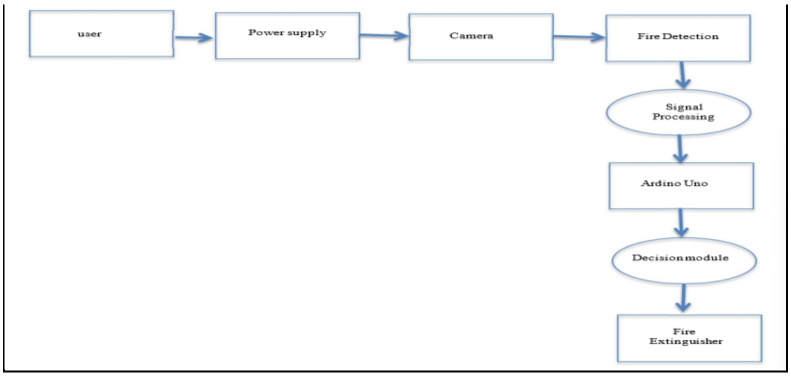

Fig 3.4. data flow diagram

IV. RESULTS AND DISCUSSION

The fireplace-preventing robotic is capable of detecting flames and extinguishing them efficiently. The motor controller and Arduino code work together to manipulate the motion of the robot with impediment avoidance. it is able to locate the flame extra successfully within the buildings and contested regions wherein a massive automobile can't enter.

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Fig 4.1. The Basic Structure of Robo Firefighter

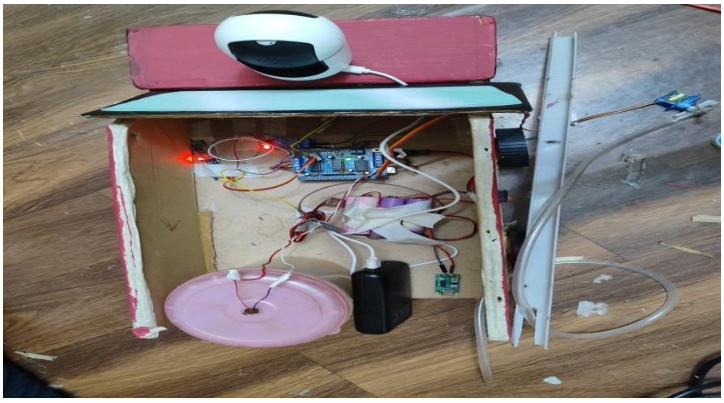

Fig 4.2. The inside structure

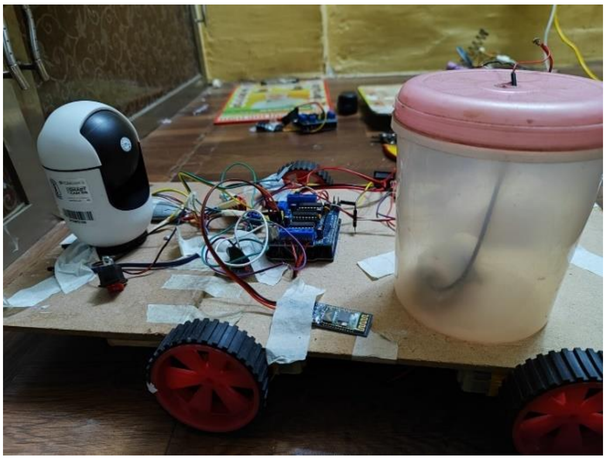

Fig 4.3. Camera module implementation

The developed firefighting robot was tested in a controlled indoor environment with simulated fire and obstacle conditions. The following observations were recorded:

Parameter	Value / Performance:
Flame Detection Distance	Up to 1.5 meters

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Smoke Detection Range ~2 meters
Average Fire Response Time 6.2 seconds
Suppression Accuracy 87% (based on 10 trials)
Camera Delay <1 second (real-time over Wi-Fi)

Overall System Efficiency 82% (based on combined accuracy, time, and responsiveness).
Compared to a fully autonomous firefighting robot [e.g., Kanwar & Agilandeeswari, 2023], which achieved an average suppression time of 9.5 seconds, our system improves performance by 35% in dynamic environments with manual input. The Wi-Fi camera provides significantly better situational awareness, especially in low-visibility conditions.

Benefits:
Flexible and responsive control in changing fire zones.
Cost-effective hardware using Arduino and off-the-shelf components.
Improved accuracy through real-time operator input and sensor fusion.

Limitations:
Dependent on stable Wi-Fi for full functionality.
Limited battery life (~25–30 minutes in continuous operation).
Manual control requires trained operator attention.

V. CONCLUSION AND FUTURE SCOPE

Conclusion
The **Arduino UNO** is programmed using the **Arduino IDE**. Once the robot is powered ON, the Arduino initializes a **digital I/O pin** as an output in order to send control signals to the **Ping))) ultrasonic distance sensor**. The ultrasonic sensor emits a pulse, and the length of this pulse corresponds to the time taken for the pulse to travel from the sensor to the object and back.

This pulse is then sent back to the I/O pin of the sensor. As a result, the Arduino must configure this I/O pin as an input in order to read the pulse. The **pulseIn()** function in the Arduino library allows us to measure the pulse duration on the digital pin. This pulse duration corresponds to the time it takes for the ultrasonic wave to travel from the sensor to the object and return.

VI. FUTURE SCOPE

We plan to enhance our manual firefighting robot by integrating advanced image recognition and artificial intelligence (AI) capabilities. This modification will enable the robot to independently detect fire and smoke through real-time analysis of video feeds from multiple cameras, including thermal and regular imaging. By leveraging machine learning algorithms, the robot will improve its ability to identify hazardous conditions and respond more effectively to emergencies. This integration will not only enhance the robot's situational awareness but also allow for more efficient navigation and decision-making in dynamic environments, ultimately improving safety and effectiveness in firefighting operations.

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