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Firefighting Robot with Flame and Gas Detection

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ABSTRACT

Fire hazards pose a serious risk to life, property, and the environment, particularly in industrial, residential, and laboratory settings. Traditional firefighting methods often endanger human personnel due to exposure to extreme heat, toxic gases, and unstable conditions. This project presents the design and development of a Firefighting Robot with Flame and Gas Detection, aimed at improving fire safety through automated hazard detection and suppression. The system integrates an Arduino Uno microcontroller with flame and gas sensors (MQ-2) for real-time monitoring, a Bluetooth module (HC-05) for wireless control, and a servo-driven water pump for targeted fire extinguishing. The three-wheeled chassis, powered by DC motors and controlled via a motor driver (L298N), ensures mobility in confined spaces. Upon detecting flames or hazardous gases, the robot activates a buzzer to alert the operator and initiates the suppression mechanism. The modular design allows for scalability and potential integration of autonomous navigation and advanced imaging systems in future iterations. This work demonstrates a compact, cost-effective, and efficient firefighting solution that minimizes human risk while ensuring rapid and precise fire response in hazardous environments.

Keywords: Firefighting robot, Flame detection, Gas detection, Arduino Uno, Bluetooth control, Autonomous fire suppression

I. INTRODUCTION

Fire incidents pose a significant threat to life, property, and the environment, often escalating rapidly due to the presence of flammable materials and toxic gases. Traditional firefighting methods require human intervention, exposing firefighters to extreme heat, hazardous smoke, and potentially explosive gases. To mitigate these risks, the integration of robotics and sensor-based technologies has emerged as an innovative solution. One such advancement is the development of a Firefighting Robot with Flame and Gas Detection, designed to detect, monitor, and suppress fires while minimizing human exposure to danger. This robot is engineered to operate in hazardous environments by combining mobility, sensory detection, and fire suppression mechanisms in a single autonomous or remotely controlled platform. It utilizes flame sensors to identify fire sources through infrared radiation detection and gas sensors (such as MQ-2) to monitor harmful gases like smoke, LPG, and carbon monoxide. Upon detecting a hazard, the system activates a buzzer to alert users and triggers a servo-controlled water pump to extinguish the flames with precision targeting. The robot's movement is facilitated by a three-wheeled chassis powered by DC motors and controlled via an Arduino Uno microcontroller. The inclusion of an HC-05 Bluetooth module allows wireless control from a smartphone or computer, enabling the operator to navigate the robot toward the hazard from a safe distance. A motor driver module (L298N) manages directional movement, while a relay module safely controls the high-power water pump. The modular design ensures flexibility for upgrades, such as autonomous navigation or the integration of advanced thermal imaging sensors.

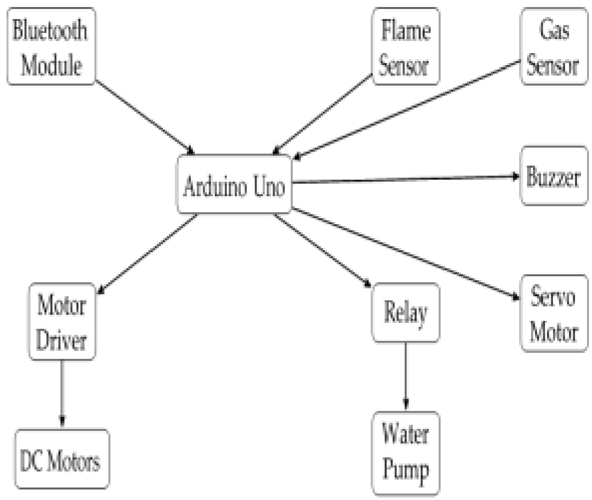

Figure 1: Block Diagram of Firefighting Robot

This system addresses two key aspects of firefighting: early hazard detection and rapid response. By providing real-time monitoring of flames and gases, the robot enhances situational awareness and enables prompt suppression before the fire spreads. Its portability and compact design make it particularly suitable for small-scale applications, including residential buildings, laboratories, and industrial facilities. In essence, the Firefighting Robot with Flame and Gas Detection represents a practical, cost-effective, and safe firefighting solution. By merging robotics, sensor technology, and wireless communication, it offers a significant step toward reducing human risk while improving the efficiency and precision of fire management operations.

II. LITERATURE REVIEW

Advancements in robotics and sensor technology have spurred the development of firefighting robots capable of detecting flames and hazardous gases, enhancing safety and response effectiveness.

Li et al. (2022) developed a flame-detection model using thermal imaging combined with the YOLOv4-F algorithm. Their system enables swift and accurate flame recognition, particularly useful in obscured or smoke-filled environments. Similarly, Tohti, Zhang, and Geni (2023) addressed challenges in flame recognition caused by environmental lighting and processing speeds. They proposed a convolutional neural network-based classifier improved by preprocessing and dual-signal flame sensor calibration, delivering faster flame recognition in challenging lighting conditions.

In the realm of integrated sensing, Boopalan et al. (2018) presented a robot outfitted with a vision camera and gas sensors capable of detecting carbon dioxide, carbon monoxide, and flames. Controlled via Arduino and Wi-Fi, the system also supports remote monitoring via live video feeds—offering both fire and toxic gas alert functionality. Building on multi-sensor fusion, a recent study described an intelligent fire-fighting robot combining RGB and infrared thermal imaging with improved path-planning using an ACO variant. This approach enables autonomous patrolling and precise fire source localization under complex conditions.

In broader AI-based detection, Narkhede et al. (2021) utilized multi-modal AI sensor fusion—combining a gas sensor array with thermal imaging. Their fused model achieved 96% accuracy in identifying gas types, superior to single-sensor approaches, underscoring the efficacy of integrated sensing. The use of autonomous ground vehicles in real-world firefighting scenarios was showcased by Jindal et al. (2021). Their robot, deployed in urban high-rise firefighting challenges (MBZIRC 2020), integrated thermal cameras, autonomous navigation, and a water-ejection mechanism, demonstrating both precise fire detection and suppression capabilities. Another notable application is detailed by Sen Li et al. (2023), who developed an indoor autonomous inspection and firefighting robot that integrates SLAM (Simultaneous Localization and Mapping) with flame image recognition. The robot performs autonomous navigation indoors and identifies fire sources using image processing.

III. RESEARCH METHODOLOGY

The Firefighting Robot operates as follows:

The methodology for the development and operation of the Firefighting Robot with Flame and Gas Detection integrates several hardware components, sensors, and control systems to ensure effective and autonomous operation in hazardous environments. This section outlines the detailed process through which the system operates, focusing on each critical component's functionality and interaction with the overall system.

1. Initialization Process:

Upon system startup, the Arduino Uno microcontroller initializes all the essential components. The microcontroller acts as the central processing unit, setting up the motor driver (L298N), Bluetooth module (HC-05), flame sensor, gas sensor (MQ-2), water pump, servo motor, and buzzer. During this phase, the robot enters a standby mode, awaiting external input from the operator or sensor-triggered commands. The initialization ensures that the components are ready for responsive action, with the microcontroller acting as the command center to process inputs from both sensors and external commands.

2. Bluetooth Control:

The robot's movement and functionality are controlled remotely through the HC-05 Bluetooth module, which receives commands from a connected smartphone or computer. The Bluetooth module communicates wirelessly with the Arduino, sending commands for various actions such as movement directions (Forward, Backward, Left, Right), stop commands, and speed adjustments. The Arduino processes these commands and relays them to the L298N motor driver, which controls the two DC motors that drive the robot's wheels. The speed of the robot can be adjusted through Bluetooth commands (+/-), enabling the user to navigate the robot efficiently through hazardous areas.

3. Flame Detection:

The flame sensor continuously scans for infrared radiation emitted by fire sources. As a fire is detected, the flame sensor sends a signal to the Arduino, which then triggers the buzzer to alert the user about the presence of fire. This early detection system is designed to operate even in low-visibility conditions, where flames may be the first indicator of an emergency. The Arduino processes the sensor input and immediately responds to activate the appropriate safety measures.

4. Gas Detection:

The MQ-2 gas sensor is integrated into the system to detect hazardous gases such as smoke, LPG, and carbon monoxide. The sensor continuously monitors the surrounding environment for gas concentration levels. If the detected gas levels exceed a predefined threshold, the Arduino activates the buzzer to alert the operator about the potential danger. This gas detection mechanism works in conjunction with the flame detection system to provide a multi-sensor approach to hazardous environment monitoring.

5. Fire Suppression Mechanism:

Upon detection of a fire, the robot enters an active firefighting mode. The Arduino triggers a relay module to activate the water pump, which is responsible for extinguishing the detected fire. The pump is coupled with a servo motor that rotates the nozzle, directing water toward the fire source with precision. This feature enhances the robot's ability to target fires accurately, providing efficient suppression with minimal resource wastage. The integration of servo motors allows for more control over the water delivery process, ensuring that the water reaches the fire directly, even in confined or hard-to-reach spaces.

6. Speed Control:

The speed of the robot is an essential aspect of its operation, especially in navigating through complex or dangerous environments. The speed is adjustable through Bluetooth commands, where the user can increase or decrease the speed based on the environment's demands. Pulse Width Modulation (PWM) is used to control the speed of the DC motors. The predefined speed range is between 50 (minimum speed) and 100 (maximum speed). This feature ensures that the robot can move at a controlled pace in different scenarios, from quick navigation in open spaces to slow and precise movement when approaching fire sources.

7. Debugging Mode:

To facilitate troubleshooting and improve the system's performance, the robot includes a debugging feature accessible via the Serial Monitor on the Arduino IDE. In debug mode, real-time feedback is provided, including information on the commands being processed, the current speed of the robot, and the status of movement. This mode helps the researcher or operator identify and resolve issues promptly by providing visibility into the internal processes and operations of the robot.

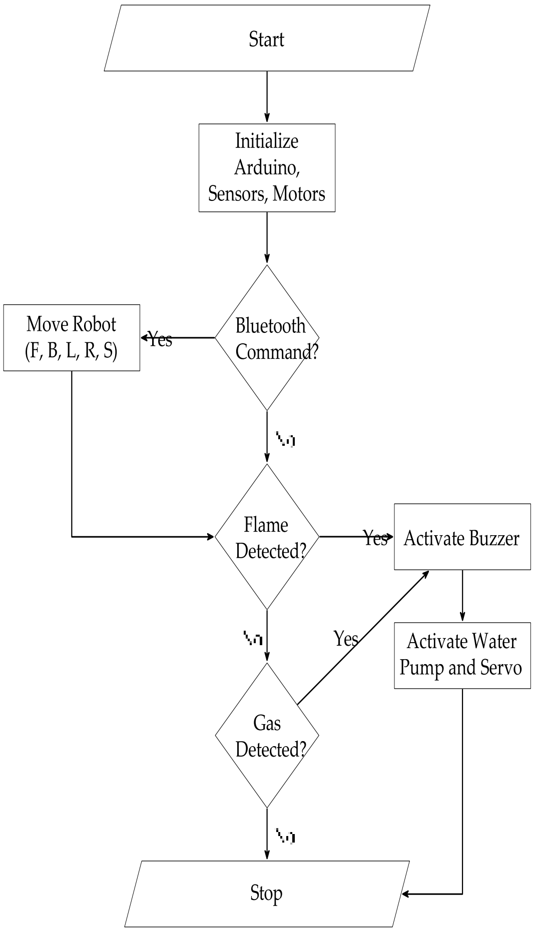

Figure 2: Flowchart of Firefighting Robot Operation

IV. MARERIAL AND METHODS

This table outlines the components and their functions in the Firefighting Robot system. The core components include the Arduino Uno microcontroller, flame and gas sensors for hazard detection, and the motor and water pump mechanisms for fire suppression. The system also includes a Bluetooth module for remote control, a servo motor for targeting the water spray, and a relay module for safely controlling high-power components. The entire setup is powered by a Li-ion battery, ensuring mobility and operational efficiency. The robot's performance is validated through functional tests, ensuring seamless integration of all components for effective firefighting in hazardous environments.

Table 1: Material and Methods for Firefighting Robot with Flame and Gas Detection

Component	Description
Microcontroller	Arduino Uno: The central control unit that processes signals from sensors and controls actuators such as motors, water pump, and buzzer.
Flame Sensor	IR-based sensor that detects flames by sensing infrared radiation emitted by fire. The sensor triggers the buzzer upon detection.
Gas Sensor	MQ-2 sensor: Detects harmful gases such as smoke, LPG, and carbon monoxide. The sensor sends signals to the Arduino when gas levels exceed a threshold.
Bluetooth Module	HC-05: Enables wireless communication between the robot and a smartphone/computer for remote control and navigation commands.
Motor Driver	L298N: Controls the DC motors, enabling the robot's movement (forward, backward, left, right) based on received Bluetooth commands.
DC Motors	Two DC motors that provide mobility to the robot's three-wheeled chassis, powered by the L298N motor driver.
Water Pump	A pump used to extinguish the detected fire. Controlled by the Arduino via a relay module to ensure the water is dispensed accurately.

Component	Description
Servo Motor	Used to rotate the water pump nozzle to target the fire source with precision during suppression.
Relay Module	Used to control high-power components like the water pump. Ensures safe operation by activating the pump when flame detection is triggered.
Buzzer	Emits an audible sound when a flame or hazardous gas is detected, alerting the user to the emergency.
Power Supply	Li-ion battery pack that powers all components, ensuring the robot operates for an extended period.
Speed Control	PWM (Pulse Width Modulation) control allows adjusting the speed of the DC motors, which can be modified remotely via Bluetooth commands.
Testing Setup	Prototypes are tested for functionality including sensor integration, motor control, and response to hazardous conditions. Performance evaluations are conducted.

V. RESULTS AND DISCUSSION

The results section presents the functional prototypes and assembly setups of the firefighting robot, highlighting key components such as flame and gas detection sensors, motor control systems, and power supply modules. Each figure illustrates the integration of these components for autonomous fire detection and extinguishing capabilities, along with mobility features. The prototypes were tested to ensure effective sensor integration, motor functionality, and response to hazardous conditions, supporting the robot's operational readiness for real-world applications in fire detection and suppression.

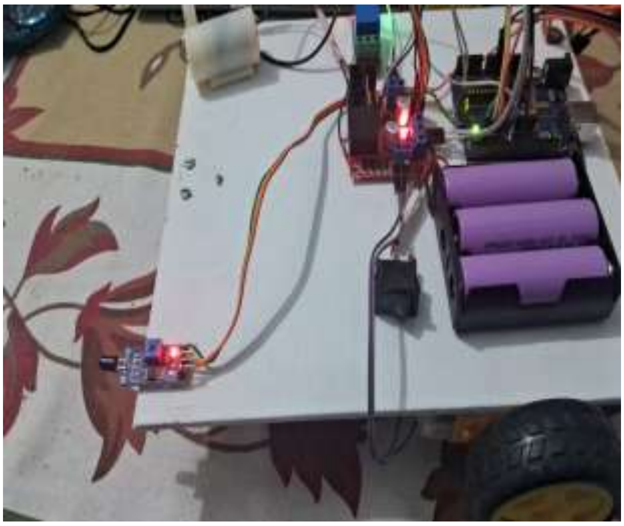

Figure 3: Prototype Setup of Firefighting Robot with Flame Detection and Power Supply Module

The figure shows the partial assembly of a firefighting robot, featuring a flame sensor connected to a microcontroller for fire detection. The setup includes a battery pack for power supply, motor driver circuitry for movement, and associated wiring for sensor integration. The components are mounted on a wheeled base, indicating readiness for mobility testing.

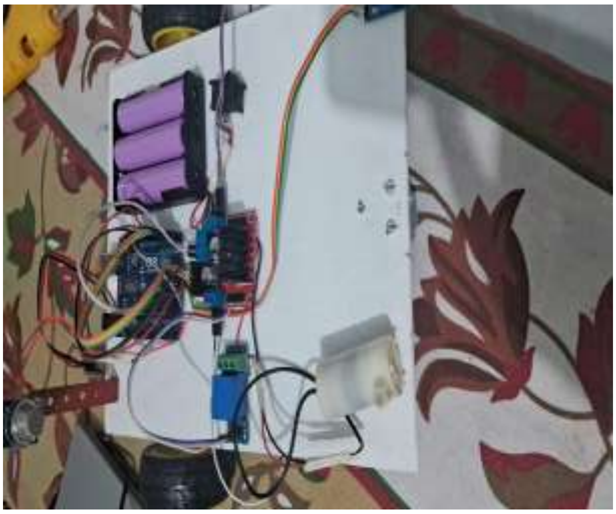

Figure 4: Prototype Assembly of Firefighting Robot with Flame and Gas Detection

The image shows the hardware setup of a firefighting robot, incorporating an Arduino Uno microcontroller, L298N motor driver, Li-ion battery pack, and water pump motor. The system is wired to enable flame and gas detection, motor control, and water spraying. This configuration serves as the core control and actuation unit for the robot’s autonomous firefighting operations.

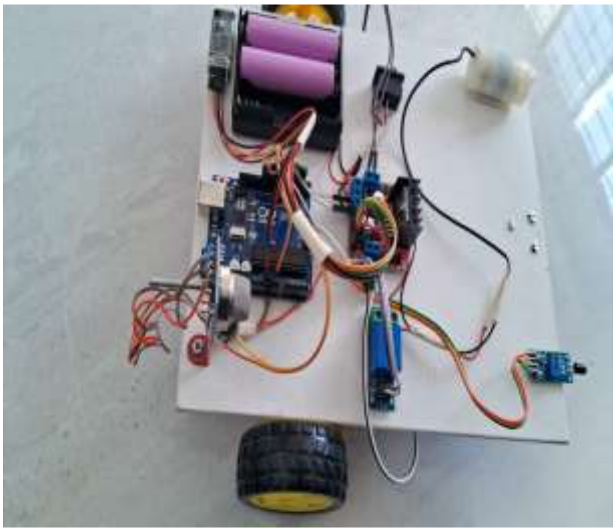

Figure 5: Prototype of Firefighting Robot with Flame and Gas Detection

The figure shows a wheeled robotic prototype equipped with various sensors and modules, including an Arduino microcontroller, flame sensor, gas sensor, motor driver, and rechargeable battery pack. The system is designed to detect fire and hazardous gases, enabling autonomous or remote-controlled firefighting operations. This arrangement demonstrates the integration of hardware components for real-time hazard detection and mobility.

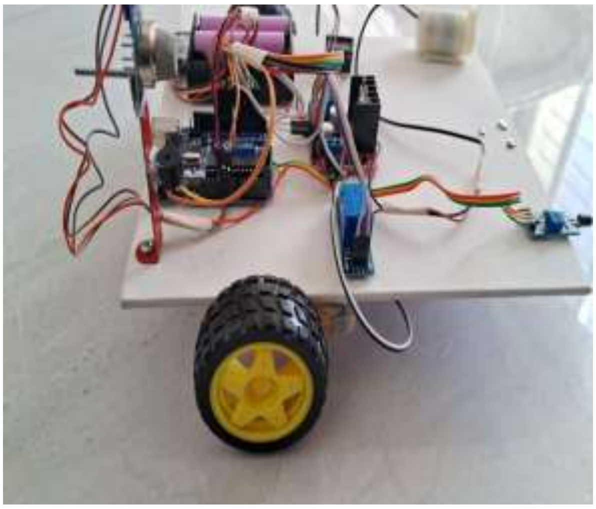

Figure 6: Prototype Firefighting Robot with Flame and Gas Detection

The figure shows a functional prototype of a firefighting robot equipped with flame and gas sensors, driven by a dual-wheel chassis. It uses an Arduino Uno microcontroller for sensor integration and control, along with a relay module for activating the extinguishing mechanism. The design enables autonomous fire detection and mobility for hazardous environment operations.

Figure 7: Detection of Nearby Bluetooth Classic Devices

The figure displays a list of detected Bluetooth Classic devices within range, along with their respective MAC addresses. The highlighted device "HLK_B50_0504_BT" is actively connected or selected, as indicated by the green highlight. This list helps identify and pair with specific devices for communication or data transfer.

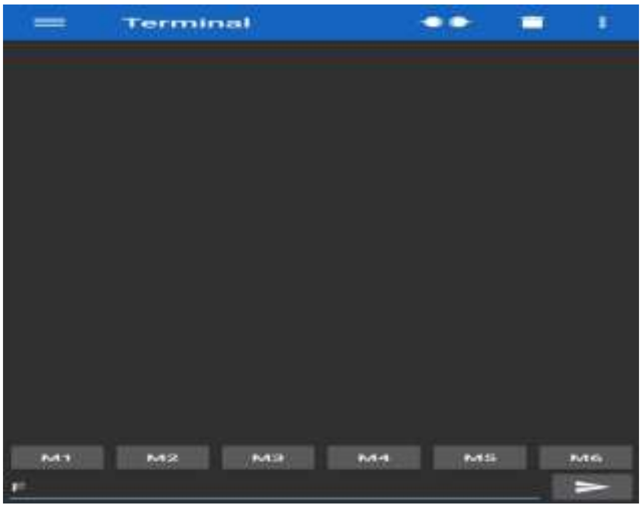

Figure 8: Terminal Interface with Function Keys

VI. CONCLUSION

The Firefighting Robot with Flame and Gas Detection represents a significant advancement in automated fire safety systems, offering an effective, safe, and reliable approach to hazard detection and suppression in high-risk environments. By integrating flame sensors for infrared fire detection and gas sensors for identifying harmful gases such as smoke, LPG, and carbon monoxide, the system ensures rapid identification of threats. Its Bluetooth-controlled chassis enables remote operation, allowing users to navigate the robot toward a hazard from a safe distance, thereby minimizing human exposure to extreme heat and toxic fumes. A servo-driven water pump provides targeted fire suppression, ensuring efficient use of extinguishing resources while improving the effectiveness of firefighting operations. The system's modular architecture not only simplifies assembly and maintenance but also offers a foundation for future enhancements. These could include autonomous navigation using GPS or LiDAR, AI-based flame recognition, integration of thermal imaging for improved detection accuracy, and additional environmental sensors for broader hazard monitoring.

Designed with adaptability in mind, the robot is suitable for small-scale applications such as residential complexes, laboratories, and industrial facilities, yet it can be scaled for larger operational demands. Overall, this project demonstrates the potential of combining robotics, sensor technologies, and wireless communication to create a compact yet powerful firefighting tool—one that enhances safety, reduces response time, and provides a versatile platform for future fire safety innovations.

VII. FUTURE SCOPE

The Firefighting Robot with Flame and Gas Detection presents numerous opportunities for future development, enabling it to become more autonomous, intelligent, and versatile. One key enhancement could be the integration of autonomous navigation using GPS, LiDAR, or Simultaneous Localization and Mapping (SLAM) technology, allowing the robot to identify the shortest and safest route to a fire source without human intervention. The addition of AI-based image processing and thermal cameras could improve detection accuracy, even in smoke-filled or low-visibility environments. Expanding the system's connectivity to include Wi-Fi or IoT-based communication would enable remote monitoring and control over long distances, allowing real-time data sharing with emergency services. Incorporating multiple fire suppression mechanisms, such as foam or dry chemical systems, would make the robot suitable for different types of fires. The robot could also be equipped with environmental mapping capabilities to log hazardous areas, aiding in post-incident analysis and preventive planning. For industrial applications, integration with automatic fire alarm systems could allow the robot to respond instantly to detected hazards. By adopting these advancements, the firefighting robot can evolve from a remote-controlled unit into a fully autonomous, intelligent fire response system capable of operating efficiently in a wide range of environments.

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