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Design and Implementation of an ESP32-Based Fire Extinguisher Robot for Mining Operations

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Abstract: This work involves developing a Bluetooth-controlled fire extinguisher vehicle using the ESP32 microcontroller, enhanced with a gas sensor for safety and autonomous operation. The vehicle is remotely controlled via a mobile device, thanks to the ESP32's Bluetooth functionality, allowing precise navigation and fire suppression. The ESP32 serves as the system's core, working alongside an L293D Motor Driver Shield, a fire sensor, and a water pump to control both movement and fire-extinguishing actions. A 3.3-5V submersible water pump with a 20cm pipe activates when fire is detected. In autonomous mode, the fire sensor enables the vehicle to detect and react to flames without user input. Control is achieved through a Bluetooth Terminal device, which connects to the ESP32 via Bluetooth. This allows the user to maneuver the vehicle, activate the pump, and monitor gas sensor data from a device. The vehicle is powered by batteries, with a custom PCB ensuring efficient power distribution. This work showcases the ESP32's capabilities in sensor integration and remote-control technology, emphasizing innovations in autonomous fire-fighting and safety.

Keywords: ESP32 Microcontroller, Gas Sensor (MQ-3), L293D Motor Driver Shield, Fire Sensor.

I. INTRODUCTION

Underground mining operations are inherently hazardous, posing a variety of risks such as fires, structural collapses, explosions, toxic gas leaks, and mechanical accidents, all of which jeopardize the safety and lives of miners. Ensuring safety in such high-risk environments requires the implementation of advanced systems capable of swiftly detecting and addressing potential dangers. Early warning systems that identify fire outbreaks and harmful gases are essential for minimizing accidents and protecting workers in underground mines. This paper introduces the development of a mini fire extinguisher robot, specifically designed to tackle fire hazards in underground mining environments, particularly within confined areas of mines. The robot is operated remotely through a mobile device, significantly reducing the need for human intervention in dangerous areas. This approach minimizes risks to human life while enhancing response times in fire emergencies. Outfitted with fire detection sensors and an MQ-3 gas sensor, the robot can detect both flames and hazardous gases in hard-to-reach mining locations. The heart of the system is an ESP32 microcontroller, which features integrated Wi-Fi and Bluetooth, enabling seamless communication between the robot and the operator's mobile device. This allows the operator to remotely control the robot's movements and fire-extinguishing mechanisms, facilitating the navigation of hazardous areas without requiring physical presence in dangerous zones. Real-time data transmission allows for continuous monitoring of environmental conditions, such as fire outbreaks and gas concentrations, enabling swift responses to emerging threats. Additionally, the robot's real-time feedback system enhances operational efficiency, offering critical insights that aid in rapid hazard detection and response. This work illustrates how remote-controlled robotic systems can significantly improve safety protocols in underground mining by reducing human exposure to dangerous conditions and advancing fire-fighting and gas detection technologies. These innovations are crucial for promoting safety and operational efficiency in the mining industry, particularly in environments where immediate intervention can save lives.

II. METHODOLOGY

A. Component use

This robot car integrates several critical components to ensure safe and efficient operation. At its core is the **ESP32 microcontroller**, recognized for its processing power and built-in Bluetooth, allowing for seamless remote control and data transfer to the operator. To detect fire hazards, the robot car is equipped with a **flame sensor** to identify flames and a **gas sensor** for early detection of harmful gases and smoke in the environment. This provides timely alerts and adds an extra layer of protection in hazardous environments. For fire suppression, the robot uses a **submersible water pump** that activates to spray water when flames are detected.

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B. Operation of The System

Once powered on, the system initializes the ESP32 microcontroller, establishing a Bluetooth connection with a compatible smartphone or remote-control device. This setup allows the operator to maneuver the robot toward potential fire hazards. Upon reaching the target area, the robot's fire and gas detection sensors continuously monitor the environment. The flame sensor identifies visible flames, while the gas sensor assesses air quality, ensuring that harmful gases are promptly recognized and addressed. In the event of a fire, the robot's suppression system can be operated through the connected devices. The operator can manually engage the submersible water pump, which sprays water directly onto the flames for effective extinguishing.

C. System Block Diagram and Flowchart

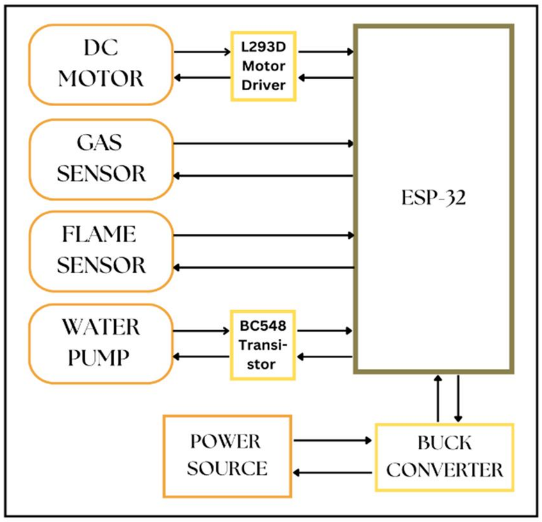


Figure 1: Block Diagram of Proposed System

Figure 1 illustrates the block diagram of the system, where various components are managed by the ESP32 microcontroller. The DC motor is powered by the L293D motor driver, enabling control over both motor direction and speed through an H-Bridge circuit. The gas sensor continuously monitors for hazardous gases, ensuring safety in the environment. The water pump is controlled via a BC548 transistor, which functions as a switch to activate the pump when necessary. Power for all components is efficiently regulated through a buck converter connected to the primary power source.

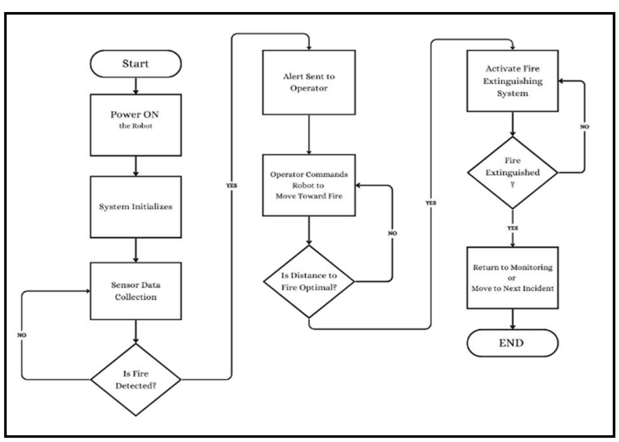


Figure 2: System Flowchart

In Figure 2, the system flowchart illustrates the operational sequence: the system powers on, collects sensor data, and detects fire hazards. The operator directs the robot toward the fire, and once within range, the fire-suppression system is manually activated. This cycle repeats until the fire is fully extinguished.

III. RESULT AND DISCUSSION

This section discusses the outcomes expected from the fire suppression robot, focusing on its ability to detect fire hazards and hazardous gases in dangerous environments. The system is designed to enhance safety by enabling remote operation and minimizing risks in high-risk zones like underground mining areas.

The ESP32 microcontroller successfully coordinates the entire system, with the L293D motor driver providing smooth control over the motor's direction and speed, allowing precise maneuvering of the robot. The gas sensor effectively detects hazardous gases, promptly sending alerts to the operator through the Bluetooth connection.

For fire suppression, the BC548 transistor reliably acts as a switch to activate the submersible water pump, which responds immediately upon the operator's command, spraying water to extinguish the flames. Power is efficiently managed by the buck converter, ensuring a steady supply to all components during operation.

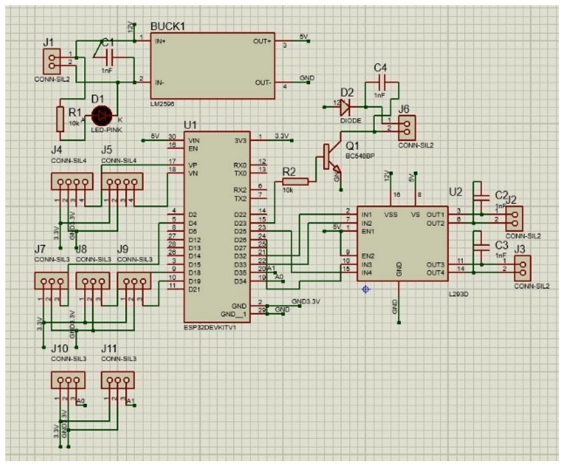
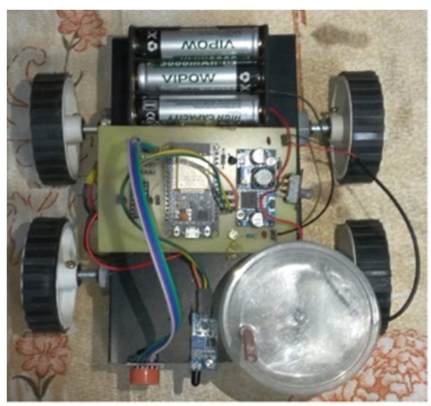
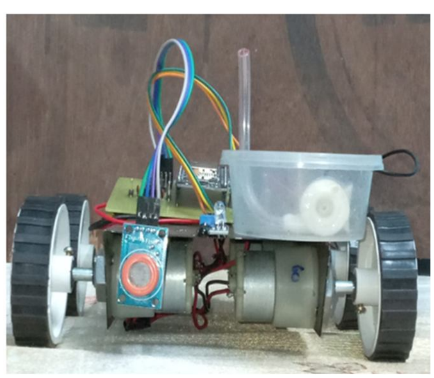


Figure 3: Connection of Proposed System



(i)



(ii)

Figure 4 (i), (ii): Top and Front View of Proposed System

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A. Control of the system

The system is operated through the Serial Bluetooth Terminal app, which allows the user to control the vehicle remotely via the Bluetooth functionality of the ESP32 microcontroller. By sending specific commands through the app, the operator can manage both the vehicle’s movements and the fire-extinguishing functions with ease.

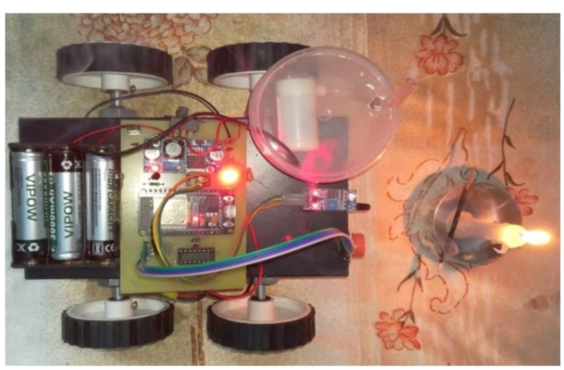
The control scheme is straightforward:

F: Move Forward
S: Stop the vehicle
R: Turn Right
L: Turn Left
W: Activate the water pump to extinguish fire
w: Deactivate the water pump

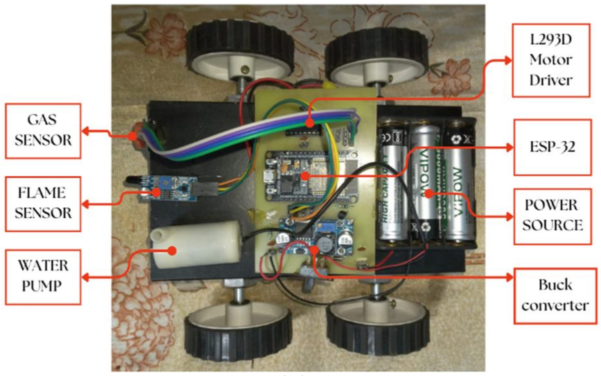
Figure 5: Control Interface on Bluetooth Terminal

B. Detection of Fire and Gas Hazards

The image depicts a demonstration of a remotely operated fire extinguisher vehicle utilizing an ESP32 microcontroller. In figure 6(i), the vehicle's configuration is visible, comprising essential components such as the battery-powered source, motor driver, water pump, and sensors for flame and gas detection. The water pump is connected to a small reservoir, prepared to dispense water upon fire detection. A lit candle simulates fire, triggering the flame sensor, while an incense stick is used to simulate the presence of harmful gases, activating the gas sensor. On the right, a smartphone displays real-time terminal outputs like "Fire Founded" and "Gas Founded," confirming successful hazard detection. This demonstrates the vehicle’s autonomous ability to recognize environmental dangers. With Bluetooth connectivity, the system allows for remote monitoring and control, ensuring prompt response to fire threats and enabling efficient suppression operations.



(i)



(ii)

Figure 6(i), (ii): Detection of Fire and Gas Hazards by the Vehicle

Figure 7: Component Layout of Proposed System

IV. CONCLUSION

This research presents the efficacious implementation of the ESP32 microcontroller in the development of a manually operated fire extinguishing robot, specifically designed for hazardous environments such as underground mines. The robot, equipped with fire and gas sensors in conjunction with a submersible water pump, provides a pragmatic solution for remote firefighting and monitoring, particularly in areas deemed too perilous or inaccessible for human intervention. The robot's precise locomotion is facilitated by an L293D motor driver, while real-time data transmission via Bluetooth technology ensures that operators can respond expeditiously to both fire and gas hazards, thereby mitigating risks. The system is powered by a lithium battery, with stable power regulation achieved through a buck converter and a custom-designed printed circuit board (PCB), ensuring reliable operation. This study underscores the potential of robotic systems in industrial safety applications, offering a cost-effective and scalable approach to enhance emergency response times and reduce human exposure to life-threatening hazards

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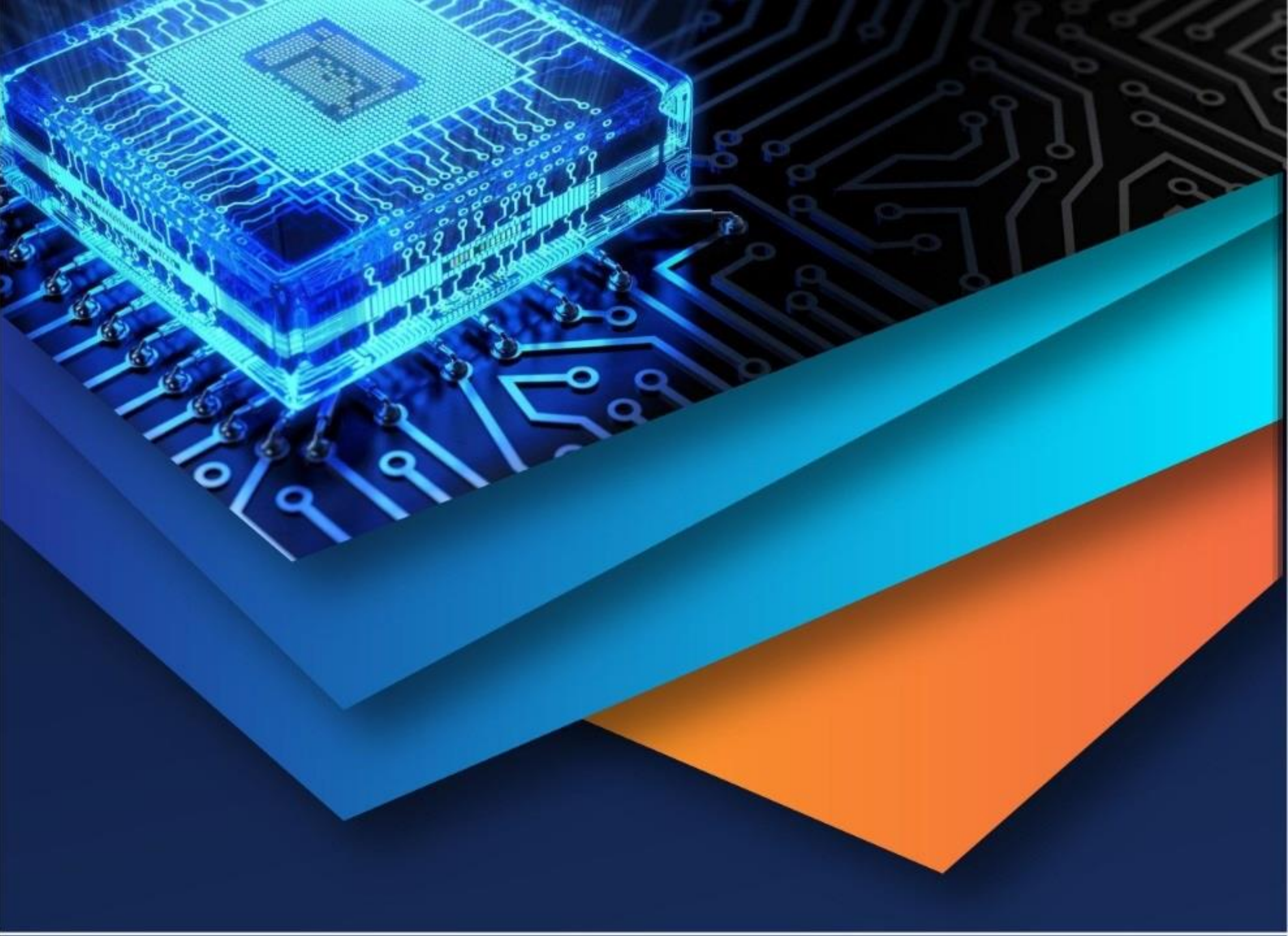

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