Design and Implementation of a Humanoid Firefighter Robot with Real-Time Monitoring and Firefighting Applications

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Abstract: In this paper, a mobile phone-controlled humanoid firefighter robot, with a Bluetooth speaker for announcements, and a camera for real-time monitoring is developed. The robot is designed to enhance firefighting efforts, particularly in environments that are hazardous or inaccessible to human firefighters. The robot can be remotely controlled via a mobile phone, utilizing Bluetooth connectivity to ensure reliable communication and maneuverability, enabling it to operate in intense fire conditions. The integrated BT speaker allows for critical announcements and communication during firefighting operations, enhancing coordination and safety. Equipped with a water delivery system, the robot can actively extinguish fires. The onboard camera provides a live feed to the operator, facilitating precise navigation and targeted firefighting. This robot aims to significantly improve the efficiency and safety of firefighting operations, providing a robust solution for tackling fires in challenging scenarios.

1 INTRODUCTION

One of the most hazardous and potentially life-threatening problems that contemporary civilization has is firefighting, and the Humanoid Firefighter Robot project intends to provide a solution to this problem. Firefighters are frequently put in situations where they are exposed to extreme dangers, such as high temperatures, poisonous gasses, collapsed structures, and restricted vision. These situations, in many instances, pose a substantial threat to the lives of human beings. We have built a firefighting robot that is capable of independently or remotely navigating fire-prone situations, detecting fire sources, and extinguishing flames, all while offering real-time monitoring and communication capabilities. This is done in order to limit these risks and give an alternative that is safer and more effective. The creation of a robot that is capable of performing vital firefighting operations in hazardous regions where human participation would be either too risky or ineffective is the primary purpose of this project.

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1.1 Objectives

The objectives of this project are –
1. Construct a Humanoid Robot That Is Fireproof: Construct a robot that is long-lasting in order to guarantee that it can function safely in high temperature conditions.
2. Integrate Real-Time Monitoring and Sensors: In order to provide precise fire detection and real-time video monitoring, the robot should be outfitted with thermal imaging cameras, gas detectors, and infrared sensors.
3. Utilize artificial intelligence and machine learning to achieve autonomous navigation and real-time decision-making in complicated fire scenarios. This is the third step in the implementation of autonomous navigation software.
4. Develop a Mobile Control Interface: In order to enable operators to move the robot, activate fire suppression systems, and make announcements, it is necessary to develop a mobile interface that allows for remote control.

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5. Improve Mobility and Power Management: Improve the robot's mobility for a variety of terrains and expand its operating range by optimizing the battery life and utilizing technologies that allow for long-range communication.

1.2 Industrial Applications

The Humanoid Firefighter Robot has a wide range of applications across civilian, industrial, military, and public sectors, where fire hazards pose serious risks to life and property. Equipped with advanced sensors, mobility systems, and fire-suppression capabilities, this robot can be deployed in various firefighting environments, reducing the need for human firefighters in dangerous situations. In densely populated urban areas, the robot can navigate burning buildings, detect hotspots with thermal imaging, and relay real-time data to human operators, assisting in effective firefighting. Its capabilities in high-rise buildings, where traditional firefighting equipment struggles, are particularly valuable. In industrial and chemical plants, the robot can operate safely around hazardous materials, gather data on gas levels and potential risks, and suppress fires with specialized firefighting tools, without putting human firefighters at risk. Beyond firefighting, the robot supports search and rescue in disaster zones, using thermal imaging to locate survivors in smoke-filled or collapsed areas and communicating with them via onboard systems to improve survival chances. In military scenarios, the robot's rugged design enables it to fight fires in harsh environments and hazardous areas without endangering personnel. Additionally, it can effectively prevent and manage fires in public infrastructure, such as airports and subway systems, where rapid response is critical. Overall, the Humanoid Firefighter Robot is a versatile solution that enhances safety and efficiency in firefighting and emergency response, marking a significant advancement in firefighting technology and supporting human rescuers with real-time feedback and high-risk exploration capabilities.

1.3 Review of Research Papers Published on Similar Hardware

The literature on firefighting robots highlights advancements in robotic systems designed to address the inherent risks of firefighting and rescue operations. Firefighting is inherently hazardous, and human firefighters face challenges when rescuing victims trapped in fire, prompting the development of robotic alternatives that can either operate autonomously or be controlled remotely. Early research focused on robotic structural design, control systems, and environmental detection algorithms, with advancements in each area enabling robots to locate and extinguish fires, assist in navigation, and enhance situational awareness through sensory feedback. Recent innovations include unmanned aerial vehicles (UAVs) for forest and high-rise firefighting, including tethered drones with mixed propulsion systems for maneuverability. Various robotic prototypes, like Qrob and Thermite RS series, can operate in confined spaces and providing real-time data through advanced sensor integration. These robots are designed with features such as stair-climbing abilities, high-temperature resistance, and compatibility with fire extinguishing systems, making them suitable for environments where human intervention is too dangerous. The robots' structural resilience, diverse locomotion systems, and water jet capabilities underscore their adaptability to different firefighting scenarios, from high-density urban fires to industrial and military applications (1).

2 HARDWARE DESCRIPTION

2.1 Components used

This Humanoid Firefighter Robot has several different components that allow it to autonomously explore hazardous settings, identify fires, and provide water to extinguish them. Additionally, it can provide real-time monitoring and communication capabilities.

The ESP8266 microcontroller (Figure 1) serves as the central processing unit, which is responsible for directing the activities of the robot as well as handling the input from sensors and the output to motors, the water system, and communication modules and other components. The data that is gathered by the sensors is processed, decisions are made on the appropriate actions (such as moving toward a fire source or making announcements), and signals are sent to the motors, water system, and BT speaker. ESP8266 is a WiFi-enabled microcontroller board that uses the ESP8266 chip, designed to simplify the development of Internet of Things (IoT) applications

Figure 1: Microcontroller (ESP8266).

The robot has a Bluetooth (BT) speaker , which is designed to be used for the purpose of making announcements while firefighting operations are being carried out. During an emergency, the speaker can broadcast warnings, instructions, or updates to humans in the surrounding area, which ultimately helps improve coordination. The microcontroller is responsible for activating the speaker whenever the robot detects critical conditions, such as very high temperatures (2).

Figure 2: Bluetooth Speaker.

In order to make real-time monitoring and navigation possible, an ESP32-based camera (Figure 3) has been attached. It will offer the remote operator with a live video feed, which will enable them to do manual supervision whenever it is required. Additionally, the camera is beneficial to the robot's ability to navigate autonomously since it enables it to visually recognize obstructions, fire sources, and other significant environmental cues (3).

Figure 3: Camera (ESP32).

An RC receiver and transmitter are included in the water supply system (Figures 4, 5, 6) that the robot is equipped with. This technology allows for remote activation of the robot. If the robot detects a fire, it has the capability to activate the water pump, which applies water to the fire in order to put it out. The TP4056 Power Bank Module Type-C is a compact circuit board engineered to charge single-cell lithium-ion 1200mAh batteries using a USB power source (4).

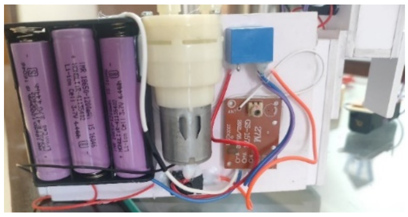

Figure 4: Water pump and receiver circuit.

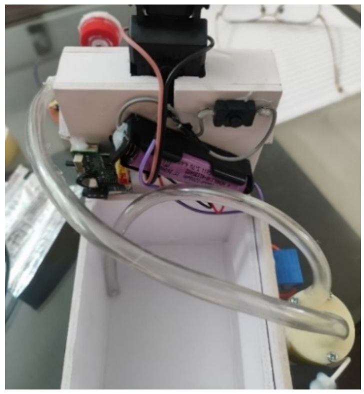

Figure 5: Water tank.

Figure 6: Transmitter.

5V DC servomotors (Figure 7) are utilized by the robot for the purpose of movement and dexterity. These servomotors provide for precise control over the robot's locomotion. The wheels or tracks of the robot are driven by these motors, which can speed up to one hundred revolutions per minute. This enables the robot to traverse a variety of terrains and are controlled by the L289 motor drive (Figure 8), which supplies the required power and signal modulation for effective movement. This allows for more efficient movement. The microprocessor sends low-power signals to the motor drive, which then translates those signals into high-power impulses that are used to operate the robot's motors. It is imperative that this component be present to guarantee a fluid and responsive movement (5).

Figure 7: 5V DC Servomotor.

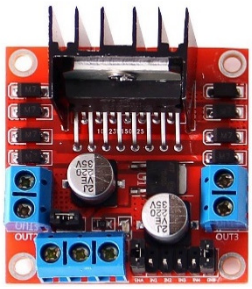

Figure 8: L289 Motor Drive.

The sturdy yet lightweight chassis supports all components, and wheels or tracks can be chosen based on the terrain, allowing adaptability to different surfaces encountered during firefighting tasks. This flexibility, paired with precise motor control, enhances the robot's ability to maneuver in challenging environments. The robot's design creates a unified firefighting system capable of responding to high-risk situations with minimal human involvement. By incorporating sensors, cameras, communication modules, and an efficient water delivery system, the Humanoid Firefighter Robot reduces the need for human presence in hazardous areas while providing real-time situational awareness and responsive firefighting capabilities (6).

2.2 Connectivity

Fig 2.9 illustrates a detailed wiring diagram for a basic robotic system that utilizes the NodeMCU ESP8266 microcontroller and the L298N H-Bridge motor driver module. The NodeMCU is the brain of the setup, responsible for controlling the motors, which in turn manages the direction and speed of the motors. A 9V battery powers the entire system, including the motors and the microcontroller.

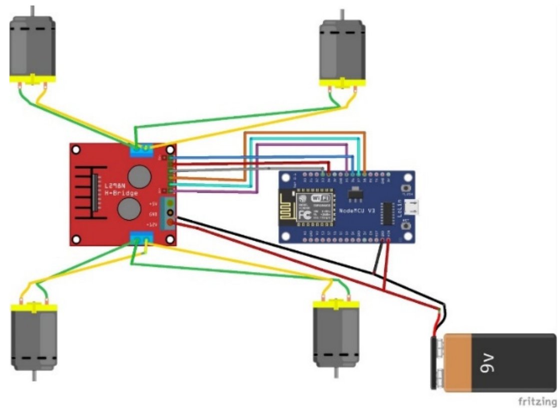

Figure 9: Connectivity Diagram.

NodeMCU ESP8266 Positioned on the right side of the diagram, the NodeMCU microcontroller plays a central role in controlling the robot. It communicates with the L298N motor driver via multiple GPIO pins. These connections allow the microcontroller to send signals to control the motor direction and speed. The NodeMCU is also powered by the 9V battery, connected through the GND and VIN pins.

L298N Motor Driver is responsible for controlling the motors based on the input received from the NodeMCU. The motor driver has multiple pins connecting to the NodeMCU (in various colors in the diagram). The connections include: o IN1, IN2, IN3, IN4: These pins receive signals from the NodeMCU to control the motors' forward or backward movement. o Enable Pins: These control the speed of the motors by varying the input voltage using PWM (Pulse Width Modulation). o The +12V, GND, and +5V pins are connected to the power source and the NodeMCU to ensure consistent voltage flow.

Four DC motors are used in the setup, two for the left side and two for the right. Each pair is connected to the L298N motor driver, which manages their rotation direction and speed. The wiring from the motors to the H-Bridge allows bidirectional control, meaning the robot can move forward, backward, and turn left or right by controlling the motor pairs. A 9V battery provides the necessary power for both the NodeMCU and the motors. The positive terminal is connected to the +12V input of the L298N motor driver, while the negative terminal is grounded and connected to both the motor driver and the NodeMCU to ensure a common ground.

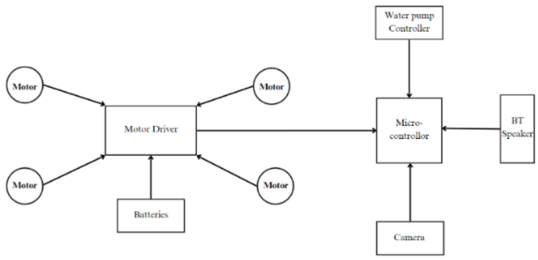

Figure 10: Working flowchart.

2.3 Software

The RC FPV and ESP8266 WiFi Robot Car apps (Figure 11) are integral to the operation of the firefighting robot, enabling it to function effectively in complex environments. The ESP8266 WiFi Robot Car app, designed to operate over a WiFi connection, facilitates seamless remote control of robots using the ESP8266 microcontroller, making navigation and movement intuitive and responsive. This app handles key functions such as guiding the robot's movements, controlling motors, and ensuring precise manoeuvrability in challenging settings. Meanwhile, the RC FPV app provides essential real-time video streaming from the robot's camera, allowing operators to assess situations safely from a distance, a crucial feature in firefighting where visibility is often compromised by smoke and flames. Both applications are fully integrated into the robot's hardware to ensure uninterrupted communication and control. This integration is critical to establishing a responsive and user-friendly interface, allowing operators to manage the robot effectively in real-world firefighting scenarios. By leveraging these apps, the robot can be guided with minimal latency, enhancing situational awareness and operational efficiency while keeping human operators safe. This combination of applications ensures fast, reliable communication, precise handling, and real-time feedback—all vital for effective emergency response. The intuitive interface not only aids in navigation and control but also significantly enhances both the efficiency and safety of firefighting operations (7).

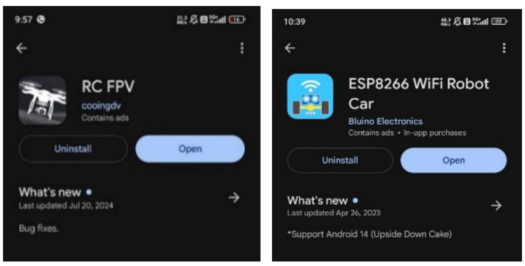

Figure.11: Applications used for control and monitoring.

3 RESEARCH METHODOLOGY

3.1 Component Selection, Assembly and Integration

Developing the firefighting robot began with selecting specialized components that would support its core functions. The team chose the versatile ESP8266 microcontroller, known for its WiFi capability, to enable effective remote control. A range of sensors including thermal imaging, gas detection, and infrared was integrated to enhance environmental awareness and fire detection. Mobility was ensured using 5V DC servomotors powered by an L298 motor driver, with a 1200mAh lithium-ion battery supplying necessary power. To protect against extreme heat, the robot was coated with a fireproof layer, and an RC-controlled water delivery system was added for firefighting capabilities.

The assembly process involved constructing a durable chassis that could endure tough conditions. Motors were mounted with precision to enable smooth movement, and sensors were positioned for maximum environmental coverage. Extra care was taken to secure connections, particularly for motor drivers and sensors, along with added fireproofing and insulation to handle high temperatures. A Bluetooth speaker was included for emergency audio alerts, enhancing the robot's communication abilities (8).

Software development followed, focusing on control algorithms, a user-friendly interface, and mobile app integration for seamless remote operation. With the ESP8266 WiFi Robot Car software, the team enabled mobility functions, while real-time video streaming was achieved through the RC FPV app, allowing operators to monitor the robot's surroundings with minimal latency (9).

3.2 Testing, simulation and Calibration

The final development stages involved extensive testing, fine-tuning, and simulations to ensure the robot's readiness for real-world firefighting. The sensors were carefully calibrated to deliver accurate readings of temperature and gas levels, and mobility tests showed that the robot could navigate around obstacles and in confined spaces effectively. Through simulated firefighting drills, the team gathered valuable feedback, leading to adjustments that improved both the robot's responsiveness and the user interface of the control app. After full integration of all components, real-time tests were carried out to verify the reliability of the communication link between the robot and the app, confirming the system's readiness (10).

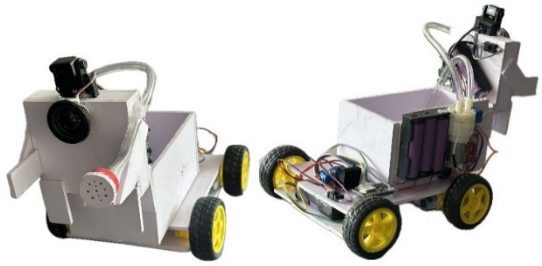

Figure 12: Implemented Robot.

4 RESULT AND CONCLUSION

The Humanoid Firefighter Robot showed strong promise in firefighting operations by reliably detecting fires, navigating tough terrains, and suppressing flames with its onboard water system. The robot's movement was efficient, though some limitations appeared in extreme conditions. Its fireproof coating proved effective, but prolonged heat exposure may need more advanced materials. The water system handled small fires well, though a more powerful solution is necessary for larger incidents (11).

Still, enhancing the water delivery system for larger fires, improving mobility for varied terrains, and optimizing communication for challenging environments could further strengthen the robot's effectiveness. These areas for improvement don't detract from the project's value but rather highlight how it advances toward autonomous firefighting, reducing risks for human firefighters and improving emergency response efficiency (12).

4.1 Conclusion

The creation of the Humanoid Firefighter Robot marks a major advancement in using robotics and technology for safety-critical operations. Built with sophisticated elements like the ESP8266 microcontroller, thermal and infrared sensors, and a reliable water delivery system, the robot is designed to perform in extreme conditions, such as high temperatures, harmful gases, and restricted visibility (13).

In summary, the Humanoid Firefighter Robot showcases the potential of integrating robotics and advanced technology into firefighting efforts. It efficiently detects fires, manoeuvres through challenging environments, and assists in flame suppression, providing a substantial advantage by reducing risks faced by human firefighters and improving emergency response effectiveness. Although the project has met key milestones, ongoing development will help refine its performance and broaden its scope (14).

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