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Haptic Glove Guided Robotic Arm

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Abstract

The integration of haptic glove technology with robotic arms provides a leap in the field of teleoperation, offering users a precise interaction with robotic systems. This technology combines feedback mechanisms with a wearable glove interface, allowing users to manipulate objects in remote or hazardous environments through a robotic arm. The haptic glove is embedded with advanced sensors and actuators that capture finger movements, which are then processed in real-time to control the corresponding actions of the robotic arm. Simultaneously, haptic feedback provides a sense of pressure, enabling operators to perform tasks with increased control. The advancements in technology have expanded the applications of haptic glove-controlled robotic arms across various fields.

Keywords: Haptic technology, Robotics, Embedded Systems, Feedback system, Rescue operations, Teleoperation, Robotic arm, wireless communication, obstacle avoidance.

1. Introduction

The Haptic Glove Guided Robotic Arm project represents a fusion of advanced haptic technology and robotics to create a tele-operated system that enables users to control a robotic arm through intuitive hand gestures, enriched with real-time tactile feedback. This integrated setup allows for remote operation of robotic arms in environments where direct human presence may be challenging or hazardous like dangerous industrial settings or remote exploration sites. The project aims to enhance user control, increase accuracy, and improve the realism of interaction by replicating a user's natural hand movements and conveying a sense of touch through haptic feedback. This system allows operators to remotely manipulate objects with a high level of precision, bridging the gap between human dexterity and machine strength. In the Haptic Glove Guided Robotic Arm, when the robotic arm interacts with an object, the feedback is relayed back to the user's glove, creating a virtual sense of touch. This is crucial in applications requiring precision, as it allows the user to perceive and respond to the environment in real-time, making delicate or complex manipulations more manageable. By combining haptic feedback with gesture-based control, the project aims to provide an immersive, controlled experience in robotic manipulation, significantly improving task performance in challenging scenarios. The motivation behind the development of a haptic glove-guided robotic arm system is rooted in the need for safer, more precise, and intuitively operated robotic solutions in environments that pose a risk to human operators.

2. Problem Statement

In environments that pose inherent dangers to human life such as those involving toxic materials, disaster zones, or confined spaces the need for precise, controlled interventions is paramount. In such settings, the risks of human intervention are compounded by various factors, including exposure to hazardous substances, physical instability, and environmental unpredictability. Traditional teleoperation systems are typically limited in their ability to provide real-time sensory feedback. This lack of feedback introduces a risk of over- or under-exerting force, leading to potential errors that may damage equipment, impair task effectiveness, or create safety hazards, especially in high-stakes environments. The Haptic Glove Guided Robotic Arm overcomes these challenges by integrating advanced sensory and control features. Real-time haptic feedback enables operators to feel and respond to physical cues, while gesture-based control replaces complex interfaces with natural hand movements, making operation more intuitive and reducing the need for training.

3. Scope and Relevance

The Haptic Glove Guided Robotic Arm with Obstacle Avoidance represents a significant leap in remote-controlled robotics, combining feedback mechanism and real-time video streaming. This design enables operators to interact and manipulate remote environments effectively and safely. The Haptic Glove Guided Robotic Arm is particularly valuable in disaster response scenarios where human presence is dangerous or impossible. Whether dealing with chemical spills, radiation zones, natural disasters, or unstable structures, this system offers a remote yet responsive solution. In environments with high levels of toxicity or radiation, it is critical to limit human exposure. The robotic arm allows operators to perform cleanup operations, contain spills, and inspect equipment remotely. After the occurance of natural disasters, with unstable ground, debris and hazardous materials complicating rescue and recovery operations, the robotic arm can navigate these environments, using obstacle avoidance to detect and move around barriers. It can be used to clear debris, perform search-and-rescue missions, and provide immediate assistance like water spraying, all while maintaining the safety of human operators.

4. Objectives

- To create a robotic arm that accurately mimics the hand movements of the operator, by utilizing a glove embedded with flex sensors and accelerometers[3] , this system will capture and translate hand gestures into robotic actions in real time.
- To design and integrate a dependable water pump and sprayer mechanism capable of targeted fire suppression, thus efficiently control and extinguish fires in high-risk areas, providing a crucial safety feature for environments where manual intervention may be dangerous or impractical.
- To incorporate to an obstacle avoidance system and handle various objects. This robotic arm will be capable of picking up items from one location and placing them at another, enabling remote operations for tasks that require precision and strength in hazardous or restricted areas.
- To integrate an IP camera, that will provide real-time video streaming, essential for monitoring and navigating dangerous or difficult-to-access locations. Additionally, the camera will support human detection and object detection, allowing operators to make informed decisions based on live visual data, even when line-of-sight is restricted.
- To set up a reliable communication system using a GSM module to support two-way audio. By capturing audio at the remote site and transmitting operator voice commands, this feature will facilitate direct communication, enabling the operator to convey instructions and receive feedback in real-time, enhancing situational awareness and control.

- To enhance situational awareness, the system will incorporate a range of environmental sensors, including temperature, gas, and flame sensors

5. Methodology

The user wears a glove with integrated flex sensors and MPU6050 Sensor, which track finger bends and hand movements. These signals are processed by ESP32 microcontroller on the glove and sent wirelessly to ESP32 of the rover. The rovers ESP32 controls 2 DC Motors via an L28 Motor driver for movement and 4 server motors for robotic arm manipulation. An ultrasonic sensor helps in obstacle detection by providing distance measurements to the ESP32. An IP camera[1] on the rover streams video to the mobile app giving the user a real time view of the viewer's surroundings.The system enables intuitive gesture based control of the rover and its robotic arm supported by time visual feedback for precise operation in various tasks. Using a GSM module[2] two way communication is made possible Integration of various sensors like flame sensors, gas sensors, temperature sensor along with the water pump can be done so that the magnitude of the sensor crosses a great threshold value water spraying system is initiated[4][5].

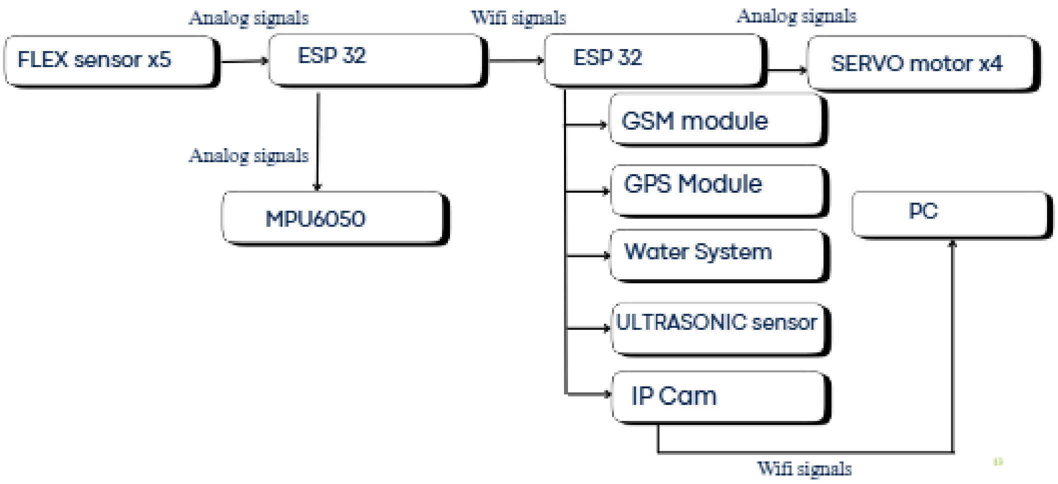


Figure 1: Methodology

6. System Requirements

ESP32 Microcontroller - The ESP32 acts as the primary controller for both the haptic glove and the rover, managing various aspects such as sensor data processing, wireless communication, and motor control. Its dual-mode Wi-Fi and Bluetooth capabilities make it ideal for real-time applications where low-latency, wireless control is required.

Flex Sensors - Flex sensors are attached to the glove's fingers to detect bending motions, capturing finger movements and translating them into commands for the robotic arm.

MPU6050 Sensor - The MPU6050 Inertial Measurement Unit captures orientation and motion data of the glove, including pitch and roll. This sensor includes an accelerometer and a gyroscope, which provide precise orientation information for controlling the robotic arm's direction.

MG995 Servo Motors - These servo motors are used to control the joints of the robotic arm, allowing it to manipulate objects with precision. They provide consistent speed and position control, ensuring that the arm's actions are smooth and precise.

30RPM DC Motors - The 30RPM motors provide the torque needed for stable, slow-speed movement, which is crucial when the rover needs to carry the robotic arm and other components through rugged or uneven terrain.

Ultrasonic Sensors - The ultrasonic sensor helps the system detect obstacles by measuring the distance to objects in the rover's path.
ESP32 Cam - The ESP32-CAM provides live video streaming, allowing the operator to view the rover's surroundings and the robotic arm's actions in real-time.
12 V DC pump - The water pump supports tasks like firefighting, irrigation, or cleanup in specialized applications. Powered by a 12V DC supply, the pump can be activated remotely via the ESP32 and a relay. Its versatility enhances the rover's functionality in diverse scenarios.
12 V Li Battery - With a 12V output, the battery offers a stable and adequate power supply, supporting extended operational time and reliability in field use.
L298 motor driver - The L298 motor driver manages the DC motors, allowing for control over the direction and speed of the rover.
Temperature Sensor - The temperature sensor is used to monitor environmental conditions in hazardous areas, enabling real-time detection of abnormal temperature levels.
Flame Sensor - It is used to detect the presence of fire in hazardous or hard-to-reach areas.
Gas Sensor - It is essential for detecting harmful or flammable gases in hazardous environments, where human presence may be unsafe.
Arduino IDE - The Arduino Integrated Development Environment (IDE) is used to program the ESP32 microcontrollers. The Arduino IDE allows for easy coding, debugging, and uploading of firmware to control components such as flex sensors, IMU, servos, and the camera.
Jupyter Notebook - Jupyter Notebook is used for analyzing sensor data, visualizing performance metrics, and developing algorithms. With Jupyter Notebook, users can plot sensor data, calibrate sensors, and evaluate control algorithms to enhance the system's performance.

7. Circuit Diagram

The circuit diagram for the connection and integration of the temperature sensor, gas sensor and flame sensor with ESP32 microcontroller is provided in Figure 2 and Figure 3 respectively.

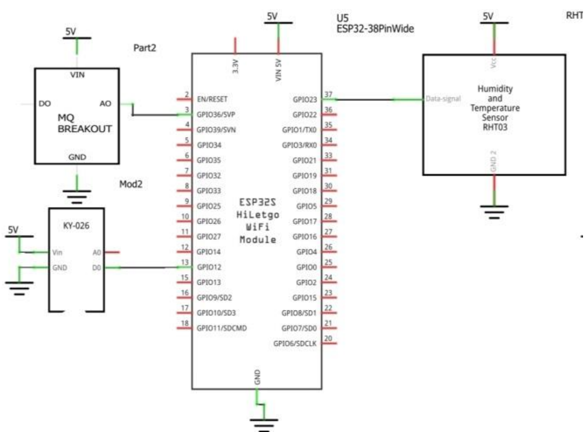


Figure 2: The integration of Temperature, Flame and Gas Sensors

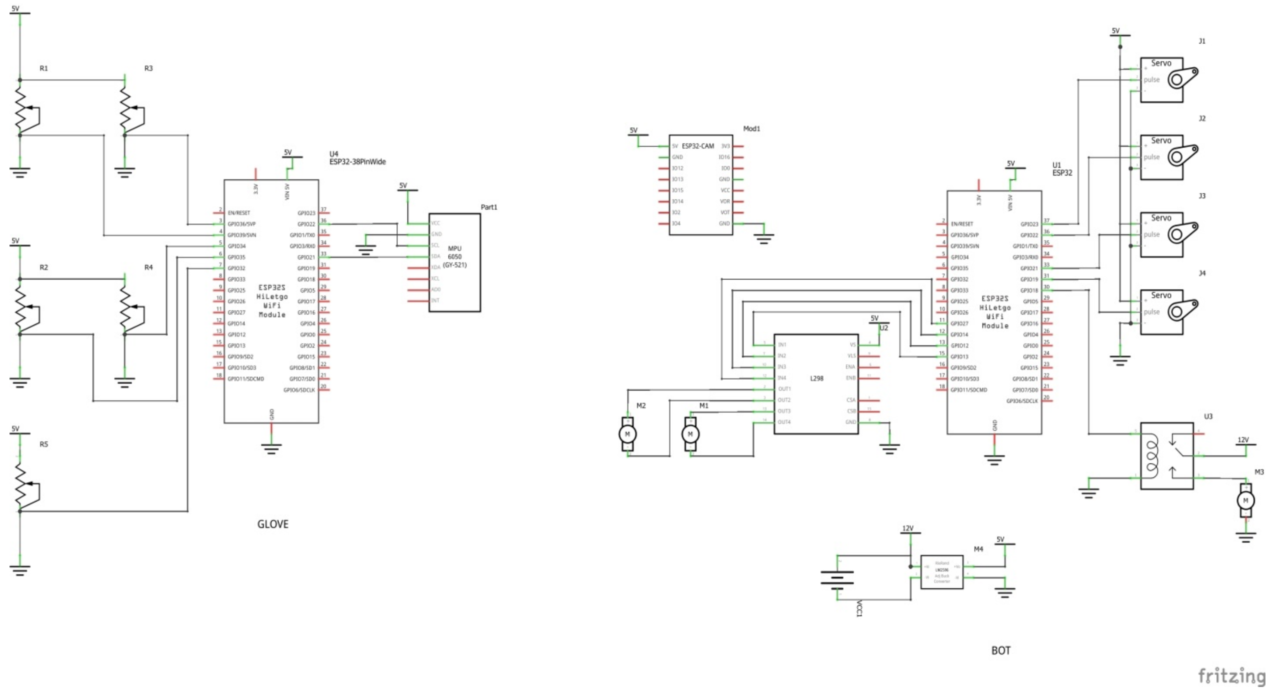


Figure 3: The circuit diagram of the glove and robotic arm

8. Result

Hardware and software components, such as temperature, gas, and flame sensors, the robotic arm, IP camera, GSM module, water pump, and programming environments, were systematically identified and procured. The circuit design for the haptic system, covering sensors, flex circuits, and actuators for gesture capture and feedback, is now complete, and work on the robotic arm has commenced. Additionally, the temperature, gas and flame sensors are interfaced with the ESP32[9] and the digital results are obtained through Arduino IDE. The flex sensors[7] and servo motors[6] are caliberated. The flex sensors are attached to the servo motors through ESP32[8] and the corresponding movements are obtained. The ESP32 camera is also interfaced with the Arduino IDE by making the camera as a hotspot client and the laptop or device through which the streaming takes place as the hotspot client. These results establish a foundation for the project's on-going development toward operational functionality.

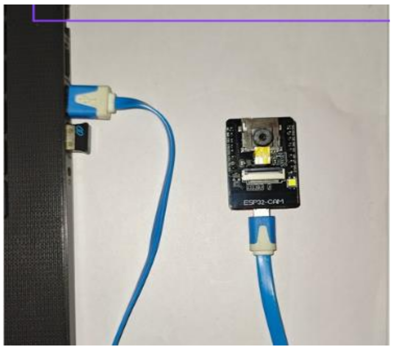


Figure 4: ESP32 camera powered with the laptop

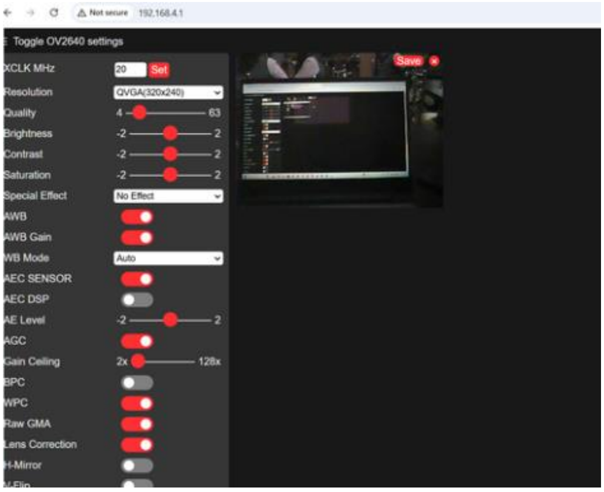


Figure 5: Streaming of ESP32 Camera

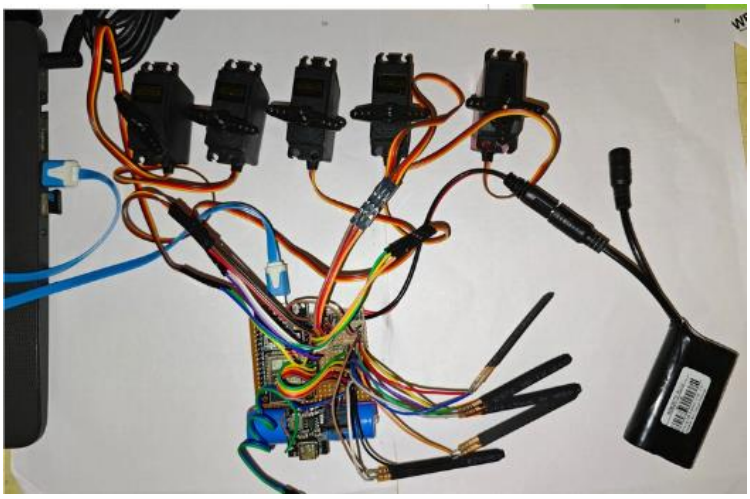


Figure 6: The Flex Sensors and Servo motors attached to ESP32 in resting position

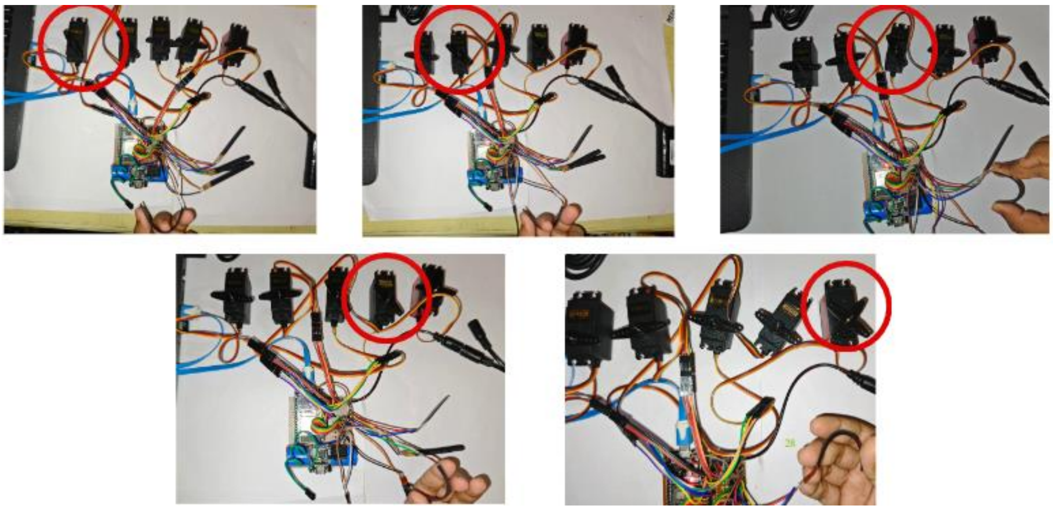


Figure 7: Servo motors when the corresponding flex sensors are bended

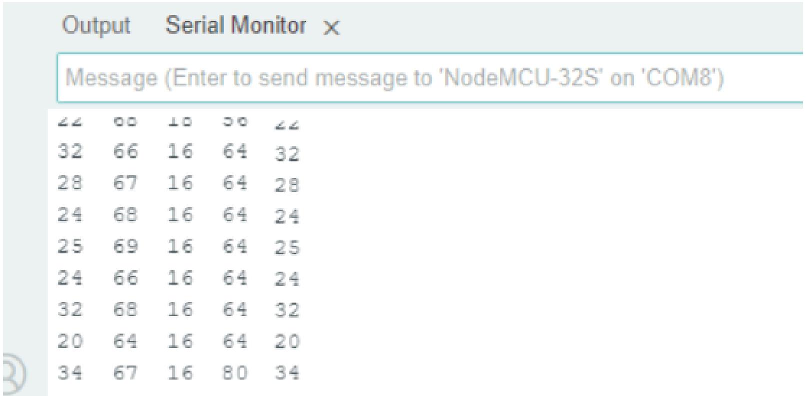


Figure 8: Servo motors when the corresponding flex sensors are bended

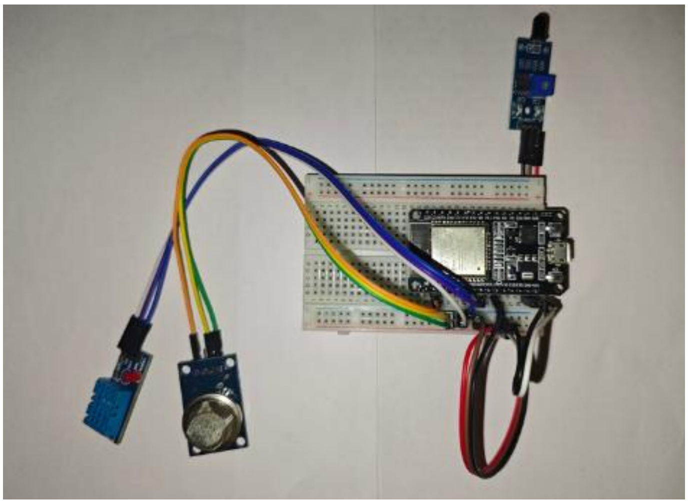
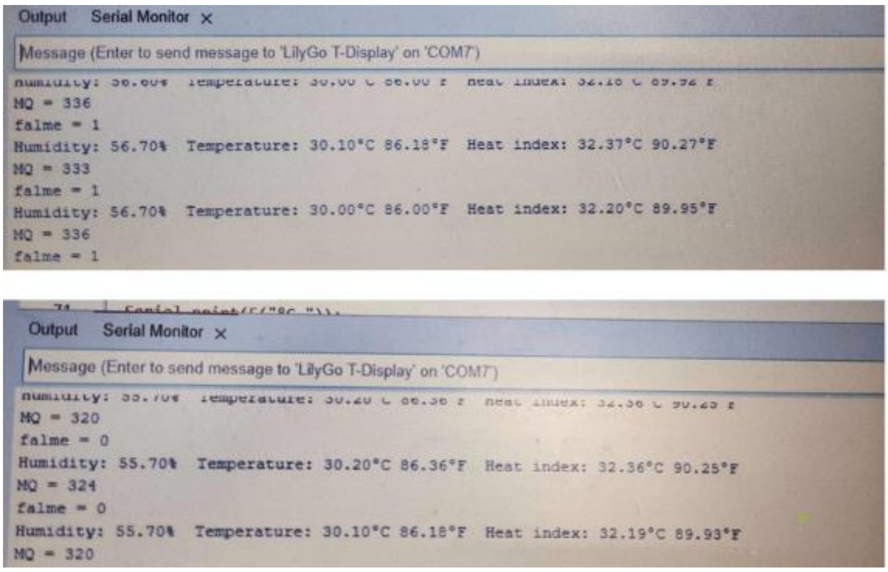


Figure 8 : The sensors attached to an ESP32 board



The data when flame is absent

The data when flame is present

Figure 9: Arduino IDE digital data of temperature, gas and flame sensor

9. Conclusion

The Gesture-Controlled Rover with Haptic Feedback for Hazardous Environments project demonstrates an innovative solution for remote operation in areas where human presence may be dangerous or impractical. Through the integration of advanced control systems, such as gesture-based commands and haptic feedback, the rover achieves a high level of precision, adaptability, and real-time responsiveness. By incorporating sensors, an IP camera, and a two-way communication system, it enables operators to monitor environmental conditions, handle objects, and perform critical tasks from a safe distance. This project not only addresses key challenges in hazardous environment operations—such as fire suppression, obstacle removal, and environmental sensing—but also highlights the potential for similar technology to be adapted across various sectors, from disaster response to industrial safety. The successful design and integration of hardware and software components in this prototype lay the groundwork for future enhancements, ultimately moving toward a fully operational system that prioritizes both safety and efficiency in high-risk scenarios.

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