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GESTURE CONTROLLED ROBOT WITH OBSTACLE AVOIDANCE AND DETECTION

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Abstract:

This paper presents the design and implementation of a gesture-controlled robot with obstacle avoidance and detection using an ESP32 microcontroller. The robot interprets hand gestures through an MPU6050 accelerometer-gyroscope module, transmitting commands wirelessly to control movement. Dual L298N motor drivers regulate the BO motors for smooth navigation. To enhance autonomous operation, a VL53L0X time-of-flight sensor detects obstacles, ensuring real-time avoidance and safe traversal. A buzzer provides audio feedback for alerts and status indications. The system is powered by a rechargeable lithium-ion battery, ensuring portability and efficiency. The integration of gesture-based control with obstacle detection enables intuitive human-robot interaction, making it suitable for applications such as assistive mobility, surveillance, and automation. This paper discusses the hardware configuration, control algorithms, and experimental results demonstrating the robot's effectiveness. Future enhancements may include advanced machine learning for gesture recognition and sensor fusion for improved obstacle detection accuracy.

Keywords - Gesture-controlled robot, ESP32, MPU6050, VL53L0X, obstacle avoidance, motor control, L298N, BO motors, human-robot interaction, automation.

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I. INTRODUCTION

In recent years, technological advancements in robotics and human-machine interaction have led to the development of intuitive control systems that enhance accessibility and convenience. One such innovation is gesture-controlled technology, which allows users to interact with machines using simple hand movements. This paper presents the development of a gesture-controlled robot and a gesture-controlled wheelchair designed to assist individuals with physical disabilities. By integrating gesture-based control with obstacle detection and avoidance, this system enhances mobility, independence, and ease of use.

Traditional mobility solutions, such as manual or joystick-operated wheelchairs, require significant physical effort from users. However, individuals with severe mobility impairments, including those with neuromuscular disorders, spinal cord injuries, or paralysis, may struggle to operate these conventional systems. Gesture-based control offers an alternative by providing an intuitive, hands-free method of navigation. A user can simply tilt their hand in different directions to control movement, eliminating the need for excessive physical strain. The system is built around an ESP32 microcontroller, which serves as the primary processing unit. It receives input from an MPU6050 accelerometer-gyroscope sensor, worn on the user's hand. The sensor detects variations in hand orientation and converts them into corresponding signals, which are transmitted wirelessly to control the robot or wheelchair. These signals are processed and used to regulate BO motors via dual L298N motor drivers, ensuring smooth and precise movement.

For enhanced safety and autonomous navigation, the system incorporates a VL53L0X time-of-flight sensor for obstacle detection and avoidance. This sensor continuously scans the surrounding environment and detects objects in the path of movement, enabling real-time adjustments to prevent collisions. A buzzer provides auditory feedback, alerting users about obstacles, system errors, or status updates. The entire system operates on a lithium-ion battery, ensuring reliable power efficiency and portability.

The gesture-controlled robot car acts as a prototype for refining and testing the system's accuracy before implementing it in a real-world wheelchair application. By first developing and optimizing the technology in a robotic model, potential improvements can be made to enhance its usability, responsiveness, and obstacle avoidance capabilities for wheelchair applications.

This project holds significant potential in the field of assistive technology, particularly for individuals with disabilities who face challenges with traditional mobility solutions. Unlike standard electric wheelchairs that rely on joysticks or complex button-based control mechanisms, a gesture-controlled wheelchair provides a more natural and effortless interaction model. This makes it a practical solution for those with limited hand dexterity.

Beyond assistive mobility, this gesture-controlled system can be applied to various domains, including automation, remote-controlled robotics, smart home integration, and industrial transport systems. The ability to control devices using hand gestures offers a futuristic and user-friendly approach to human-machine interaction.

This paper explores the design, hardware components, control methodology, and experimental results of the proposed system. The findings demonstrate the effectiveness of integrating gesture-based navigation with obstacle detection, paving the way for future enhancements such as machine learning-based gesture recognition and multi-sensor fusion for improved environmental perception.

The integration of gesture-based control in mobility solutions aligns with the growing demand for smart assistive technologies that enhance the quality of life for individuals with disabilities. Unlike voice-controlled systems, which may be ineffective in noisy environments, gesture control provides a silent, intuitive, and precise method of interaction. This makes it especially useful in hospitals, rehabilitation centers, and homes where minimal external noise is preferred.

One of the major challenges in implementing gesture-controlled mobility solutions is ensuring real-time responsiveness and accuracy in motion translation. Since hand movements vary among individuals, the system must be designed to accommodate different levels of gesture precision and adaptability. The use of the MPU6050 accelerometer-gyroscope module enables efficient tracking of hand movements, while signal filtering techniques help reduce noise and improve response accuracy.

Another key aspect of the project is the modular nature of the system, which allows for easy scalability and modification. By adjusting the software and sensor configurations, the same technology can be adapted for autonomous robotic systems, smart appliances, and industrial automation. Future iterations may include machine learning algorithms to enhance gesture recognition accuracy and voice-command integration to offer multimodal control options.

By bridging the gap between gesture recognition and autonomous mobility, this project represents a step forward in assistive robotics and smart control systems.

I.MATERIALS AND METHODS

A. ESP32-DEV MODULE

Fig. 1 ESP32-DEV module

Role: The ESP32 Dev Module functions as both a transmitter and receiver in this project**.** The transmitter ESP32 collects gesture data from the MPU6050 sensor and wirelessly sends movement commands via Wi-Fi/Bluetooth. The receiver ESP32 processes these commands to control BO motors via L298N motor drivers while also handling obstacle detection and buzzer alerts**.**

How it works:

Transmitter: The transmitter ESP32 reads hand movement data from the MPU6050 sensor, processes it into directional commands (forward, backward, left, right, stop), and transmits it wirelessly via Wi-Fi/Bluetooth. This enables gesture-based control, allowing the user to operate the wheelchair or robot car without physical contact.

Receiver: The receiver ESP32 receives commands from the transmitter, processes them, and controls BO motors via L298N motor drivers. It also monitors the VL53L0X sensor for obstacles, stopping movement and activating the buzzer if necessary. This ensures safe and accurate navigation for both the gesture-controlled robot.

Thus, a total of two ESP32 Dev Modules are used in this system, one as a transmitter and the other as a receiver.

A. MPU6050 (GYROSCOPE SENSOR)

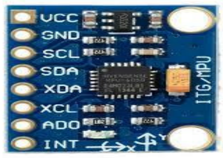

Fig. 2 MPU6050- Gyroscope sensor

The MPU6050 is a 6-axis motion tracking sensor that combines a 3-axis gyroscope and a 3-axis accelerometer in a single module. It measures angular velocity and linear acceleration, making it ideal for motion sensing applications like gesture-controlled robots and wheelchairs.

In this project, the MPU6050 detects hand movements, sending raw data to the transmitter ESP32 via I2C communication. The ESP32 processes these values to determine directional commands (e.g., forward, backward, left, right) and transmits them wirelessly. The gyroscope tracks rotation, while the accelerometer detects tilts, enabling precise gesture-based control for mobility solutions.

A. L298N MOTOR DRIVER

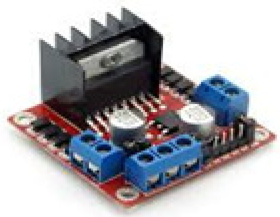

Fig. 3 L298N – Motor driver

The L298N is a dual H-Bridge motor driver used to control the speed and direction of DC motors. It can handle two motors simultaneously, making it ideal for applications like gesture-controlled robot cars and wheelchairs. It operates on 5V logic and can drive motors with voltages between 5V and 35V at up to 2A per channel.

In this project, the receiver ESP32 sends movement commands to the L298N, which then controls the BO motors accordingly. By adjusting PWM (Pulse Width Modulation) signals, the L298N regulates motor speed, allowing smooth, precise motion while ensuring efficient power management.

B. Lithium Battery

A Lithium-Ion (Li-Ion) battery is a high-energy-density, rechargeable power source commonly used in robotics and electronic applications. It offers lightweight design, long cycle life, and efficient power delivery, making it ideal for gesture-controlled robot cars and wheelchairs.

In this project, the Lithium-Ion battery powers the ESP32 microcontroller, L298N motor drivers, and sensors. Its high voltage output (typically 3.7V or 7.4V per cell) ensures stable performance for motors and wireless communication. Additionally, low self-discharge and fast recharging make it a reliable energy source, supporting extended operation for uninterrupted gesture-based mobility control.

Capacity: Choose based on the expected runtime. For example, a 2200mAh or 4000mAh battery could give several hours of operation, depending on the power consumption of your robot.

A. Buzzer (for Alerts)

A buzzer is an electronic component that produces sound alerts when activated. It is extensively utilized for providing notifications, issuing warnings, and delivering feedback signals in robotics and embedded systems.

In this project, the buzzer is controlled by the ESP32 and serves as an alert system for the gesture-controlled robot car and wheelchair. It produces a beeping sound when an obstacle is detected by the VL53L0X sensor, ensuring user awareness. Additionally, it can be used to indicate power status, system errors, or command execution, enhancing the safety and usability of the mobility system.

B. VL53L0X SENSOR

Fig. 4 VL53L0X – Time-of-Flight (ToF) laser-ranging sensor

The VL53L0X is a time-of-flight (ToF) distance sensor that accurately measures distances using laser-based technology. It provides precise obstacle detection by calculating the time taken for an infrared laser to reflect off an object and return to the sensor.

In this project, the VL53L0X sensor is used in the gesture-controlled robot car and wheelchair for real-time obstacle detection and avoidance. It continuously scans the environment and sends distance data to the ESP32 microcontroller. If an obstacle is detected within a predefined range, the ESP32 stops motor movement and activates the buzzer, ensuring safe and smooth navigation.

II. WORKING:

The system consists of two ESP32 modules, one as a transmitter and the other as a receiver. TheMPU6050 sensor (attached to the user's hand) detects gesture movements and sends data to the transmitter ESP32 via I2C communication. This data is processed and transmitted wirelessly (via Wi-Fi/Bluetooth) to the receiver ESP32, which interprets the commands and controls the BO motors through the L298N motor driver.

For obstacle detection, the VL53L0X sensor continuously scans the surroundings. If an obstacle is detected, the ESP32 stops the motors and triggers a buzzer alert for safety. The lithium-ion battery powers the entire system, ensuring reliable and efficient operation.

This setup allows gesture-based navigation, making it an intuitive and contactless mobility solution for disabled persons. The modular design enables easy modifications and future upgrades, such as AI-based gesture recognition and voice control integration.

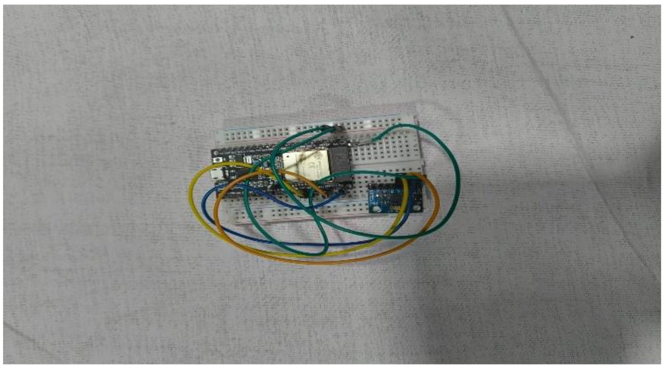

Fig. 5 Working model – Transmitter part

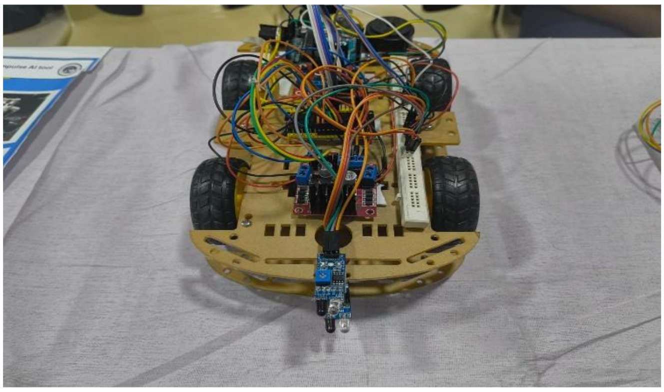

Fig. 6 Working model – Receiver part

I.SOFTWARE:

transmitter ESP32 reads gesture data from the MPU6050 sensor using I2C communication and processes it using embedded C/C++ code. The receiver ESP32 interprets these signals and controls the L298N motor driver for motor movement.

For obstacle detection, the VL53L0X sensor continuously measures distance, triggering the buzzer if an obstacle is detected. Wi-Fi/Bluetooth communication protocols enable seamless wireless transmission. Future enhancements may include machine learning integration for improved gesture recognition and a mobile app for remote monitoring and control.

The software also includes PWM control for smooth motor speed regulation and interrupt handling for real-time obstacle detection. Future updates may integrate cloud-based data storage, voice commands, and AI-driven adaptive gesture recognition. Performance analysis can further enhance system efficiency.

FUTURE ENHANCEMENTS:

The gesture-controlled robot car and wheelchair system can be significantly improved with advanced technologies. AI-based gesture recognition can be integrated to enhance accuracy, making the system more adaptable to different users. Additionally, voice control integration will provide an alternative input method, allowing users to operate the system through speech commands. A mobile application can be developed for remote control, real-time tracking, and system diagnostics via Wi-Fi or Bluetooth. For better navigation, GPS and IOT connectivity can enable location tracking and cloud-based monitoring. To improve obstacle detection, multiple VL53L0X sensors or LiDAR technology can be used for enhanced environmental mapping and safer mobility. Battery optimization techniques, such as solar charging or intelligent power management, can extend operational time. Lastly, customizable gesture profiles can be introduced, making the system more user-friendly for individuals with varying levels of motor control, thus increasing its accessibility and real-world applicability.

CONCLUSION:

The gesture-controlled robot car and wheelchair provide an innovative and accessible mobility solution for disabled individuals.

By integrating ESP32 microcontrollers, MPU6050 sensors, VL53L0X sensors, and L298N motor drivers, the system enables wireless, intuitive navigation using simple hand gestures. The inclusion of obstacle detection ensures safety, while the buzzer alerts enhance user awareness. Powered by a lithium-ion battery, the system offers efficient and reliable performance.

Future enhancements such as AI-based gesture recognition, voice control, and IoT connectivity can further improve usability. This project demonstrates a cost-effective, user-friendly, and scalable approach to assistive technology, promoting greater independence for disabled users.

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