HANDS FREE SMART WHEELCHAIR WITH VOICE AND GESTURE CONTROL FOR USERS WITH DISABILITIES

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Introduction:

The proposed hands-free smart wheelchair is an assistive mobility system designed for users with severe physical disabilities who are unable to operate conventional manual or joystick-based wheelchairs. The system primarily targets tetraplegia patients, semi-paralyzed individuals, and injured army people, enabling them to achieve independent mobility with minimal physical effort. It utilizes head gesture recognition through an MPU6500 sensor to detect directional movements, which are processed by an ESP32 microcontroller to generate control commands such as forward, left, and right.

In addition to gesture-based control, the system incorporates voice command functionality, allowing users to operate the wheelchair using simple spoken instructions via an Android device. These commands are transmitted to the controller using Bluetooth and further communicated wirelessly through the ESP-NOW protocol for real-time response. This dual-mode input system enhances flexibility, reliability, and ease of use for users with varying levels of physical capability.

By integrating head gesture and voice-based control, the system eliminates the need for manual operation and significantly improves accessibility. It provides a safe, intuitive, and efficient mobility solution, thereby enhancing independence, confidence, and quality of life for the intended users.

Objectives:

1. To design and develop a hands-free smart wheelchair for physically disabled users.
2. To implement voice recognition technology for controlling wheelchair movement.

3. To integrate gesture control using sensors for alternative navigation.
4. To ensure safety and reliability
5. To enhance independence and mobility of users with minimal physical effort.
6. To combine multiple control modes for flexibility and convenience.

Methodology:

The methodology describes the systematic design and implementation of a hands-free smart wheelchair using sensor-based and voice-controlled inputs. The system primarily relies on head gesture recognition, where user head tilts in forward, backward, left, and right directions are captured and translated into navigation commands. An MPU6500 sensor acquires real-time accelerometer and gyroscope data, and a complementary filter is applied to fuse these readings, ensuring accurate and stable orientation estimation. The filtered data is processed by the ESP32 transmitter unit, where thresholding and dead-zone filtering techniques are used to eliminate noise and unintended movements. The ESP32 then converts the processed data into directional commands such as forward, left, and right.

In addition to gesture control, a smartphone-based voice interface provides an alternative mode of operation, where voice commands are transmitted via Bluetooth to the ESP32. Wireless communication between the transmitter and receiver modules is established using the ESP-NOW protocol, ensuring low-latency and reliable real-time data transfer. The ESP32 receiver unit decodes the incoming commands and generates appropriate motor control signals based on the desired movement. These signals are processed to achieve differential drive control, enabling precise navigation of the wheelchair.

Two digital-to-analog converters (DACs) are used to convert digital signals into analog voltages, allowing independent speed control of each motor. The motor drivers amplify these signals to the required voltage and current levels to drive the motors effectively. The system uses two 24 V, 250 W BLDC motors powered by two 12 V, 7 Ah batteries connected in series. A chain and sprocket mechanism is employed for efficient torque transmission and smooth movement. Overall, the integrated system ensures safe, accurate, and hands-free wheelchair operation, providing reliable mobility assistance for users with physical disabilities.

The working of the model can be understood by below block diagrams (fig 1&2):

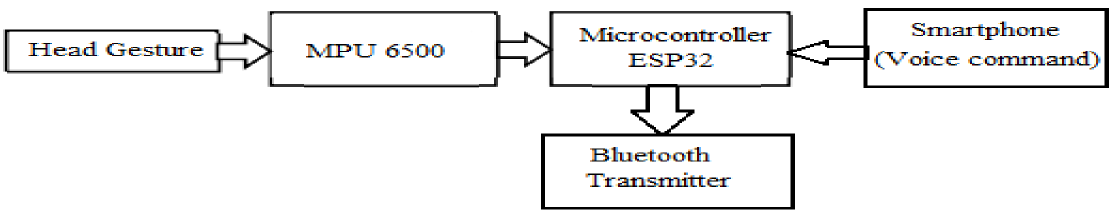

Fig 1: Block Diagram of Transmitter

The fig 1 is the Transmitter section interprets user inputs through head gestures and voice commands. The MPU-6500 sensor detects head movements and sends motion data to the ESP32 microcontroller, which processes the input to identify the intended direction. The smartphone acts as a voice input device, sending commands to the ESP32 via Bluetooth. The processed gesture or voice signals are then transmitted wirelessly to the receiver unit, enabling hands-free wheelchair control.

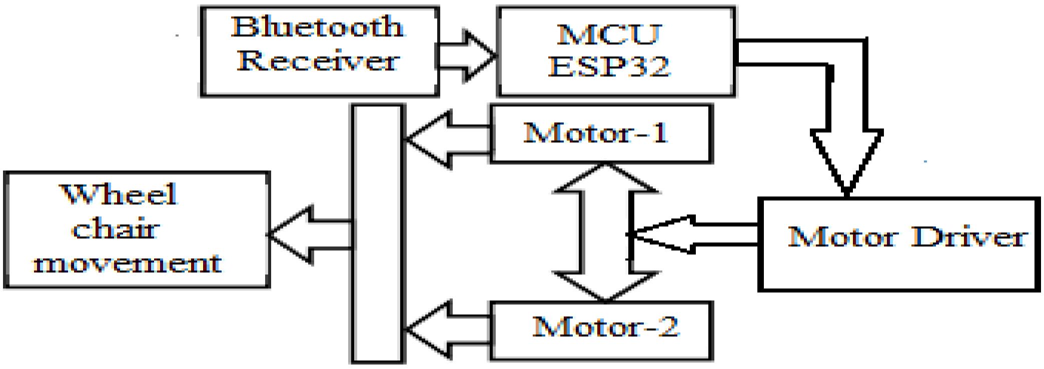

Fig 2: Block Diagram of Receiver

The fig 2 is receiver unit, mounted on the wheelchair, executes the control commands received from the transmitter. The ESP32 decodes the Bluetooth data and directs the motor driver to control the DC motors for movement in the desired direction. An ultrasonic sensor is integrated to detect nearby obstacles and stop the wheelchair when needed. Together, these components ensure smooth motion and safe operation of the system.

Results and Conclusions:

The developed hands-free smart wheelchair system successfully demonstrates an effective assistive mobility solution for individuals with severe physical disabilities. The integration of head gesture recognition using the MPU6500 sensor provides accurate and responsive control of wheelchair movement. The use of a complementary filter ensures stable and noise-free orientation data, improving overall system reliability. The ESP32 microcontroller efficiently processes both gesture and voice inputs, enabling real-time command execution. The addition of voice control through a smartphone enhances accessibility and provides an alternative mode of operation for users.

Wireless communication using the ESP-NOW protocol ensures low-latency and reliable data transmission between the transmitter and receiver units. The receiver module accurately decodes commands and generates appropriate control signals for motor operation. The use of DACs enables smooth and independent speed control of the motors, allowing precise navigation and turning. The BLDC motors, powered by a 24 V battery system, deliver sufficient torque and stable performance under varying load conditions. The chain and sprocket mechanism ensures efficient power transmission and smooth movement of the wheelchair.

The system performs effectively in executing forward, reverse, left, and right movements with good responsiveness. It reduces the need for manual effort and significantly enhances user independence and comfort. The design is cost-effective, modular, and suitable for real-world applications in homes and rehabilitation environments. However, minor challenges such as sensor calibration, wireless interference, and mechanical alignment need further improvement. Overall, the project proves to be a reliable and practical prototype, with strong potential for future enhancements such as AI-based control, autonomous navigation, and health monitoring features.

Project Outcome and Industry Relevance:

The hands-free smart wheelchair project successfully achieves its main goals by developing a system that helps physically disabled users move independently without using their hands. The wheelchair can be controlled using voice commands, making it easy for users to operate it by speaking simple instructions. It also uses head gesture control, where movements of the head are detected and converted into directions like forward, left, and right. By combining both voice and gesture control, the system provides flexibility and convenience for different users. The design ensures safety and reliable performance through stable communication and smooth motor operation. Overall, the system reduces physical effort and helps users become more independent in their daily life.

In terms of industry relevance, the project aligns with the growing demand in the assistive technology and healthcare sectors, where intelligent mobility solutions are increasingly required. It has potential applications in hospitals, rehabilitation centers, elderly care facilities, and home-based healthcare systems. The system can support medical device industries in developing advanced smart wheelchairs with improved accessibility features. Additionally, it is relevant to the IoT and embedded systems industry, as it incorporates wireless communication, sensor integration, and real-time control mechanisms. With further development, the project can be transformed into a market-ready product, contributing to innovation in healthcare technology and improving the quality of life for physically challenged individuals.

Working Model vs. Simulation/Study:

The proposed system is implemented as a real-time working model rather than a simulation or theoretical study. The prototype uses actual hardware components such as the MPU6500 sensor, ESP32 microcontrollers, DACs, and BLDC motors to demonstrate practical performance. The system enables hands-free control using both head gestures and voice commands, making it more flexible and user-friendly compared to conventional systems.

In comparison with existing methods, traditional joystick control requires continuous manual effort and is not suitable for users with severe disabilities. Voice control systems provide hands-free operation but are affected by environmental noise and slower response. The proposed system combines gesture and voice control, ensuring faster response, higher accuracy, and improved reliability. Gesture control provides real-time responsiveness, while voice commands offer additional flexibility, making the system more robust for real-world applications.

We can better understand the working of the model by comparing it with joystick and voice control method as shown below:

Comparison of Control Methods:

Parameter	Joystick Control	Voice Control Only	Proposed System (Voice + Gesture)
Hands-Free Operation	No	Yes	Yes
Response Time	Medium	Slow	Fast
Control Accuracy	Medium	Medium	High
User Effort	High	Low	Very Low
Reliability	Medium	Affected by noise	High

The details of the MPU-6500 sensor's response and speed of the wheelchair with respect to head tilt angle is as shown below:

Head Tilt Angle vs Wheelchair Speed:

Head Tilt Angle (°)	Sensor Response	Wheelchair Speed Level
0° – 10°	Within dead zone	No movement
10° – 15°	Small tilt detected	Very low speed
15° – 20°	Moderate tilt detected	Low speed
20° – 25°	Clear intentional tilt	Medium speed
25° – 30°	Large tilt detected	High speed
30° – 35°	Maximum safe tilt	Maximum speed
> 35°	Beyond operating range	Speed limited / unchanged

Overall, the working prototype validates the system's real-time performance, safety, and reliability. The inclusion of a dead zone and maximum tilt limit ensures controlled and safe operation. This practical implementation proves that the system is more effective and reliable than simulation-only approaches, making it suitable for real-world assistive mobility applications.

Project Outcomes and Learnings:

In this project, we successfully built a hands-free smart wheelchair that can be controlled using both head movements and voice commands. The system works in real time and is able to move the wheelchair smoothly in different directions like forward, left, and right. We were able to combine different components like sensors, ESP32, wireless communication, and motors into one complete working system. The wheelchair responds quickly to user input and provides a safe and comfortable way of movement. Overall, the project shows that it is possible to create a practical and low-cost solution for people with physical disabilities.

While working on this project, we learned many important technical skills. We understood how to work with sensors like MPU6500 and how to process real-time data. We also gained knowledge about ESP32 programming, Bluetooth and ESP-NOW communication, and motor control. We faced challenges like sensor calibration, signal noise, and proper alignment of mechanical parts, which helped us improve our problem-solving skills. This project also gave us hands-on experience in combining hardware and software together. In the end, we learned how to design a real-world engineering solution that can actually help people in daily life.

Future Scope:

The proposed hands-free smart wheelchair can be further enhanced by integrating artificial intelligence and machine learning algorithms for advanced gesture recognition and adaptive control based on user behavior. The system can be upgraded with autonomous navigation capabilities using technologies such as SLAM (Simultaneous Localization and Mapping), enabling the wheelchair to move safely in complex environments without continuous user input. The inclusion of advanced obstacle detection using LiDAR, ultrasonic sensor fusion, or computer vision can significantly improve safety and navigation accuracy.

Future development can incorporate IoT-based remote monitoring, allowing caregivers or medical professionals to track the wheelchair's location, usage, and system status in real time. Integration of health monitoring sensors such as heart rate, temperature, and fall detection can transform the wheelchair into a smart healthcare device. The system can also be enhanced with mobile or web-based applications for configuration, control, and performance monitoring.

Further improvements can be made by implementing voice recognition using NLP (Natural Language Processing) for more accurate and flexible command interpretation. The use of energy-efficient power management systems and advanced battery technologies can increase operational time and reliability. Additionally, the design can be made more compact and ergonomically optimized for better user comfort.

The project can also be extended with brain-computer interface (BCI) technology for users with extremely limited mobility. Integration with cloud platforms can enable data analysis and predictive maintenance. With these advancements, the system has strong potential to evolve into a fully intelligent, automated assistive mobility solution, contributing significantly to the future of healthcare and rehabilitation technology.