Gesture Controlled Wheel Chair With Smart Home Automation

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Abstract - *The evolution of assistive robotics has significantly enhanced the independence of individuals with severe motor impairments. However, traditional control interfaces – such as joysticks or voice recognition – often present barriers in noisy environments or for users with limited upper- limb strength. This research addresses the dual challenge of mobility and environmental control by developing a gesture – based ecosystem. By utilizing high-sensitivity flex sensors integrated into a wearable glove, we propose a system that translates finger kinematics into precise navigational commands for an automated wheelchair. Unlike standalone mobility aids, this architecture leverages the ESP-NOW protocol to create a low-latency bridge between the user and their immediate environment, allowing for the seamless control of the household appliances alongside physical movement. This integration aims to move beyond simple transport, fostering a holistic approach to ' Ambient Assisted Living' (AAL).*

***Key Words*: Wheelchairs, Home Automation, implementation, intelligent wheel chair.**

1. INTRODUCTION

Assistive mobility devices are essential for improving the quality of life of individuals who experience difficulty in independent movement. Wheelchairs are widely used to support people with physical disabilities, elderly individuals, or patients recovering from injuries. Traditional wheelchairs are typically operated manually or through joystick-based electronic control systems. However, these methods may not always be convenient for users who have limited hand strength, restricted arm movement, or neurological disorders that affect motor control. With the rapid advancement of embedded systems and sensor technology, researches have started developing more intelligent and user-friendly control mechanisms for mobility devices. One such approach is gesture-based control, where human body movements are used as input commands to operate electronic systems. Hand gestures are particularly suitable for assistive technologies because they are natural, intuitive, and require minimal physical effort.

In a gesture-controlled system, wearable sensors are used to capture finger or hand movements and convert them into electrical signals. These signals are then processed by a microcontroller that interprets them as control instructions. Wireless communication technologies allow these commands to be transmitted to a receiver unit that performs the required action. The proposed system introduces a gesture-controlled wheelchair integrated with a basic smart home automation feature.

The system uses a glove equipped with flex sensors to detect finger bending. An ESP32 microcontroller processes the sensor readings and identifies predefined gestures. These commands are transmitted wirelessly using the ESP-NOW communication protocol to another ESP32 unit mounted on the wheelchair. The receiver then controls servo motors that simulate wheelchair movement.

2. LITERATURE REVIEW

Several Researchers around the world have explored various technologies to enhance the functionality and accessibility of intelligent wheelchairs. Early electric wheelchairs were mainly controlled using joysticks or mechanical switches. Although these systems provided basic mobility assistance, they were not suitable for users who had limited hand coordination or muscle strength.

The landscape of smart wheelchair research has historically transitioned from mechanical improvements to sophisticated human-machine interfaces (HMI). Early breakthroughs, such as the work by Kim et al. (1997), emphasized the necessity of 'shared control,' where the system assists the user in obstacle avoidance. While effective, these systems often relied on rigid input methods. More recent explorations have shifted toward physiological and kinetic signaling. Studies by Wang and Popovic (2009) demonstrated that wearable sensors could provide a more intuitive 'language' for machine control compared to traditional joysticks. However, a recurring limitation in existing literature (such as the work discussed by Lu Tao regarding intelligent trends) is the 'siloed' nature of these devices; they focus either on mobility or on smart home interaction, but rarely both.

Current research into Brain-Computer Interfaces (BCI) offers high autonomy but suffers from high computational costs and user fatigue. In contrast, this project builds upon the efficiency of Micro-Electro-Mechanical Systems (MEMS), as seen in gesture-recognition studies, but optimizes the data transmission layer. By replacing standard Bluetooth or Wi-Fi with the ESP-NOW protocol, we address the latency and power consumption gaps identified in previous wireless HMI implementations. Another advanced approach involves the use of brain–computer interfaces (BCI), where brain signals are used to control assistive devices. These system offer promising possibilities but often require specialized equipment and complex signal processing techniques, making them expensive and difficult to implement in low-cost applications. Gesture recognition has emerged as a practical and user-friendly method for controlling electronic devices.

Many studies have focused on the use of wearable sensors such as accelerometers, gyroscopes, cameras, and flex sensors to detect hand gestures. Among these technologies, flex sensors are widely used in glove-based systems because they directly measure finger bending and provide reliable input signals.

3. METHODOLOGY

The proposed system is developed to control a wheelchair and a basic home appliance using hand gestures detected through wearable sensors. The methodology involves the integration of sensing devices, microcontrollers, wireless communication, actuators, and a relay switching mechanism. The complete system is divided into two major sections: the gesture detection (transmitter) unit and the wheelchair control (receiver) unit. The overall operation of the system is achieved through a sequence of sensing, signal processing, wireless communication, and actuator control. The gesture detection unit consists of a wearable glove equipped with flex sensors attached to the fingers. Flex sensors are variable resistive devices whose resistance changes depending on the bending angle of the sensor. When a finger bends, the sensor's resistance increases, which produces a corresponding change in the output voltage.

Each flex sensor is connected to the analog input pins of the ESP32 microcontroller using a voltage divider configuration. As the user moves their fingers, the ESP32 reads the changing analog values through its internal Analog-to-Digital Converter (ADC). These sensor readings represent different finger positions and form the basis for gesture recognition. After acquiring the analog values from the sensors, the ESP32 processes the data by comparing the readings with predefined threshold values. These threshold values determine whether a finger is in a bent or straight position. Based on the detected finger movement, the system assigns a specific command to each gesture.

For example:

- Index finger bending corresponds to the left movement command.
- Little finger bending corresponds to the right movement command.
- Ring finger bending indicates a forward movement command.
- Middle finger bending represents the backward movement command.
- Thumb bending is used to toggle the home appliance control.

The ESP32 converts these gesture interpretations into command messages that will be transmitted to the wheelchair control unit.

To allow wireless interaction between the glove and the wheelchair system, the project uses the ESP-NOW communication protocol. ESP-NOW is a peer-to-peer wireless communication method supported by ESP32 devices, enabling direct data exchange without the need for a traditional Wi-Fi network. In the transmitter unit, the ESP32 sends the generated command message to the receiver ESP32. The ESP-NOW protocol ensures fast data transfer and minimal communication delay, which is essential for real-time control of the wheelchair.

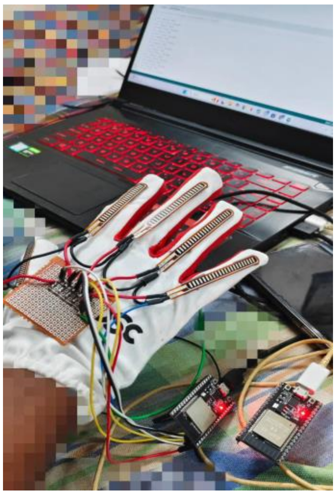

Fig-1:. Glove with Flex Sensors

Overall, The decoded command is then used to control the actuators responsible for wheelchair movement and appliance operation. Two SG90 servo motors are used in the system to simulate wheelchair movement. One servo motor is responsible for controlling the steering direction (left or right), while the second servo motor controls the forward and backward step movement.

Based on the received command:

- If the command is LEFT, the steering servo rotates in the left direction.
- If the command is RIGHT, the steering servo rotates in the right direction.

- If the command is FORWARD, the movement servo performs a forward motion.
- If the command is BACKWARD, the movement servo perform a backward motion.

System Workflow: Start System → Gesture Input → Signal Acquisition → Gesture Detection → Command Generation → Wireless Transmission → Command Reception→ Command Processing → Motor Control Execution → Wheelchair Movement → Loop Continuation

4. SYSTEM ARCHITECTURE

The proposed Gesture Control Wheelchair with Smart Home Automation is designed as an embedded system that integrates gesture sensing, wireless communication, motion control, and appliance switching. The system architecture is organized into two primary modules: the gesture detection unit (transmitter module) and the wheelchair control unit (receiver module). These modules communicate wirelessly using the ESP-NOW protocol supported by ESP32 microcontrollers. The architecture allows user gestures to be detected, processed, transmitted, and executed in real time. The transmitter module functions as the user interaction interface of the system. It consists of flex sensors attached to the fingers of a wearable glove, an ESP32 microcontroller, and supporting electrical components.

The ESP32 continuously reads these analog signals and compares them with predefined threshold values. Based on these values, the microcontroller identifies the gesture performed by the user. After command generation, the ESP32 transmitter sends the data wirelessly to the receiver module using the ESP-NOW communication protocol, which enables fast and efficient device-to-device communication without requiring a traditional Wi-Fi network.

The Communication between the gesture glove and the wheelchair control unit is established using ESP-NOW, a low-latency wireless protocol developed for ESP-series microcontrollers. This protocol allows direct -peer-to-peer data exchange between ESP32 devices.

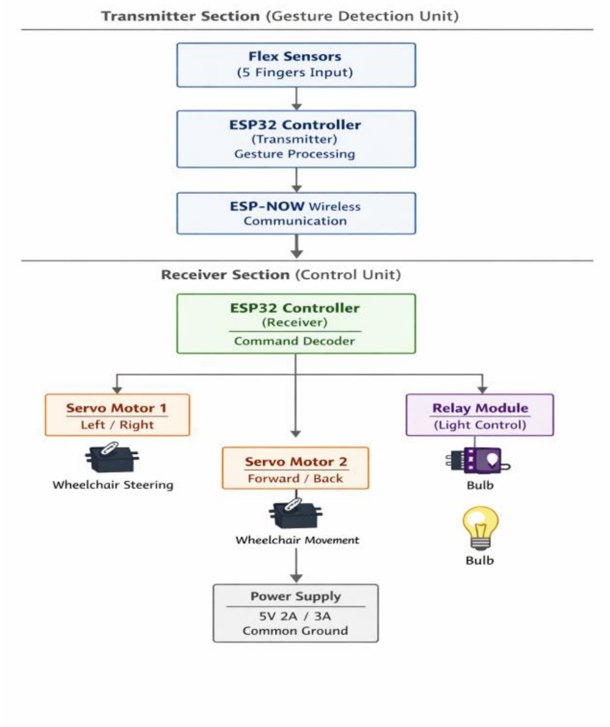

Fig-2: System Architecture of a proposed system.

In the system architecture, the transmitter ESP32 sends command packets that contain the interpreted gesture information. The receiver ESP32 listens for these packets and processes them immediately upon arrival. The use of ESP-NOW ensures minimal communication delay, which is essential for responsive wheelchair movement and real-time control. The receiver module is mounted on the wheelchair platform and acts as the control center for the entire system. It consists of another ESP32 microcontroller, servo motors for movement control, and a relay module for home appliance switching.

The receiver ESP32 continuously monitors incoming wireless messages from the transmitter. Once a command is received, the controller decodes the instruction and determines the appropriate action.

For wheelchair movement, the ESP32 sends control signals to two SG90 servo motors. One servo motor is responsible for steering control, enabling the wheelchair to move left or right. The second servo motor handles the forward and backward movement mechanisms. When the receiver interprets a directional command, it rotates the appropriate servo motor to produce the desired movement. This mechanism allows the wheelchair to respond directly to the user's hand gestures. All components are powered using a 5V power supply, and a common ground connection is maintained to ensure stable operation of the ESP32, servo motors, and relay module.

Overall, the system allows a user to control wheelchair movement and home appliances using simple hand gestures, making it especially useful for assisting people with mobility disabilities.

5. IMPLEMENTATION

The implementation of the Gesture Control Wheelchair with Smart Home Automation involves the integration of hardware components and embedded software to create a functional assistive system. The system is developed using two ESP32 microcontrollers that communicate wirelessly using the ESP-NOW protocol. The overall implementation includes the setup of the gesture detection unit, wireless communication configuration, actuator control, and home automation switching. The hardware portion of the system is divided into two main sections: the transmitter unit and the receiver unit.

The transmitter unit is responsible for detecting hand gestures and generating control commands. In this unit, five flex sensors are attached to the fingers of a glove so that each sensor corresponds to a specific finger movement. The ESP32 continuously reads the analog signals from the sensors and processes the values to determine the gesture being performed. Based on predefined threshold values, the system identifies the corresponding command such as left, right, forward, backward, or light control. After identifying the gesture, the ESP32 prepares a command message that will be transmitted to the receiver module.

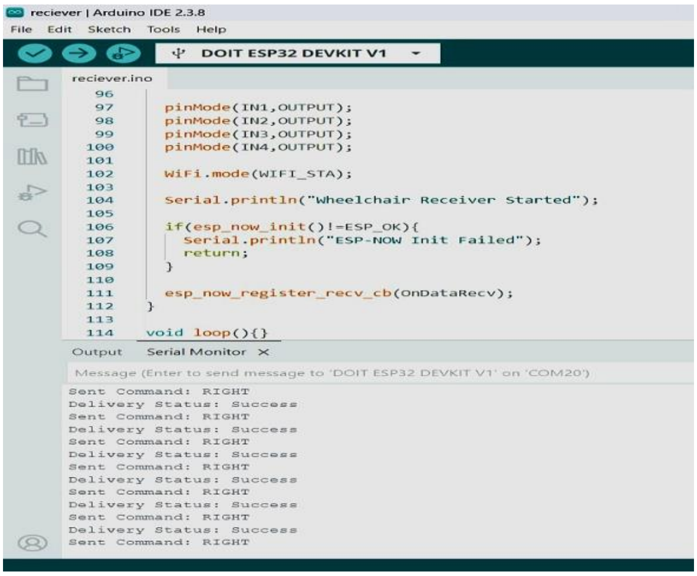

Fig-3: Software Implementation Result

The receiver unit is installed on the wheelchair platform and is responsible for executing the commands received from the transmitter. It consists of another ESP32 microcontroller, two SG90 servo motors, and a relay module. The receiver ESP32 operates in listening mode and waits for wireless commands sent from the transmitter ESP32. When a command is received, the controller interprets the instruction and activates the appropriate actuator.

One servo motor is used to control the left and right steering movement, while the second servo motor manages the forward and backward motion. These servo motors are connected to the digital output pins of the ESP32 and are controlled using pulse-width modulation (PWM) signals generated by the microcontroller. Communication between the transmitter and receiver modules is achieved using the ESP-NOW protocol, which enables direct wireless communication between ESP32 devices without requiring a router or internet connection. The transmitter ESP32 sends command packets containing gesture information to the receiver ESP32. The receiver is configured with the transmitter's MAC address to allow secure communication between the two devices. This communication method provides fast data transmission with minimal delay, allowing real-time control of the wheelchair system. Gesture recognition is implemented through threshold comparison of sensor values. The ESP32 reads the analog values from the flex sensors and compares them with predefined limits to determine whether a finger is bent or straight.

Each finger gesture corresponds to a specific command:

- Index finger → Move left
- Little finger → Move right
- Ring finger → Move forward
- Middle finger → Move backward
- Thumb → Toggle light ON/OFF

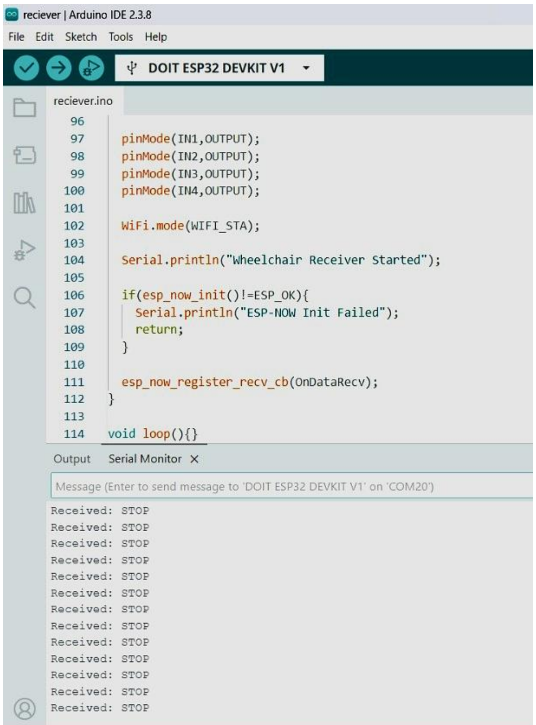

Fig-4: Stop Command (indication of implementation)

When a gesture is detected, the transmitter ESP32 converts the recognized pattern into a command string. This command is then transmitted wirelessly to the receiver ESP32. The receiver ESP32 processes the received command and controls the servo motors accordingly.

- When a left command is received, the steering servo rotates in the left direction.
- When a right command is received, the steering servo rotates in the right direction.
- When a forward command is detected, the movement servo rotates to produce forward motion.
- When a backward command is received, the movement servo rotates in the opposite direction to produce reverse movement.

This motor control mechanism enables the wheelchair to move according to the user's hand gestures. The home automation functionality is implemented using a relay module connected to the receiver ESP32. The relay acts as an electrically operated switch that controls the power supply to an external AC device. When the user performs the thumb gesture, the transmitter sends a command to toggle the relay state. The receiver ESP32 then activates or deactivates the relay, switching the connected bulb ON or OFF. This feature demonstrates the ability to control household appliances using simple hand gestures. All components in the system are powered using a 5V DC adapter with a current capacity of 2A or 3A. This power supply provides sufficient current to operate the ESP32 modules, servo motors, and relay module simultaneously.

The results are monitored through the Arduino IDE serial monitor, where transmitted and received commands are displayed. Successful command transmission and correct actuator response confirm that the system functions as intended.

6. RESULT AND DISCUSSION

After completing the hardware assembly and software programming, the gesture control wheelchair system was tested to evaluate its performance and reliability. The system consisted of two ESP32 microcontrollers configured as transmitter and receiver modules. The transmitter unit was connected to five flex sensors mounted on a glove, while the receiver unit was connected to two SG90 servo motors and a relay module controlling a demonstration bulb. The power supply was provided using a 5V adapter capable of delivering sufficient current to operate the ESP32 modules, servo motors, and relay simultaneously. All components were connected with a common ground to ensure stable electrical operation.

Fig-5: Bulb glowing when gesture is shown.

The Arduino IDE serial monitor was used to observe the communication between the transmitter and receiver modules and to verify that gesture commands were correctly transmitted and executed. During testing, the flex sensors successfully detected finger bending movements and produced measurable variations in analog voltage values. The ESP32 transmitter continuously monitored these values and compared them with predefined threshold levels to identify specific gestures.

Each finger movement was mapped to a unique command. When a finger was bent beyond the defined threshold, the corresponding command was generated and prepared for wireless transmission. The system demonstrated consistent gesture detection when the sensors were properly positioned on the glove.

Example communication output observed during testing:

Transmitter Output:

Sent Command: LEFT_FORWARDDelivery Status: Success

Receiver Output:

Received Command: LEFT_FORWARD

Testing showed that directional commands such as left, right, forward, and backward were executed reliably when gestures were clearly performed. The relay module connected to the receiver ESP32 was tested using the thumb gesture assigned for appliance control. When the thumb gesture was detected, the transmitter sent a command to toggle the relay state.

Upon receiving this command, the receiver ESP32 activated or deactivated the relay, switching the connected bulb on or off. The switching operation occurred immediately after the gesture command was received, demonstrating that the system could effectively control external electrical devices.

Overall, the results confirm that the proposed system successfully demonstrates the concept of gesture-controlled wheelchair operation combined with basic smart home automation features.

7. CONCLUSION

The Gesture Control Wheelchair with Smart Home Automation project demonstrates a practical approach for assisting individuals with limited mobility by enabling wheelchair control through simple hand gestures. The system integrates flex sensors, ESP32 microcontrollers, wireless communication technology, and actuator components to create an intuitive and responsive assistive device.

In this project, flex sensors mounted on a wearable glove are used to detect finger bending movements. These sensor readings are processed by the ESP32 transmitter, which interprets the gestures and converts them into control commands. The commands are then transmitted wirelessly using the ESP-NOW protocol to a receiver ESP32 located on the wheelchair control unit. The receiver processes the incoming data and activates the corresponding servo motors to control the direction of movement such as left, right, forward, or backward.

The system also incorporates a basic home automation feature by integrating a relay module that controls an external electrical device.

Overall, the developed system provides a simple, cost-effective, and user-friendly solution for gesture-based wheelchair control combined with basic smart home functionality. By allowing users to control movement and appliances using natural hand gestures, the system has the potential to improve convenience and independence for individuals with mobility challenges.

Although the current prototype demonstrates the core concept successfully, further enhancements such as obstacle detection, speed regulation, and advanced gesture recognition techniques could improve safety and functionality. With additional development, this technology could be adapted for real-world assistive mobility applications and integrated with more advanced smart environments.

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