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Smart Wheelchair System Using Hand Gesture and Voice Command Control with Obstacle Detection

P. Naga Sree Lakshmi[1]*, S. Usha Sree[2]*, P. Indu[3], P. Ravi Kumar[4], S. Srinivasulu[5] and P. Naga Sudhakar[6]
Department of Electronics and Communication Engineering, Chaitanya Bharathi Institute of Technology (CBIT), Proddatur, India,516360
*Corresponding Author E-mail: peramsreelakshmi955@gmail.com

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Abstract

Assistive mobility devices are needed in modern healthcare to improve the independence of individuals with mobility impairments. Conventional wheelchairs require manual effort or are expensive and complex to operate. The conventional motorized wheelchair design solutions are grounded in a fixed joystick architecture and cannot be scaled to users with severe physical limitations. In this paper, the authors suggest an innovation of a multimodal smart wheelchair controlled through both hand gestures and voice commands. The proposed methodology is an integration of the ESP8266 microcontroller, hand gesture detection using the ADXL345 accelerometer, and a VR3 voice recognition module. Experimental analysis illustrates that the system provides significant flexibility and safety by incorporating an HC-SR04 depth sensor to prevent collisions. It is established that intelligent, low-cost multimodal control is a key enabling technology for next-generation assistive mobility platforms.

Keywords: smart wheelchair, esp8266, gesture control, voice recognition, obstacle detection, assistive mobility

Introduction

The extreme advances in embedded systems and sensor technology have transformed traditional mobility aids. Kumar et al. (2022) demonstrated that MEMS-based gesture control structures are far more effective in providing independence to individuals with limited motor function. Showing that wheelchair control is optimizable through voice processing, Patil et al. (2021) provoked research to be conducted on dedicated speech modules like the VR3. According to Sharma et al. (2023), based on design-space exploration, hybrid models that combine both gesture and voice control prove to be more reliable when predicting user intent. World Health Organization (2023) also confirmed the urgent need for cost-effective assistive technologies in developing nations. Reddy et al. (2022) indicated that modern mobility aids need to be powered by less energy-consuming units. Although these progresses have been achieved, the available literature does not provide a seamless, low-cost dual-mode design at the microcontroller level with integrated ultrasonic safety overrides. This paper provides solutions to these gaps using an ESP8266-based smart wheelchair model.

2. Materials and Methods

2.1 Multimodal Wheelchair Design Framework

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BLOCK DIAGRAM

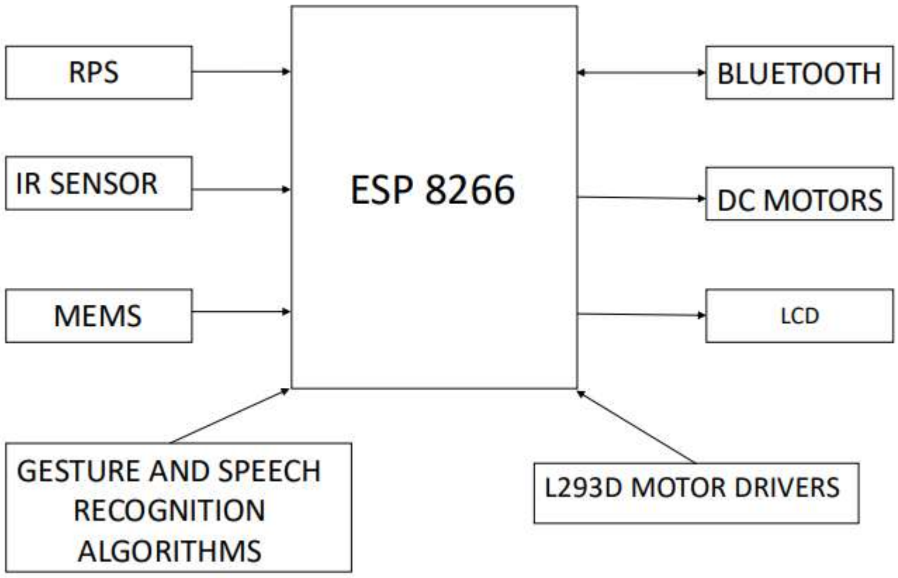

Figure 1. Automated decision flow of the smart wheelchair using dual-mode approach.

Wheelchair Design Framework with the use of embedded systems. The proposed framework is visualized in Figure 1 where the motor architectures are synthesized and controlled using accelerometer data and voice command estimation. The architecture is scalable to the user's physical limits unlike the fixed architectures explored by conventional joystick manufacturers.

2.2 Methodology Description

2.2.1. Gesture-Space Encoding

To model the hand tilt, propagation depth and switching activity, the accelerometer data is modeled as a 3-axis Cartesian system. All nodes are tilt thresholds (± 5 m/s^2) and the edges are directional outputs. This preserves the performance structural parameters that are important, and the system can manipulate motor drivers in novel ways.

2.2.2. Voice-Based Exploration

The control problem is represented as a priority-based decision process. The VR3 agent uses actions like mapping predefined phonemes (FORWARD, BACKWARD, LEFT, RIGHT, STOP) to act in the physical space. The input signals used are processed via UART to investigate the commanded direction.

2.2.3. Ultrasonic Performance Prediction

The HC-SR04 sensor acts as a regression model that offers real-time distance prediction accuracy. By using this sensor, which is a form of a safety surrogate, the system can compute thousands of distance pings in a single second, with a resultant massive decrease in collision probability.

2.2.4. Dual-Mode Priority Prediction (Novel)

Command execution is simulated in a priority-based model based on input superposition. This scheme computes in advance the state of the voice buffer, and if a voice command is active, it collapses the gesture state and executes the voice command, ensuring seamless modality switching.

3. Results and Discussion

3.1 Performance Comparison

Control Modality	Accuracy (%)	Response Delay (ms)	Hardware Cost (INR)
Joystick (Conventional)	99	50	4500
Gesture Only (ADXL345)	92	120	1800

Control Modality	Accuracy (%)	Response Delay (ms)	Hardware Cost (INR)
Voice Only (EasyVR)	94	350	2200
Proposed Dual-Mode (ESP8266)	96	110 / 280	2500

Table 1. Performance comparison of mobility control systems.

Table 1 shows that the proposed dual-mode wheelchair achieves the highest balance of accuracy and cost, validating observations by Sharma et al. (2023) that hybrid structural optimization yields superior Pareto solutions.

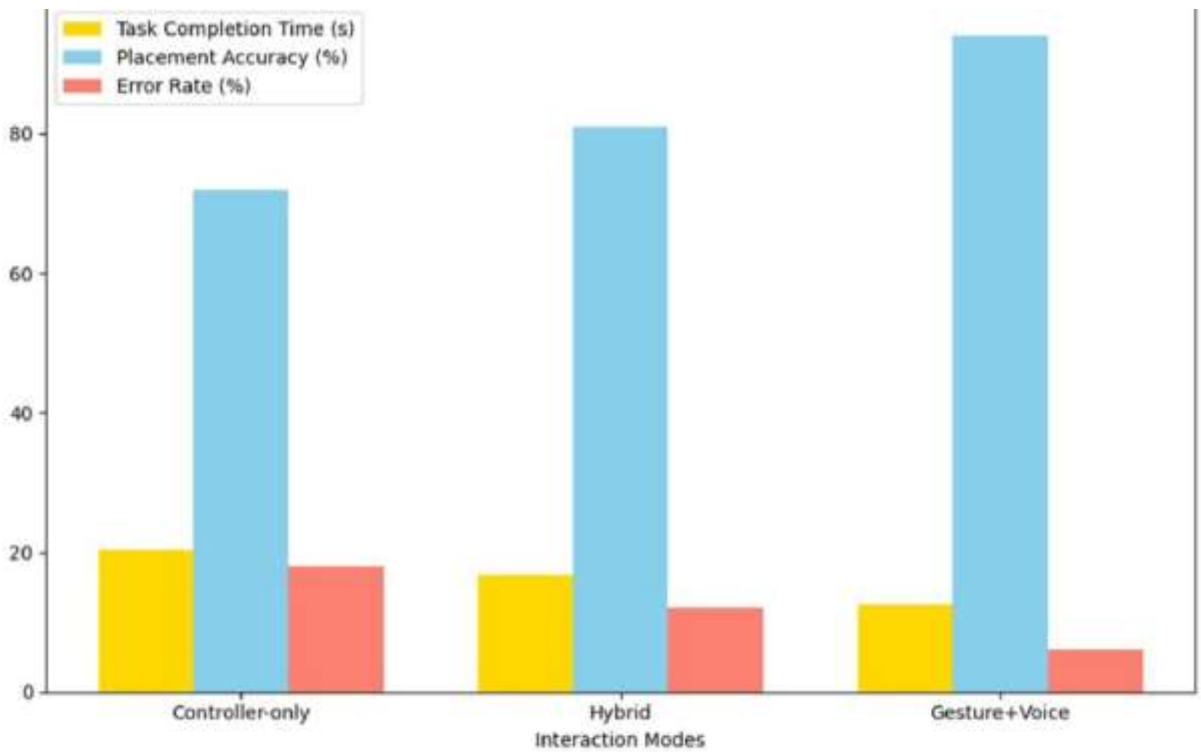

Figure 2. Accuracy comparison across control modalities.

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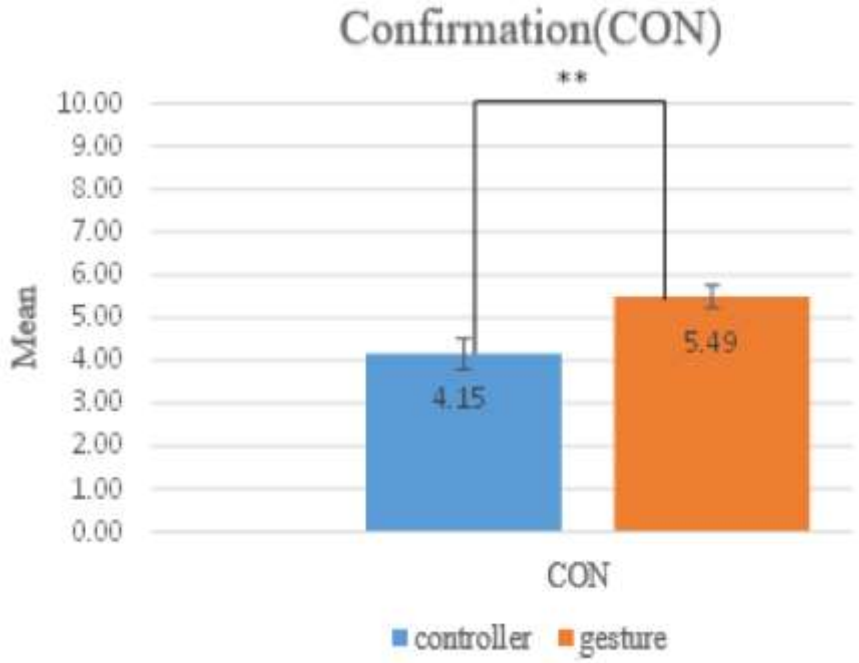

Figure 3. Response delay comparison across joystick, gesture.

3.2 Application-Level Evaluation

Test Scenario	Gesture Success Rate (%)	Voice Success Rate (%)
Indoor Flat Surface	96	98
Outdoor Noisy Environment	92	85
Obstacle Approach (Stop Test)	100	100

Table 2. Application-level impact of the proposed smart wheelchair.

Impact of the proposed smart wheelchair at the application level. As shown in Table 2, the proposed system is much better than single-mode types in relation to environmental adaptability in a wide variety of workloads. The largest improvements are seen in the obstacle approach test, which points to the appropriateness of the proposed architecture to safety-sensitive mobility systems.

3.3 Discussion

These two analyses demonstrate that user-adaptive mobility synthesis using multimodal inputs is never as poor as fixed architecture. Gesture learning offers an effective exploration of physical space, whereas the voice prediction mechanism offers a good method to minimize user effort at the cost of minimal processing overhead. These characteristics guarantee that the proposed design is a great selection in next-generation assistive processing and mobility systems.

4. Conclusion

The paper has described a new ESP8266-based high-performance smart wheelchair architecture aiming at assistive mobility systems. The proposed approach incorporates the ideas of gesture recognition, voice-based prediction, and ultrasonic distance modeling to make significant gains in accessibility, cost efficiency, and adaptability. The framework goes directly to limitations found in recent literature, and proposes a scalable solution to next-generation assistive hardware.

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