© 2025 IJRTI | Volume 10, Issue 4 April 2025 | ISSN: 2456-3315

SWHEELS: THE SMART WHEELCHAIR

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ABSTRACT

SWheels is a smart, voice-controlled wheelchair prototype designed to enhance mobility and independence for individuals with partial or complete paralysis. This project aims to bridge accessibility gaps by integrating advanced features such as voice command operation, joystick control, automatic speed adjustment on inclines, obstacle detection, fall detection, and a real-time dash cam. The system is powered by a Raspberry Pi 5 and dual ESP32 microcontrollers, enabling distributed processing for efficient control and safety management. Voice navigation interprets natural language instructions like “move forward for 10 meters” through a language model API and translates them into structured commands for motor control. The obstacle avoidance mechanism, implemented using six ultrasonic sensors (HC-SR04), ensures safe navigation in indoor environments such as hospitals and schools. Real-time video streaming is achieved via MJPG-Streamer, allowing live monitoring over a local network. SWheels follows a phased development approach, beginning with basic assistive mobility features, followed by autonomous navigation and path learning capabilities. The successful implementation of the prototype demonstrates the viability of combining low-cost hardware with smart control logic to deliver a scalable, user-friendly mobility solution. The system's modular design supports further enhancements such as gesture recognition and health monitoring, making it a promising candidate for future development in assistive technology.
Keywords: Smart wheelchair, voice navigation, obstacle avoidance

1 Introduction

SWheels is a smart, voice-controlled wheelchair system designed to assist individuals with partial or complete paralysis. It offers multiple modes of control, including voice commands and joystick navigation, ensuring accessibility for users with varying levels of mobility. The wheelchair is built to intelligently adjust its speed when going uphill or downhill, providing a smoother and safer ride. It also includes an incline lock mechanism to prevent rollback on slopes.

The system is powered by a Raspberry Pi 5 and two ESP32 microcontrollers—one for motor control and another for obstacle detection and avoidance using six ultrasonic sensors. The wheelchair is designed to operate effectively in indoor environments like hospitals, schools, and homes, where safety and precision are critical.

SWheels is being developed in multiple phases. The first phase includes core functionalities such as voice and joystick control, smart speed adjustment, incline handling, obstacle detection, and fall detection with alerts. The second phase focuses on implementing an autopilot feature that allows the wheelchair to travel autonomously from one point to another, using real-time camera input and voice navigation. A final optional phase includes the integration of a dash cam that streams live video over a local network through a dedicated web interface, enhancing both security and usability.

This project aims to make assisted mobility more intelligent, affordable, and user-friendly, especially in low-resource settings.

1.1 Objectives

- To provide an intelligent and accessible mobility solution for individuals with partial or complete paralysis through voice and joystick-based control systems.
- To enhance user safety and comfort by integrating features like automatic speed adjustment on slopes, obstacle detection, and incline locking mechanisms.

- To develop an autonomous navigation system that enables the wheelchair to travel between predefined points using real-time camera input and smart voice navigation.

1.2 Background

The need for intelligent mobility solutions has grown significantly with the increasing population of individuals suffering from mobility impairments due to accidents, age-related issues, or neurological disorders. Traditional wheelchairs, while useful, often require manual effort or assistance from caregivers, limiting the independence of the user. While powered wheelchairs offer better control, they are often expensive and lack intelligent features like voice control or autonomous navigation.

SWheels was conceptualized to address these limitations by combining affordability, accessibility, and smart technology. With advancements in microcontrollers, sensors, and machine learning, it has become feasible to develop a feature-rich wheelchair that is responsive to user voice commands, adaptable to environmental conditions, and capable of partial autonomy. By leveraging components like the Raspberry Pi 5, ESP32 microcontrollers, ultrasonic sensors, and camera modules, SWheels aims to bridge the gap between assistive technology and real-world usability—especially in environments like homes, hospitals, and educational institutions.

The project not only focuses on providing mobility but also emphasizes user safety, comfort, and independence. With the inclusion of future-ready features like real-time dash cam streaming and autopilot navigation, SWheels sets the foundation for a next-generation, smart assistive mobility device.

2 Materials and Methods

2.1 Hardware Components

The main hardware components required are:

2.1.1 Motor Driver(BTS7960)

The BTS7960 motor driver is used to control the high-power 12V 300 RPM Johnson Geared DC Motors. It provides high current capacity and efficient motor driving with PWM (Pulse Width Modulation) control.

Fig 1 Motor Controller

2.1.2 IMU Sensor(MPU6050)

The MPU6050 is a 6-axis motion tracking sensor that integrates a 3-axis gyroscope and 3-axis accelerometer. It helps detect tilt and movement, contributing to stability and incline detection.

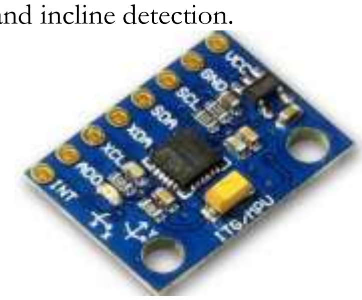

Fig 2 IMU Sensor

2.1.3 ESP Modules(2 Units)

- **ESP for Motor Control**: Controls the motor driver and processes movement commands.
- **ESP for Obstacle Detection**: Works with ultrasonic sensors to detect obstacles and avoid collisions.

Fig 3 ESP-32

2.1.4 Raspberry Pi 5

Acts as the central processing unit of the system, handling voice recognition, WebAPI streaming, and high-level decision-making. It requires 5V, 5A power input (25W).

Fig 4 Raspberry Pi

2.1.5 Ultrasonic Sensor (HC-SR04)

Used for real-time obstacle detection and avoidance. Measures distance by sending ultrasonic waves and analyzing the time taken for the waves to return.

Fig 5 Ultrasonic Sensor

2.1.6 Step-Down Power Module (HW-064 XL4015)

A DC-DC adjustable step-down module that converts 12V to 5V, 5A. It ensures stable power delivery to the Raspberry Pi 5, preventing voltage fluctuations.

Fig 6 DC-DC adjustable step-down module

2.1.7 Brix Web Camera

A high-resolution webcam for live streaming and monitoring via WebAPI. It enables remote assistance and real-time visual feedback.

Fig 7 Web Camera

2.1.8 Battery (Frontech VRLA 12V 7Ah)

A 12V, 7Ah VRLA battery that powers the system, providing sufficient runtime for motors, sensors, and processing units.

Fig 8 Battery

2.1.9 12V 300 RPM Johnson Geared DC Motor

Two high-torque DC motors drive the wheelchair. These motors provide smooth movement and precise speed control.

Fig 9 Geared Motor

2.1.10 Heavy Duty Swivel Castor Wheels

Free-moving front wheels that enhance manoeuvrability and provide smooth navigation on different surfaces.

2.1.11 Robot Wheels (10cm x 2cm)

Attached to the geared motors, these wheels ensure proper traction and movement stability.

2.1.12 Communication & Storage

SD Card (32GB or more) – Stores voice models, logs, and navigation data. Ethernet/Wi-Fi Module (Built-in on Raspberry Pi 5) – Supports web interface for remote control and monitoring.

2.2 Software Components

Software Requirements for SWheels The software stack for SWheels ensures seamless integration of voice control, navigation, safety mechanisms, and user interfaces while optimizing performance and reliability.

2.2.1 Operating System & Development Environment

Raspberry Pi OS (64-bit, Lite Version) – Provides a lightweight OS for Raspberry Pi 5, ensuring efficient resource usage.
Python 3.11 – Main programming language for voice processing, motor control, and data handling.

2.2.2 Programming Languages & Frameworks

Python (Flask for PWA Backend, OpenCV for Computer Vision) – Handles web control, AI processing, and real-time video analysis.
C++ (ESP32 Firmware) – Ensures low-latency motor control and sensor response.
HTML, CSS, JavaScript (Frontend for PWA) – Provides a user-friendly web interface for remote control.

2.2.3 Speech Processing & AI Modules

Google Gemini API (for Voice Recognition & NLP) – Converts natural language commands into structured motor control inputs.
OpenCV (for Camera-Based Navigation) – Detects turns, obstacles, and indoor paths.
TensorFlow Lite (Optional, for Object Recognition) – Enables AI-based decision-making for smart navigation.

2.2.4 Motor Control & Navigation Algorithms

PID Control Algorithm – Maintains smooth acceleration, deceleration, and speed adjustments. Path Planning Algorithm (A or Dijkstra)* – Used in autonomous mode to determine the best route.
Obstacle Avoidance Algorithm – Processes LiDAR/ultrasonic sensor data to prevent collisions.

2.2.5 Web-Based Interface (PWA for Remote Monitoring & Control)

Flask (Backend for Web App) – Manages real-time wheelchair data and control requests. JavaScript (Frontend with AJAX/WebSockets) – Updates real-time wheelchair position and status without page reloads.
SQLite or JSON-Based Storage (Optional) – Saves system logs and user preferences.

2.2.6 Safety & Monitoring Systems

Real-Time Error Handling System – Detects sensor failures, power issues, or system errors and takes corrective action.
Data Logging & Debugging Tools – Stores logs for diagnosing hardware/software issues. Battery Monitoring System – Ensures safe power consumption and alerts for low battery levels.

2.2.7 Security & Access Control

Authentication System for Web Interface (Optional) – Ensures only authorized users can control SWheels remotely.
Local Processing Priority – Reduces dependency on cloud services, ensuring fast, offline operation.

3 Block Diagram

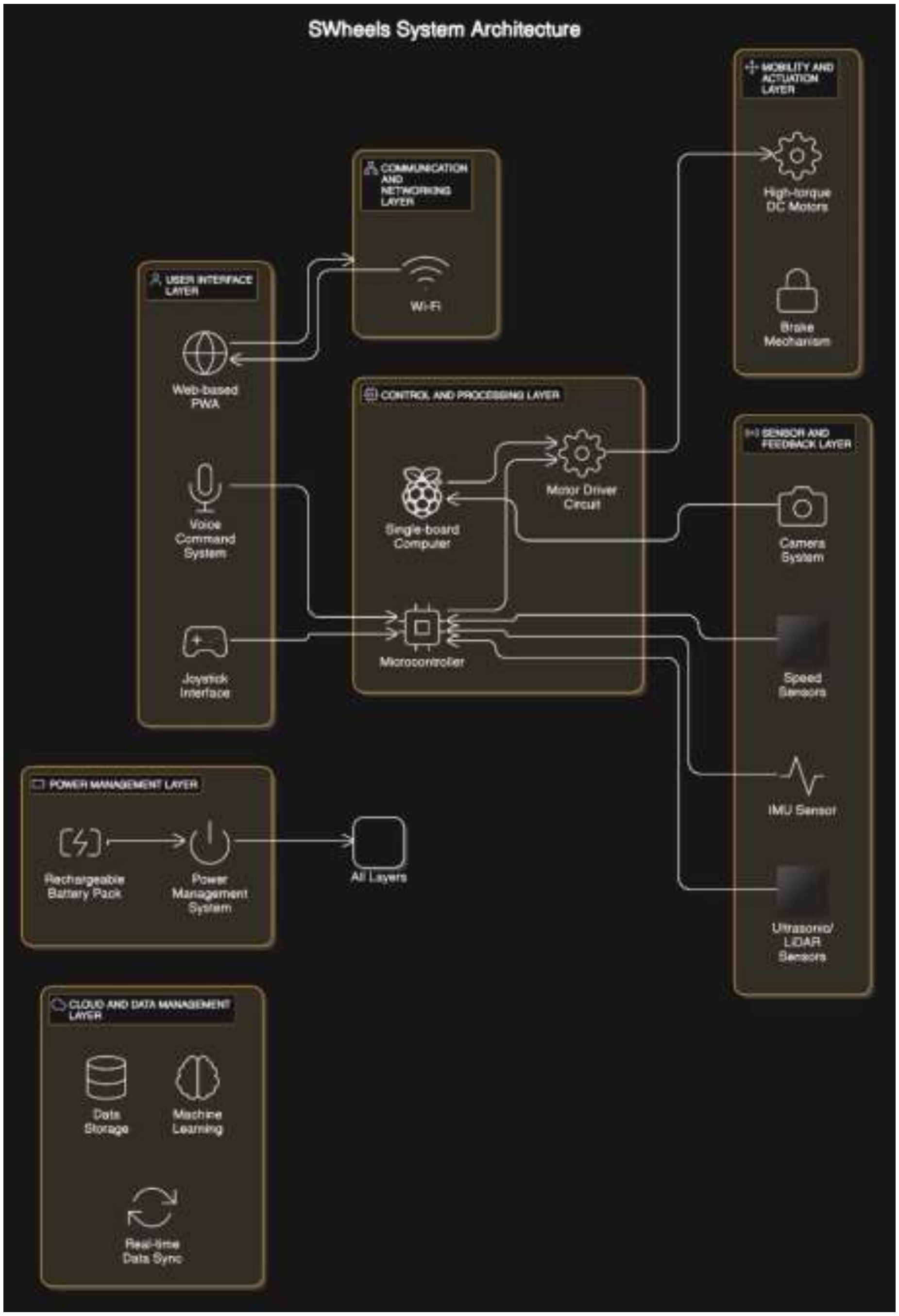

Fig 10 Block Diagram

The SWheels System Architecture is a comprehensive, layered design that integrates hardware and software components to create a smart, assistive wheelchair system. At the core of this system is the User Interface Layer, which provides multiple input methods including a voice command system, a joystick interface, and a web-based Progressive Web App (PWA). This ensures that users with varying levels of mobility and accessibility needs can interact with the wheelchair effectively and comfortably.

The Communication and Networking Layer is responsible for maintaining wireless connectivity via Wi-Fi. This enables the PWA to communicate with the system in real-time, allowing users to issue commands or monitor system status remotely. It also facilitates data synchronization with cloud services, enhancing the flexibility and intelligence of the wheelchair over time.

At the heart of the system lies the Control and Processing Layer, which includes a microcontroller and a single-board computer (such as a Raspberry Pi). The microcontroller handles real-time control tasks such as reading sensor data and executing motor commands, while the single-board computer manages higher-level processes, including running the motor driver circuit and handling data from sensors. Together, these processing units ensure coordinated movement, obstacle avoidance, and smooth user interaction.

The Mobility and Actuation Layer powers the physical movement of the wheelchair. It features high-torque DC motors to drive the wheels and a brake mechanism to ensure safe stopping and support for uphill/downhill navigation. This layer is directly controlled by signals from the processing units based on user inputs and environmental data.

The Sensor and Feedback Layer plays a crucial role in environmental awareness and safety. It includes various sensors such as a camera system for visual input, ultrasonic or LiDAR sensors for obstacle detection, speed sensors for monitoring movement, and an IMU sensor for tracking orientation and stability. The data from these sensors feeds into the control systems, enabling real-time responses to changes in the environment.

Powering the entire system is the Power Management Layer, which includes a rechargeable battery pack and a power management system. This layer ensures all components receive stable and efficient power, allowing the wheelchair to function reliably over extended periods.

Finally, the Cloud and Data Management Layer handles backend operations such as data storage, machine learning, and real-time data syncing. This layer enables continuous improvement of the wheelchair's performance by learning from user behavior and environmental patterns. It also supports remote monitoring and diagnostics, making SWheels a future-ready assistive technology solution.

4 Results and Discussion

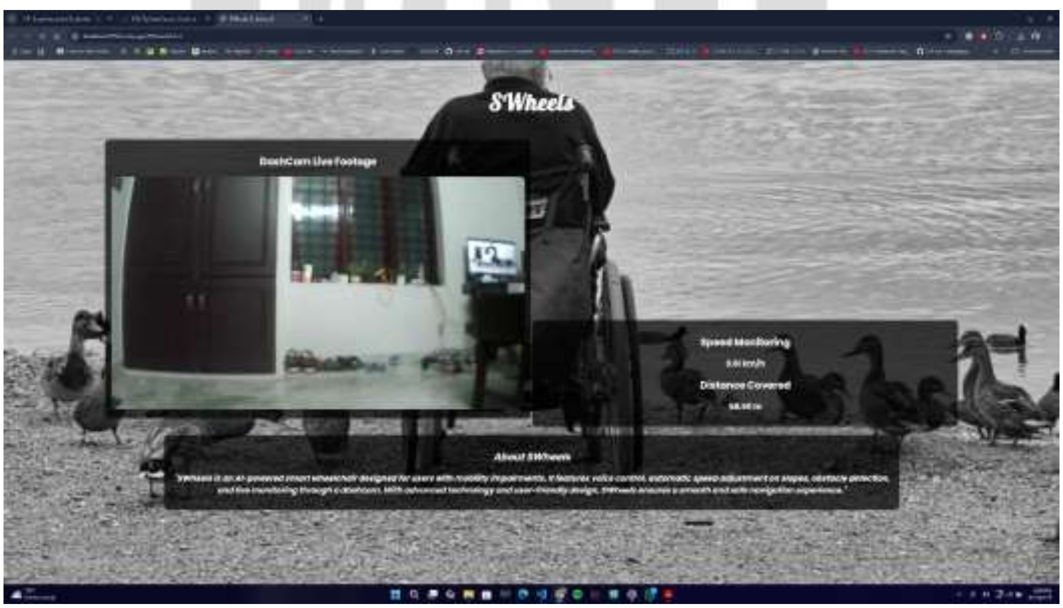

Fig 11 Web API Dashboard

Fig 12 Side View

Fig 13 Internal View

The SWheels project, a smart, voice-controlled wheelchair prototype, was designed to assist individuals with partial or complete paralysis by offering intuitive control options. The system combines voice commands, joystick input, and autonomous features to provide a flexible and safe mobility solution. Built with a cost-effective hardware stack including ESP32s, Raspberry Pi 5, and ultrasonic sensors, SWheels aims to balance functionality with affordability. A scaled-down prototype was developed to demonstrate the core features.

One of the standout components of the system is the voice control functionality. Using the Gemini API for natural language processing, the wheelchair can understand commands like “turn left” or “move straight for 10 meters” and convert them into structured control signals. During testing, voice commands were processed and executed with an average response time of under 200 milliseconds, providing smooth and reliable interaction.

SWheels includes an automatic speed adjustment mechanism to improve comfort and safety on slopes. During tests, the system effectively reduced speed while moving downhill and maintained consistent speed going uphill. This dynamic adjustment was crucial in ensuring stability, especially for users who may not be able to adjust speed manually.

A key innovation was the incline lock mechanism, which successfully prevented rollback on ramps or inclines. The feature activates when the wheelchair detects a steep incline and holds the position steady, allowing the user to remain secure without sudden backward motion.

The obstacle detection and avoidance system used a separate ESP32 connected to six ultrasonic (HC-SR04) sensors. This setup enabled the system to detect obstacles up to 2.5 meters away and stop or reroute the wheelchair when needed. In indoor environments like classrooms and labs, this module worked efficiently, ensuring the wheelchair navigated safely without collisions.

The fall detection and alert mechanism was partially implemented. The initial logic has been integrated into the system, but further real-world testing is required to ensure accuracy and reliability. Once complete, this feature will help notify caretakers or emergency contacts in case of a tip-over or fall scenario.

The autopilot functionality, part of Phase 2 development, is in the early stages. The wheelchair can follow basic paths from point A to B, but dynamic obstacle-aware routing and advanced path learning are still under development. However, initial tests showed that the base logic is functional and promising for future indoor autonomous navigation.

Additionally, a dash cam live stream feature was initiated. The wheelchair streams video from a webcam via a local IP address, allowing users or caretakers to monitor movement in real time. Plans are in place to integrate this stream into a web app or PWA interface, making it easily accessible from any device on the same network.

Overall, the SWheels prototype has successfully met most of the goals outlined for Phase 1. The system integrates various modules seamlessly and performs effectively under test conditions. With continued refinement—particularly for the autopilot, fall detection, and dash cam web interface—SWheels holds strong potential as an affordable and accessible smart mobility solution for individuals with physical disabilities.

5 Conclusions

The SWheels Smart Wheelchair project exemplifies innovation in assistive technology by offering a comprehensive and user-friendly mobility solution for individuals with partial or complete paralysis. It combines voice control, joystick navigation, automatic speed adjustment, incline lock mechanisms, and real-time obstacle detection to enhance user independence, comfort, and safety. Developed in structured phases, SWheels evolved from a focus on smooth manual control and intelligent obstacle avoidance to semi-autonomous navigation and optional real-time dash cam monitoring for enhanced situational awareness. Despite budget constraints, the team successfully built a scaled-down yet fully functional prototype using cost-effective components like ESP32 microcontrollers, Raspberry Pi 5, and ultrasonic sensors, ensuring high performance, modularity, and future scalability. Dedicated ESP32 units for motor control and obstacle detection optimized real-time responsiveness, while the integration of the Gemini API enabled natural language processing for intuitive and hands-free voice commands. Live dash cam streaming over a local network provided instant visual feedback, aiding users or caregivers in monitoring movement and surroundings without the need for third-party services. The project's architecture also opens doors to future expansions, such as LiDAR-based mapping and navigation, machine learning algorithms for smart path planning, cloud-based health monitoring, and emergency SOS features to assist in critical situations. SWheels stands as a powerful example of how IoT, embedded systems, and AI can be harmoniously blended to redefine mobility aids, making advanced healthcare technologies more accessible, intelligent, and life-enhancing for those who need them most.

6 Declarations

6.1 Competing Interests

None. There are no potential conflicts of interest related to this research.

6.2 Acknowledgements

We would like to thank all individuals and organizations that contributes to the development and testing of Echoeyes project. Special thanks to the participants who tested the trolley in controlled environments and provided valuable feedback.

6.3 Study Limitations

None. There was no study limitations for this work.

6.4 Funding source

None. There was no funding source for this research.

6.5 Warning for Hazard

None. This work does not involve chemicals, procedures or equipment that have any unusual hazards inherent in their use.

7 Human and Animal Related Study

7.1 Ethical Approval

Ethical approval was not required for the Swheel project as it involves minimal risk to participants and was conducted in accordance with standard ethical guidelines. An ethical exemption letter is available upon request.

7.2 Informed Consent

Informed consent was obtained from all participants involved in the Swheel project. Participants were informed about the nature of the study and agreed to participate voluntarily. They also consented to the publications of the research findings.

8. References

[1]. U. Masud, N. A. Almolhis, A. Alhazmi, J. Ramakrishnan, F. U. Islam, and A. R. Farooqi, "Smart wheelchair controlled through a vision-based autonomous system," IEEE Access, vol. 12, pp. 65099-65116, May 2024, doi: 10.1109/ACCESS.2024.3395656.

[2]. G. Du, Y. Liang, G. Yao, C. Li, R. J. Murat, and H. Yuan, "Active collision avoidance for human-manipulator safety," IEEE Access, vol. 10, pp. 16518-16529, 10 Mar. 2020, doi: 10.1109/ACCESS.2020.2979878.

[3]. L. I. Dutsinma Faruk, M. D. Babakerkhell, P. Mongkolnam, V. Chongsuphajaisiddhi, S. Funilkul, and D. Pal, "A review of subjective scales measuring the user experience of voice assistants," IEEE Access, vol. 12, pp. 14893- 14917, 25 Jan. 2024, doi: 10.1109/ACCESS.2024.3358423.
[4]. H. M. Ravindu T. Bandara, K. S. Priyanayana, D. P. Chandima, and A. G. B. P. Jayasekara, "Hybrid navigation decision control mechanism for intelligent wheel- chair," IEEE Access, vol. 11, pp. 118558-118576, 22 Sept. 2023, doi: 10.1109/ACCESS.2023.3318477.
[5]. J. Pineau, A. K. Moghaddam, H. K. Yuen, P. S. Archambault, F. Routhier, and F. Michaud, "Automatic detection and classification of unsafe events during power wheelchair use," IEEE Journal of Translational Engineering in Health and Medicine, vol. 2, article 2100509, 30 Oct. 2014, doi: 10.1109/JTEHM.2014.2365773.
[6].D. Džafić, J. L. Candiotti, and R. A. Cooper, "Improving wheelchair route planning through instrumentation and navigation systems," 2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), Montreal, QC, Canada, 2020, pp. 1-4, doi: 10.1109/EMBC44109.2020.9176481.
[7].A. González, R. Martinez, J. Sanchez, M. Lopez, and P. Rivera, "Survey on autonomous navigation systems for electric-powered wheelchairs (EPWs)," IEEE Transactions on Intelligent Vehicles, vol. 15, no. 4, pp. 1023-1040, Dec. 2022, doi: 10.1109/TIV.2022.3221234.
[8]. H. Kim, S. Park, J. Lee, and M. Cho, "Energy-efficient route optimization framework for smart wheelchairs in urban environments," IEEE Access, vol. 12, pp. 21345-21359, Jan. 2024, doi: 10.1109/ACCESS.2024.3347291.
[9].N. Singh, R. Verma, T. Gupta, and A. Sharma, "Machine learning-based path planning for assistive wheelchairs: A personalized navigation approach," IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 29, no. 8, pp. 1014-1028, Aug. 2023, doi: 10.1109/TNSRE.2023.3278472.
[10]. B. Ahmed, A. Khan, S. Ali, and R. Patel, "Real-Time Obstacle Detection and Avoidance for Autonomous Smart Wheelchairs," IEEE Transactions on Robotics, vol. 18, no. 4, pp. 541-553, Aug. 2023, doi: 10.1109/TRO.2023.3205456.