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Advancing Assistive Mobility: A ROS-Powered Autonomous Wheelchair with Dynamic Posture Intelligence

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Abstract

This paper presents the design, implementation, and testing of a ROS-powered multi-posture transformation wheelchair integrating autonomous navigation and dynamic seating adjustment. Addressing limitations of traditional wheelchairs in adaptability, comfort, and navigation, the system combines a modular 6063-T5 aluminium frame, custom linear actuators for sitting, relaxing, and bed configurations, and a rear-wheel drive mechanism with high-torque brushless DC motors. The software stack, based on ROS Melodic, incorporates LIDAR-based SLAM for mapping and obstacle avoidance, a navigation stack for path planning, and an ESP32-enabled smartphone interface for manual control. Structural testing validated the frame under a 981 N load, while posture transformation trials confirmed reliable operation with minor jerkiness at transition points. Navigation experiments demonstrated efficient path generation from multiple start positions in controlled environments, with limitations observed in dynamic, cluttered spaces. The remote-control interface was intuitive; though occasional latency was noted.

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Identified areas for improvement include navigation robustness in dynamic settings, targeted structural reinforcement, refined motion profiles for actuators, and optimized wireless communication. Future enhancements will focus on sensor fusion, advanced SLAM algorithms, adaptive motor control via machine learning, and extended real-world trials. The results establish a foundation for next-generation, user-centric mobility solutions that integrate intelligent navigation with customizable posture control to enhance independence and health outcomes.

Keywords: Assistive Technology; Autonomous Navigation; Multi-Posture Wheelchair; Robot Operating System (ROS); Robotics.

1. Introduction

Mobility impairments often necessitate the use of wheelchairs; however, traditional designs frequently lack adaptability, posture flexibility, and intelligent navigation. These limitations can lead to secondary health issues such as poor circulation, muscle atrophy, and discomfort, while also reducing user independence and confidence Reference [1–4]. To address these challenges, this research proposes a Multi-Posture Transformation Wheelchair with ROS-Based Autonomous Navigation, integrating the Robot Operating System (ROS) framework, LIDAR-based environmental sensing, and custom-designed actuators. The system aims to enhance user mobility through advanced autonomous navigation, enable dynamic posture adjustment for improved health outcomes, and provide both manual and autonomous control modes. A key design priority is cost-effectiveness and customizability, achieved through modular construction and 3D-printed components. By combining mechanical adaptability with intelligent navigation, this work contributes to the development of next-generation assistive mobility solutions.

Research in advanced wheelchair technology has increasingly focused on three main areas: autonomous navigation, posture transformation, and robotic integration frameworks. The following literature review highlights key progress and remaining gaps in each area.

1.1. Autonomous Navigation in Wheelchairs

Recent studies emphasize enhancing user safety and navigation efficiency through advanced sensing and control strategies. Developments include controlled obstacle interaction [8], improved sensor fusion for environmental awareness [6], and the adoption of user-centred design principles [10]. Commercial systems, such as LUCI, have demonstrated practical implementation, while academic works [9, 5] highlight the importance of affordability and accessibility. Trends indicate a shift toward balanced autonomy, where the wheelchair adapts to user input while ensuring safety, but challenges remain in navigating complex, dynamic environments and maintaining user trust.

1.2. Posture Transformation and User Comfort

Dynamic seating systems offer health benefits beyond basic comfort. Standing wheelchairs have been shown to improve quality of life and physiological function in paraplegic users [11], while adjustable postures have been linked to enhanced bone density and muscle tone in individuals with spinal cord injuries [12]. Despite these benefits, integration of multi-posture functionality into autonomous wheelchairs remains limited, with most designs focusing on either navigation or seating, but rarely both.

1.3. ROS Integration in Robotic Applications

ROS has emerged as a powerful middleware for robotic systems, offering flexibility in sensor integration, navigation, and control [13]. In wheelchair applications, ROS has been successfully implemented for autonomous navigation [14], though real-time performance optimization and reliability in unstructured environments remain ongoing challenges.

1.4. Gaps in Current Research

While notable progress has been achieved in wheelchair technology, the integration of multi-posture transformation with ROS-based autonomous navigation remains largely underexplored. Several key research gaps persist, limiting the full realization of such systems in real-world applications. One of the primary challenges is the real-time performance optimization of ROS in dynamic, human-centric environments, where unpredictable movement patterns and rapid environmental changes can affect navigation accuracy and safety. Additionally, there is a need for broader application of user-centered design principles to complex, multi-functional wheelchairs, ensuring that posture transformation capabilities are intuitive, accessible, and tailored to diverse user needs.

From an economic perspective, the development of cost-effective solutions that combine autonomous navigation with posture adaptability is essential for making advanced assistive technologies more widely accessible. Furthermore, comprehensive real-world validation of integrated systems is necessary to assess performance, safety, and usability beyond controlled laboratory settings. Finally, the exploration of AI and machine learning offers an untapped opportunity for adaptive navigation and intelligent posture control, potentially enabling systems that learn and optimize their behavior based on user habits and environmental conditions. Addressing these gaps could significantly advance the state of assistive mobility solutions, paving the way for ROS-powered, dynamically adaptable wheelchairs that enhance both functional independence and long-term health outcomes for users.

2. Methodology

2.1. ROS Integration in Robotic Applications

The hardware architecture of the proposed ROS-powered multi-posture transformation wheelchair was designed to be structurally robust, modular, and sensor-integrated for autonomous navigation. The design prioritized a high strength-to-weight ratio, cost-effectiveness, and ease of customization for future upgrades.

2.1.1. Frame Structure

The wheelchair frame is constructed from 6063-T5 aluminium extrusion for its optimal mechanical strength, lightweight properties, and modular adaptability. The design is divided into four key modules: base frame, seat, backrest, and leg rest, each capable of independent modification or replacement without requiring full structural redesign. The base frame serves as the primary load-bearing component and houses the electronics compartment.

It incorporates molded brackets for precise linear actuator alignment. The seat module includes height adjustment, a tilt mechanism, and removable cotton cushions over a rubber sheet covering for improved comfort. The back module enables posture adjustments between 90° and 180° using a motor-driven gear and rod system for optimal force transfer. The leg module provides adjustable support from 90° to 180°, with extendable footrests for ergonomic positioning. The overall wheelchair dimensions and module placements are shown in Figure 1, while the fully extended bed mode configuration is illustrated in Figure 2.

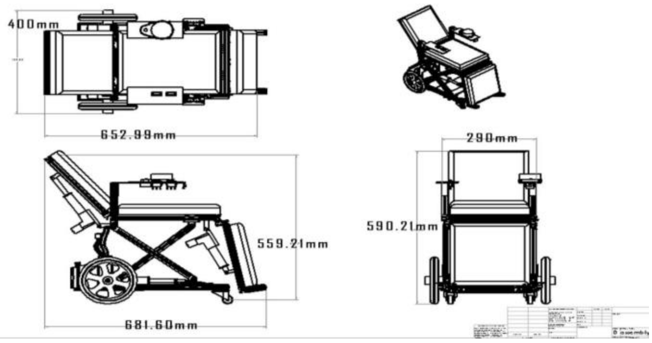


Figure 1: CAD-based orthographic and isometric dimensional views of the multi-posture wheelchair, showing key structural dimensions

Figure 2: Backrest and leg-rest modules in maximum extended 'bed mode' position (180-degree configuration)

2.1.2. Actuator System

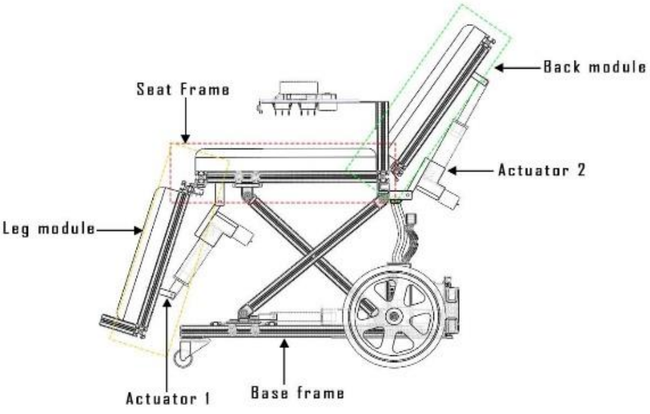


Figure 3: Side view showing the position of linear actuators for independent backrest and leg-rest control

Dynamic posture transformation is facilitated by custom-built linear actuators, enabling smooth transitions between sitting, relaxing, and bed modes. Placement and kinematics were optimized using SolidWorks 3D modelling and virtual simulation. Detailed kinematic analysis determined the necessary stroke length, torque, and acceleration profiles. High-torque, power-efficient motors were selected based on load capacity and size constraints. A microcontroller-based control unit was implemented for synchronized movement, safety interlocks, overload protection, and positional feedback. The actuators employ lead screw mechanisms to convert rotary motion into precise linear displacement (Figure 3), with refined acceleration/deceleration profiles to reduce jerk during movement.

2.1.3. Wheel Drive Mechanism

A rear-wheel drive system was selected for the wheelchair to provide optimal traction, stability, and maneuverability, especially during posture transitions when the center of gravity shifts. This configuration supports both indoor and outdoor operation while maintaining control precision under varying load distributions. The drive system incorporates high-torque brushless DC motors directly coupled to the rear wheels, eliminating the need for complex transmission systems and thereby reducing mechanical losses and potential failure points. The large-diameter, puncture-resistant rear wheels are equipped with all-terrain tread patterns to ensure reliable grip on a variety of surfaces without causing damage to indoor flooring. Complementing the rear wheels, swivel front caster wheels enable a tight turning radius, improving navigability in confined indoor environments. Additionally, an independent suspension system is integrated to maintain stability and comfort when operating over uneven terrain. Control of the drive system is managed by an electronic control unit (ECU), which governs differential steering, variable speed control, and anti-tip safety features. This integration ensures a balance between performance, safety, and user comfort during both autonomous and manual operation modes.

2.2. Software Implementation

The software stack is based on ROS Melodic running on Ubuntu 18.04, selected for its stability, modularity, and proven performance in robotic navigation systems.

2.2.1. Wheel Drive Mechanism

The wheelchair’s ROS environment integrates: Navigation Stack for global and local path planning, LIDAR and odometry sensor drivers for continuous data acquisition, and Custom ROS nodes for wheelchair-specific control logic. Figure 4 demonstrates a simulation of the wheelchair’s ROS-based navigation within the Gazebo environment.

2.2.2. Autonomous Navigation

Navigation relies on LIDAR-based Simultaneous Localization and Mapping (SLAM) for real-time environmental perception. The process includes continuous LIDAR scanning for obstacle detection, SLAM algorithm for map generation and localization, ROS path planning algorithms for optimal route calculation, and Obstacle avoidance via global and local cost maps.

2.2.3. ESP32 Remote Control

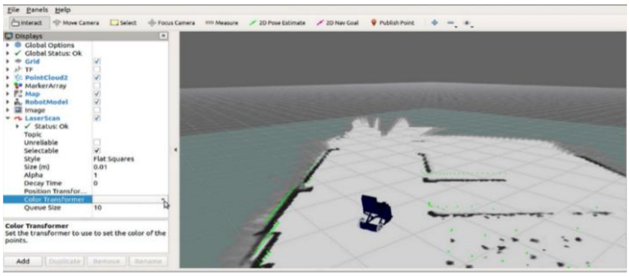
An ESP32 module enables smartphone-based manual control, with seamless mode switching between autonomous and manual operation. Wi-Fi connectivity allows low-latency communication, and the companion app supports direction control, speed adjustment, and safety overrides.

2.3. Testing Methodology

Testing was conducted to validate structural integrity, posture transformation performance, and autonomous navigation.

2.3.1. Structural Testing

Finite Element Analysis (FEA) using SolidWorks was performed with a 981 N load to simulate maximum usage conditions. The results confirmed structural stability without deformation (Figure 5).



Global Options
Global Status: Ok
Grid ☑
TF ☐
PointCloud2 ☑
MarkerArray ☐
Map ☑
RobotModel ☑
Image ☐
LaserScan ☑
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Style Flat Squares
Size (m) 0.01
Alpha 1
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Color Transformer
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Figure 4: ROS-Gazebo simulation of wheelchair movement for navigation stack validation

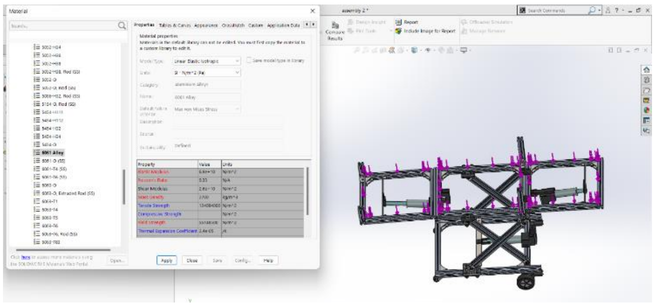


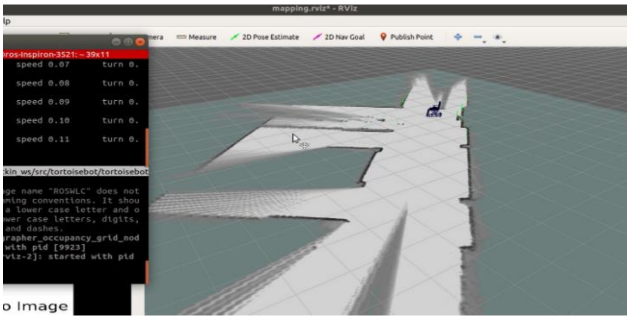
Figure 5: SolidWorks structural load analysis of aluminium extrusion frame under 981N applied force

2.3.2. Posture Transformation Testing

The actuator system was evaluated for range, speed, and smoothness of motion. Both backrest and leg-rest modules could be independently adjusted from 0° to 90°, with 1° precision using pushbutton control.

2.3.3. Navigation Testing

Experiments were conducted on the 2nd floor of the University College of Jaffna, using odometry, LIDAR, and predefined routes. The ROS navigation stack generated occupancy grid maps (Figure 7) and 2D maps of the testing area (Figure 8). Velocity commands were published to the cmd_vel topic, converted into motor commands for precise movement. The global planner determined optimal routes, while the local planner adapted to real-time obstacles.



```
ros-inspiron-3521: ~ 39x11
   speed 0.07       turn 0.

   speed 0.08       turn 0.

   speed 0.09       turn 0.

   speed 0.10       turn 0.

   speed 0.11       turn 0.
```

```
kin ws/src/tortoisebot/tortoisebot
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 a lower case letter and o
wer case letters, digits,
 and dashes.
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rviz-2]: started with pid
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Figure 6: Mapping process showing live LIDAR data acquisition and integration in ROS

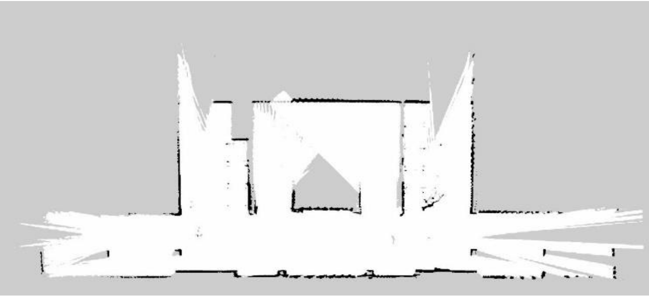

Figure 7: 2D SLAM-generated map of University College of Jaffna-2nd Floor

Figure 8: Fully assembled autonomous wheelchair prototype in testing environment

3. Results

The initial testing of the ROS-powered multi-posture transformation wheelchair produced encouraging outcomes across structural, mechanical, navigation, and control subsystems, while also identifying areas for refinement. Results are reported for each major performance domain.

3.1. Structural Performance

The 6063-T5 aluminium extrusion frame demonstrated good stability and load-bearing capacity under test conditions, confirming its suitability for wheelchair construction. The finite element analysis validated the design's ability to withstand the maximum specified load; however, slight flex was observed in the seat and backrest under peak loading conditions. This suggests that future iterations may benefit from reinforcement at stress concentration points, such as through additional support struts or the use of thicker-gauge aluminium in high-load areas.

3.2. Posture Transformation

The custom linear actuator system successfully executed transitions between sitting, relaxing, and bed configurations. Motion was generally smooth, supporting the effectiveness of the kinematic design and actuator placement strategy. User feedback confirmed satisfaction with posture range and ergonomic comfort. However, during some transitions, particularly at initiation and termination, minor jerkiness was noted. This indicates a need for refinement in motor control algorithms, potentially through improved acceleration/deceleration profiles or PID-based smoothing. The posture transformation performance remained consistent across repeated trials, confirming mechanical reliability.

3.3. Autonomous Navigation

The wheelchair was evaluated in multiple navigation trials where its initial position was randomized within the test environment. In each trial, the system successfully computed an efficient path to a predefined goal while avoiding detected obstacles.

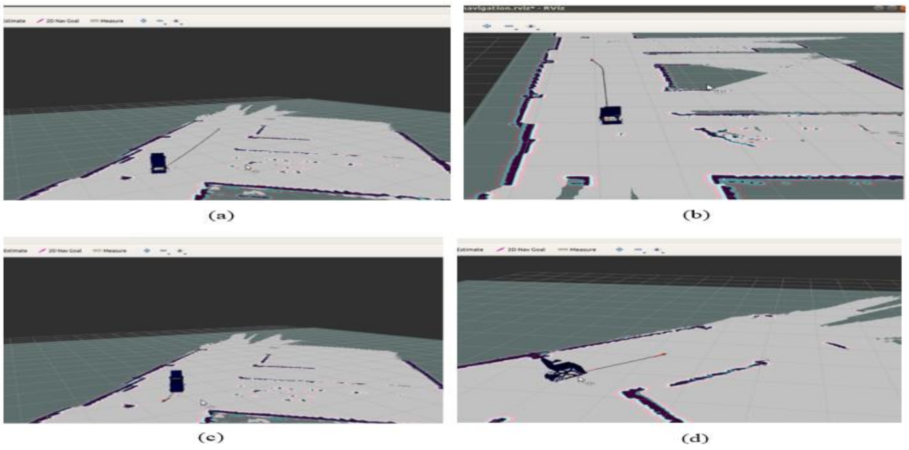

Figure 9: Navigation paths generated by the wheelchair's ROS-based autonomous system from different initial positions to a fixed goal location: (a) Path generated from starting position 1 showing obstacle avoidance; (b) Path generated from starting position 2 with optimal route computation; (c) Path generated from starting position 3 in a partially obstructed environment; (d) Path generated from starting position 4 with adaptive replanning in response to environmental constraints

The LIDAR-based SLAM system generated accurate maps of simple environments, enabling the ROS Navigation Stack to plan and execute safe routes. Path optimization was achieved through shortest-path algorithms, and the system dynamically adjusted its trajectory in response to static obstacles. Figure 10 illustrates example navigation paths generated when starting from different initial positions, showing consistent goal-reaching performance under varied conditions. While performance was strong in controlled scenarios, complex environments with dynamic obstacles revealed limitations in localization stability and obstacle prediction. These results indicate the need for sensor fusion with depth cameras or ultrasonic arrays and more advanced SLAM algorithms to improve navigation robustness in real-world settings.

3.4. Remote Control Functionality

The ESP32-based smartphone control interface provided effective manual operation as an alternative to autonomous mode. Users reported the interface to be intuitive and responsive, supporting the project's user-centered design goals. However, mild latency was noted during rapid maneuvering or when executing complex sequences. This communication lag, while not critical, may impact precision in high-demand situations. Planned improvements include optimized wireless protocols and exploration of Bluetooth Low Energy (BLE) or hybrid communication modes to reduce delay.

3.5. Challenges and Adjustments

Early load testing revealed gear damage in the original wheel drive motors, requiring their replacement with higher-torque alternatives. This outcome underscores the importance of aligning drive motor specifications with the anticipated operational loads to ensure long-term reliability. Insights gained from the iterative testing process directly informed several key improvements, including the development of targeted frame reinforcement strategies, refinement of motor control algorithms to achieve smoother posture transitions, enhancement of autonomous navigation resilience in varied environments, and reduction of communication latency to improve responsiveness during remote operation.

4. Discussion

The development and initial testing of the ROS-powered multi-posture transformation wheelchair represent a significant advancement toward intelligent, adaptive mobility solutions for individuals with disabilities. This section interprets the experimental findings in the context of the project objectives, compares them with existing literature, evaluates their broader implications, identifies current limitations, and proposes targeted directions for future research and development.

4.1. Achievement of Project Objectives

4.1.1. Mobility and Autonomy Enhancement

The ROS-based navigation system demonstrated reliable autonomous operation in controlled environments, supporting the primary objective of improving independent mobility. These findings are consistent with earlier work on autonomous wheelchair navigation [15], while extending functionality by incorporating dual-mode control through the ESP32-based remote system. This dual-mode feature addresses a common limitation in prior designs [16], where the lack of manual override restricted user autonomy.

4.1.2. Multi-Posture Transformation

The custom linear actuator system achieved its intended function of enabling sitting, relaxing, and bed configurations, thus fulfilling the objective of enhancing user comfort and mitigating health risks from prolonged static seating. This aligns with prior research demonstrating the medical benefits of variable seating positions. However, the observed jerkiness during some transitions highlights the need for refined motor control, potentially via advanced motion profiling or PID tuning to ensure smoother posture adjustments.

4.1.3. User-Friendly Interface

Positive feedback regarding the smartphone control application validates the project's user-centred design approach. The intuitive interface supports independent operation and aligns with accessibility principles found in recent assistive mobility research. This outcome strengthens the case for integrating consumer-grade, familiar devices into mobility aid control systems.

4.2. Implications of Findings

The results demonstrate the technical feasibility of integrating autonomous navigation with dynamic posture transformation within a single mobility platform. This combination addresses both functional mobility and long-term health benefits, two aspects often treated independently in wheelchair design. Nevertheless, the findings highlight important trade-offs. First, there is a balance between structural flexibility and modularity—while a lightweight, modular frame enhances adaptability and ease of maintenance, it also introduces slight flex under heavy loads, indicating the need for targeted reinforcement. Second, navigation robustness is challenged by environmental complexity; the system performs well in controlled scenarios but requires algorithmic and sensory enhancements to maintain reliability in unstructured or dynamic environments. Finally, control adaptability must be matched with system smoothness; although the wide range of motion enhances functional versatility, ensuring comfort during posture transitions remains a critical factor for user satisfaction.

4.3. Limitations of the Current Prototype

The current prototype demonstrates significant promise but requires further optimization in several key areas. Navigation in dynamic environments remains a challenge, as performance degrades in complex or changing surroundings, highlighting the need for enhanced perception and path planning capabilities. Structural reinforcement is also necessary, given the observed frame flex under high loads, which could be mitigated through selective strengthening of critical stress points. In terms of motion performance, motor control refinement is needed to address the minor jerkiness experienced during posture transitions, primarily due to limitations in the current acceleration profiles. Additionally, wireless communication latency, while not critical, can introduce delays during remote operation, potentially affecting responsiveness in high-demand scenarios. Finally, the system has undergone only limited real-world validation; although initial user feedback is positive, extensive trials in varied and realistic settings are essential to fully assess usability, reliability, and long-term performance.

4.4. Future Directions

To address the identified limitations and further align with the project vision, future work should focus on the following key areas:

- Integrating sensor fusion technologies by combining depth cameras and ultrasonic sensors with LIDAR to improve obstacle detection accuracy and enhance environmental mapping capabilities.
- Implementing advanced SLAM techniques such as graph-based methods or deep-learning-assisted approaches to achieve more robust localization and mapping in dynamic, real-world environments.
- Conducting structural optimization through finite element analysis to reinforce high-stress zones while maintaining the modularity and lightweight characteristics of the frame.
- Applying machine learning for motion control to develop predictive and adaptive adjustment profiles, enabling smoother and more seamless posture transitions.
- Carrying out extended field trials in diverse indoor and outdoor environments with a broad range of user groups to validate the wheelchair’s performance, safety, and user satisfaction under realistic operating conditions.
- Designing energy-efficient actuators and optimized power management systems to increase operational range and improve the long-term reliability of the mobility platform.
- Incorporating health monitoring capabilities by embedding physiological sensors that link posture adjustments to real-time user health data, enabling proactive and personalized mobility assistance.

These targeted improvements build upon the current achievements and position the design as a next-generation, adaptive, ROS-powered mobility system capable of significantly enhancing both the independence and overall well-being of users.

5. Conclusion

The development and initial testing of the ROS-powered multi-posture transformation wheelchair mark a significant advancement toward next-generation assistive mobility solutions for individuals with disabilities. This work demonstrates the technical feasibility of integrating autonomous navigation with dynamic posture transformation into a single, adaptive platform, addressing both functional mobility needs and long-term health benefits, areas often considered separately in traditional wheelchair design. Key achievements include the successful realization of a custom actuator system enabling smooth transitions between sitting, relaxing, and bed modes; the implementation of a ROS-based navigation system capable of autonomous operation in controlled environments; and the integration of ESP32-enabled remote control for dual-mode manual and autonomous operation. Together, these features have the potential to enhance user independence, comfort, and safety beyond what is possible with conventional wheelchairs.

Nonetheless, the prototype also revealed critical areas for improvement, including navigation robustness in dynamic environments, structural reinforcement to reduce frame flex under high loads, refinement of motor control algorithms for smoother posture transitions, and optimization of wireless communication to minimize latency. Addressing these challenges will require iterative design cycles, rigorous real-world testing, and user-centred validation to ensure that the system meets the diverse needs of its intended users. In conclusion, this research establishes a strong foundation for future work aimed at creating a next-generation, adaptive, ROS-powered mobility system that seamlessly integrates intelligent navigation, customizable posture control, and ergonomic design. The insights gained from this prototype not only inform targeted technical improvements but also pave the way for transformative innovations in assistive technology, advancing both the independence and overall quality of life for individuals with mobility impairments.

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