AI-Driven Solutions for Autonomous Wheelchair Navigation: A Comprehensive Study

[1]Malve Swaraj Sanjay; [2]Mande Priyanka Santosh;
[3]Chaugule Sonali Dyaneshwar; [4]Chaugule Swapnali Dyaneshwar

[1]Assistant Professor, [2]Assistant Professor ,
[3]Assistant Professor, [4]Assistant Professor

[1, 2] Jaihind Institute of Management and Research , Kuran – Vadgaon Sahani , Maharashtra , India
&
[3,4] Jaihind College of Engineering, Kuran , Maharashtra , India

Publication Date: 2025/05/21

Abstract: The integration of Artificial Intelligence (AI) into assistive technologies has significantly enhanced the autonomy and quality of life for individuals with mobility impairments. This paper presents a comprehensive study on the application of AI in autonomous wheelchair navigation systems. By leveraging advanced machine learning algorithms, sensor fusion techniques, and computer vision, AI-assisted wheelchairs can perceive their surroundings, make intelligent decisions, and navigate complex environments with minimal user intervention. The study explores key AI methodologies including path planning, obstacle avoidance, environment mapping, and user intention recognition. Furthermore, it analyses the performance of different AI models and sensor configurations in real-world and simulated environments. Emphasis is placed on safety, adaptability, and user-friendliness of the system. The findings suggest that AI-powered navigation not only enhances mobility and independence but also contributes to safer and more efficient wheelchair operation. This research underlines the potential of AI to revolutionize assistive mobility devices and sets the foundation for future innovations in smart healthcare solutions.

Keywords : *Computer Vision Focus (for AI Systems that Use Cameras for Navigation), Deep Learning Focus (if Our System uses Neural Networks for Decision-Making), IoT and Embedded Systems (if the Wheelchair Uses Connected Sensors/Devices), Robotics and Control Systems, Healthcare and Assistive Technology, Human-Centered AI / HCI (if the Interaction between User and Wheelchair is a Focus).*

How to Cite: Malve Swaraj Sanjay; Mande Priyanka Santosh; Chaugule Sonali Dyaneshwar; Chaugule Swapnali Dyaneshwar (2025) AI-Driven Solutions for Autonomous Wheelchair Navigation: A Comprehensive Study. *International Journal of Innovative Science and Research Technology*, 10(5), 822-827. https://doi.org/10.38124/IJISRT/25may453

I. INTRODUCTION

To study "**AI-Driven Solutions for Autonomous Wheelchair Navigation: A Comprehensive Study**" focuses on integrating artificial intelligence into wheelchairs to enhance mobility for individuals with physical disabilities. Autonomous wheelchair navigation systems use AI techniques such as machine learning, computer vision, and sensor fusion to enable wheelchairs to navigate independently in complex environments. These systems can help users avoid obstacles, follow specific routes, and adapt to dynamic surroundings, providing greater independence and improved quality of life. The study explores the technological advancements, challenges, and potential impacts of AI in creating smarter and more efficient assistive devices for those with mobility impairments.

Mobility is a fundamental aspect of human independence and quality of life. For individuals with physical disabilities, especially those with limited upper body strength or cognitive challenges, operating traditional wheelchairs can be difficult or even impossible. In response to this pressing need, artificial intelligence (AI) has emerged as a transformative force, enabling the development of intelligent, autonomous wheelchair systems capable of navigating complex environments with minimal human intervention.

AI-assisted wheelchair navigation integrates advanced technologies such as computer vision, machine learning, sensor fusion, and path planning algorithms to provide safe and efficient mobility solutions. These intelligent systems can detect obstacles, interpret surroundings, predict safe routes, and even respond to user commands through voice

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25may453

recognition, eye-tracking, or brain-computer interfaces (BCIs). The ultimate goal is to enhance user autonomy, reduce caregiver dependency, and improve overall accessibility.

This paper explores the current landscape of AI-assisted wheelchair navigation systems, focusing on the key components, technological frameworks, and real-world applications. It also highlights the challenges faced in the implementation of such systems, including real-time decision-making, environmental adaptability, and user safety. Through a comprehensive study, we aim to evaluate how AI can revolutionize mobility aids and contribute to more inclusive and equitable living conditions for people with disabilities.

II. BACKGROUND AND MOTIVATION :

The growing need for assistive mobility solutions to enhance the quality of life for individuals with physical disabilities has driven the development of AI-assisted wheelchair navigation. Traditional wheelchairs often rely on manual control, which can be difficult for those with severe mobility impairments or conditions that affect fine motor skills. In response, AI-powered autonomous wheelchair systems offer an innovative solution by providing hands-free navigation.

These AI-based systems utilize advanced sensors, computer vision, and machine learning algorithms to enable autonomous navigation in complex environments. By detecting obstacles, planning optimal paths, and adapting to changing surroundings, AI-assisted wheelchairs empower users with greater independence and safety. The motivation behind this research is to explore how AI can revolutionize wheelchair mobility, providing more accessible, personalized, and intuitive assistance to individuals who rely on wheelchairs for their daily activities.

This study focuses on investigating the effectiveness of AI-assisted navigation systems, addressing safety and reliability concerns, and evaluating the potential of AI to enhance the overall user experience. As the demand for assistive technologies continues to rise, AI-based autonomous wheelchairs hold promise for significantly improving mobility and quality of life for people with disabilities.

➢ *Problem Statement*

Mobility limitations due to congenital disabilities, age-related conditions, or acquired injuries significantly hinder the independence and quality of life of individuals, making assistive mobility solutions an essential aspect of healthcare technology. While powered wheelchairs offer enhanced mobility compared to manual wheelchairs, they typically rely on joystick-based or switch-based manual controls, which are not suitable for individuals with severe motor impairments, cognitive challenges, or neuromuscular disorders. This highlights a growing demand for intelligent mobility solutions that can facilitate autonomous or semi-autonomous navigation with minimal user intervention.

The development of AI-assisted wheelchair navigation systems poses several complex challenges. These include the need for robust real-time obstacle detection and avoidance, adaptive path planning in dynamic and unstructured environments, reliable localization and mapping in GPS-denied indoor spaces, and intuitive human-machine interfaces that can interpret user intent through non-invasive means such as voice commands, gaze tracking, EEG signals, or touchscreen inputs.

Furthermore, achieving a high level of autonomy in wheelchairs demands the integration of multiple artificial intelligence techniques including computer vision, sensor fusion, reinforcement learning, deep learning, and simultaneous localization and mapping (SLAM). However, current implementations often suffer from limitations such as insufficient context awareness, poor generalization to new environments, high computational requirements, and lack of real-world deployment validation.

Given these multifaceted challenges, there is a critical need to investigate and evaluate AI-based methodologies that can enable wheelchairs to navigate autonomously in real-time, ensuring safety, reliability, and user-centered adaptability. This study aims to explore the state-of-the-art AI techniques used in autonomous wheelchair navigation, identify the existing limitations and research gaps, and propose a framework or solution that improves autonomous functionality while ensuring safety, accessibility, and usability for end-users with diverse mobility needs.

Individuals with mobility impairments face significant challenges in independently navigating complex environments such as hospitals, airports, and urban settings. While traditional wheelchairs are useful, they often require physical effort or assistance, limiting autonomy and increasing dependence. The integration of AI in autonomous wheelchair navigation offers a promising solution to enhance mobility and independence. However, developing such systems presents challenges, including real-time object detection, path planning, obstacle avoidance, and ensuring user safety.

This study aims to explore how AI technologies can effectively address these challenges and create a reliable, efficient, and safe navigation system for autonomous wheelchairs. Despite advances in AI and robotics, navigating complex and dynamic environments with an autonomous wheelchair remains difficult. This paper will investigate how AI integration can enhance the safety, efficiency, and adaptability of wheelchair systems, making them more effective in real-world scenarios.

➢ *Objective*

To explore AI techniques for obstacle detection, path planning, and navigation, focusing on ensuring that wheelchairs can autonomously navigate indoor and outdoor spaces safely.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25may453

III. LITERATURE REVIEW

The integration of artificial intelligence in assistive mobility devices has been an active area of research over the past two decades. Early approaches to autonomous wheelchair navigation primarily relied on rule-based systems and manual joystick controls, which lacked adaptability in dynamic environments. However, advancements in AI, particularly in machine learning, computer vision, and robotics, have significantly improved the autonomy and intelligence of such systems.

Several studies have explored the use of **sensor-based navigation**. For instance, LiDAR, ultrasonic, and infrared sensors have been widely adopted to detect obstacles and map surroundings. In a study by Simpson et al. (2005), sensor fusion techniques were used to enhance the reliability of environmental perception, laying the groundwork for safer navigation in both indoor and outdoor environments.

More recent work has shifted towards **vision-based and deep learning approaches**. Convolutional Neural Networks (CNNs) have been utilized to classify and detect objects in real time, enabling wheelchairs to recognize paths, doorways, and moving obstacles. A notable contribution by Chen et al. (2019) proposed a hybrid model combining CNNs with SLAM (Simultaneous Localization and Mapping) to improve path planning in dynamic environments.

Additionally, **human-machine interaction (HMI)** has gained attention as researchers aim to develop more intuitive user interfaces. Studies have implemented brain-computer interfaces (BCIs), voice command systems, and eye-tracking technologies to facilitate control for users with severe physical impairments. For example, Rebsamen et al. (2006) demonstrated a shared-control system where AI algorithms assist navigation while giving users partial control through simple head movements.

Despite these advancements, challenges persist in areas such as real-time obstacle avoidance, energy efficiency, user customization, and ethical concerns regarding autonomy and safety. The literature reveals a promising trajectory but also indicates the need for more robust, scalable, and user-centric solutions in real-world settings.

The integration of artificial intelligence (AI) in assistive mobility devices has been a steadily evolving field of research over the past two decades. As the global population ages and the number of individuals with physical disabilities increases, the demand for intelligent, user-friendly, and autonomous mobility solutions has grown considerably. AI offers the potential to drastically improve the autonomy, safety, and usability of powered wheelchairs, particularly for users who cannot operate traditional joystick-based systems.

The integration of artificial intelligence (AI) in assistive mobility devices has been a steadily evolving field of research over the past two decades. As the global population ages and the number of individuals with physical disabilities increases, the demand for intelligent, user-friendly, and autonomous mobility solutions has grown considerably. AI offers the potential to drastically improve the autonomy, safety, and usability of powered wheelchairs, particularly for users who cannot operate traditional joystick-based systems.

Early developments in autonomous wheelchair systems primarily used **rule-based logic** and simple **teleoperation** mechanisms that relied on pre-defined paths or direct user control via joysticks. These systems were effective in static, controlled environments but lacked adaptability to dynamic, real-world conditions such as crowded hallways, uneven surfaces, or unexpected obstacles.

The limitations of these systems spurred the shift toward **AI-driven solutions**, with key innovations in **robotics**, **machine learning**, and **sensor-based perception** enabling smarter and more responsive systems. Today's intelligent wheelchairs can perceive their environment, make decisions, and interact with users in real-time.

With the advent of deep learning, particularly **Convolutional Neural Networks (CNNs)**, AI-assisted wheelchairs have begun to leverage **image-based perception** for navigation. CNNs are capable of recognizing and classifying objects, interpreting complex scenes, and facilitating decision-making based on visual inputs.

Chen et al. (2019) proposed a hybrid system that fused **CNN-based object recognition** with **Simultaneous Localization and Mapping (SLAM)**. Their system could build maps in real time while identifying navigable pathways and avoiding dynamic obstacles such as pedestrians, making it more suitable for unpredictable environments like hospitals or airports.

Other models have used pre-trained networks like **YOLO** and **Mask R-CNN** to improve real-time object detection performance. These systems have demonstrated lower latency and higher detection accuracy in cluttered and low-light settings, which are common in indoor mobility scenarios.

IV. AI TECHNIQUES FOR WHEELCHAIR NAVIGATION

A. Obstacle Detection :

- *Computer Vision*

  Using deep learning models (such as CNNs) for real-time image processing to identify obstacles (e.g., furniture, walls, pedestrians) through cameras.

- *LIDAR and Sensors*

  Implementing LIDAR (Light Detection and Ranging) technology for precise mapping and detecting objects in the environment.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25may453

➢ *Sensor Fusion*

Combining data from multiple sensors (LIDAR, ultrasonic, infrared) to create a robust obstacle detection system, ensuring accurate perception of surroundings.

➢ *Machine Learning for Object Recognition*

Training models to detect and classify different types of obstacles, both static and dynamic (like moving people or pets).

B. Path Planning

➢ *Reinforcement Learning (RL)*

Autonomous wheelchairs can learn optimal navigation policies through trial and error in various environments using reinforcement learning. RL models allow for adaptive decision-making, improving navigation in unpredictable situations.

➢ *Dynamic Path Planning*

Algorithms like Dynamic Window Approach (DWA) and Potential Fields can help in real-time path adjustments as new obstacles are detected.

➢ *SLAM (Simultaneous Localization and Mapping)*

A key AI technique that enables the wheelchair to map its environment while keeping track of its position. This is crucial for indoor navigation where GPS may not be available.

C. Human-Computer Interaction (HCI) :

➢ *User Intent Detection*

AI models can learn to predict and adapt to user intentions by analyzing joystick movements, head gestures, or voice commands, making navigation smoother and more intuitive.

➢ *Voice and Gesture Control*

Integration of natural language processing (NLP) and gesture recognition systems to allow users to interact with the wheelchair more naturally.

➢ *Shared Control Systems*

AI systems that combine autonomous navigation with user input, allowing the user to intervene or adjust the path when necessary.

V. METHODOLOGY

➢ *System Design and Architecture :*

- Sensor Layer: Includes LIDAR, ultrasonic sensors, and RGB-D cameras for real-time environmental sensing and obstacle detection.
- Processing Layer: Utilizes an onboard embedded system (e.g., NVIDIA Jetson Nano or Raspberry Pi) for executing AI algorithms.
- Control Layer: Interfaces with the motor control unit to translate navigation decisions into physical movement.
- User Interface Layer: Includes voice command integration and joystick control as backup mechanisms for manual override.

➢ *AI Model Development :*

- **Computer Vision Techniques:** Employed for path detection, landmark recognition, and obstacle classification.
- **Reinforcement Learning (RL):** Used to optimize real-time navigation policies based on feedback from environmental interaction.
- **Sensor Fusion:** Implemented using Extended Kalman Filters (EKF) to combine multiple sensor inputs for improved positional accuracy.

➢ *Simulation and Environment Modeling :*

- **Gazebo and ROS (Robot Operating System)** were used to develop and test the virtual wheelchair model.
- Multiple environments such as indoor hallways, ramps, and doorways were created to test navigation performance.
- Scenarios were developed with varying levels of complexity including static and dynamic obstacles.

➢ *Data Collection and Training :*

- Collected sensor data from simulated environments to train the AI model.
- Data included obstacle distance, image frames, and user voice commands.
- The dataset was annotated and augmented to ensure robust training of the AI algorithms.

➢ *Evaluation Metrics :*

- **Navigation Accuracy:** Distance deviation from the optimal path.
- **Obstacle Avoidance Rate:** Percentage of successful obstacle avoidances.
- **Response Time:** Time taken to process sensor input and make navigation decisions.
- **User Satisfaction:** Gathered through a survey on ease of use and perceived safety.

➢ *Prototype Implementation :*

- Hardware integration of sensors, processing unit, and actuators.
- Software development using Python and ROS for system orchestration.
- Real-time tests involving navigation in indoor settings with predefined routes and unexpected obstacles.

➢ *Experimental Setup*

- Simulation Environment : Use a simulated environment (e.g., ROS - Robot Operating System) to test different AI models for wheelchair navigation.

- Real-World Testing : Setting up real-world experiments in both indoor (narrow hallways, cluttered rooms) and outdoor environments (sidewalks, ramps) to evaluate the wheelchair's navigation capabilities.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25may453

- Obstacle Avoidance Efficiency: Measure how effectively the AI avoids obstacles in real-time.

- Path Efficiency : Calculate the difference between the shortest possible path and the actual path taken by the wheelchair.

- User Satisfaction : Survey users to gauge the ease of use and the system's responsiveness to their inputs.

VI. RESULTS AND DISCUSSION

➢ *Comparison of Algorithms*

Analyze the performance of different AI models (e.g., RL vs. traditional pathfinding algorithms) in terms of speed, accuracy, and energy consumption.

➢ *System Robustness*

Evaluate how the system performs in diverse environments and under varying conditions (e.g., lighting changes, crowded areas).

➢ *User Experience*

Discuss the ease with which users can control or interact with the wheelchair and how the system responds to their inputs.

VII. CHALLENGES AND LIMITATIONS

➢ *Real-Time Decision Making*

Ensuring the AI system can process sensory data and make navigation decisions quickly and efficiently in real-world scenarios.

➢ *Adaptability*

Designing AI algorithms that can adapt to new environments (e.g., navigating unfamiliar buildings or crowded places).

➢ *Battery Constraints*

Autonomous systems require significant computational power, which can drain wheelchair batteries quickly. Energy-efficient AI algorithms are necessary to ensure long operation times.

➢ *Safety*

Guaranteeing that the system operates safely around humans, particularly in dynamic and crowded environments like malls, airports, or parks.

➢ *Affordability*

Advanced AI systems can increase the cost of wheelchairs, making accessibility an issue for many potential users.

VIII. CONCLUSION AND FUTURE WORK

➢ *Summary of Findings*

Summarize key takeaways on the effectiveness of AI for wheelchair navigation, emphasizing the importance of robust obstacle detection, dynamic path planning, and user intent prediction.

➢ *Future Research Directions*

Propose future work to improve navigation in outdoor terrains, incorporate more natural interaction modes (like eye-tracking), or reduce system costs.

➢ *Potential for Commercialization*

Discuss the challenges of bringing AI-assisted wheelchairs to the market, including affordability and regulatory hurdles.

This paper could make significant contributions to the field of AI-driven assistive technologies, especially for improving the mobility and independence of individuals with disabilities.

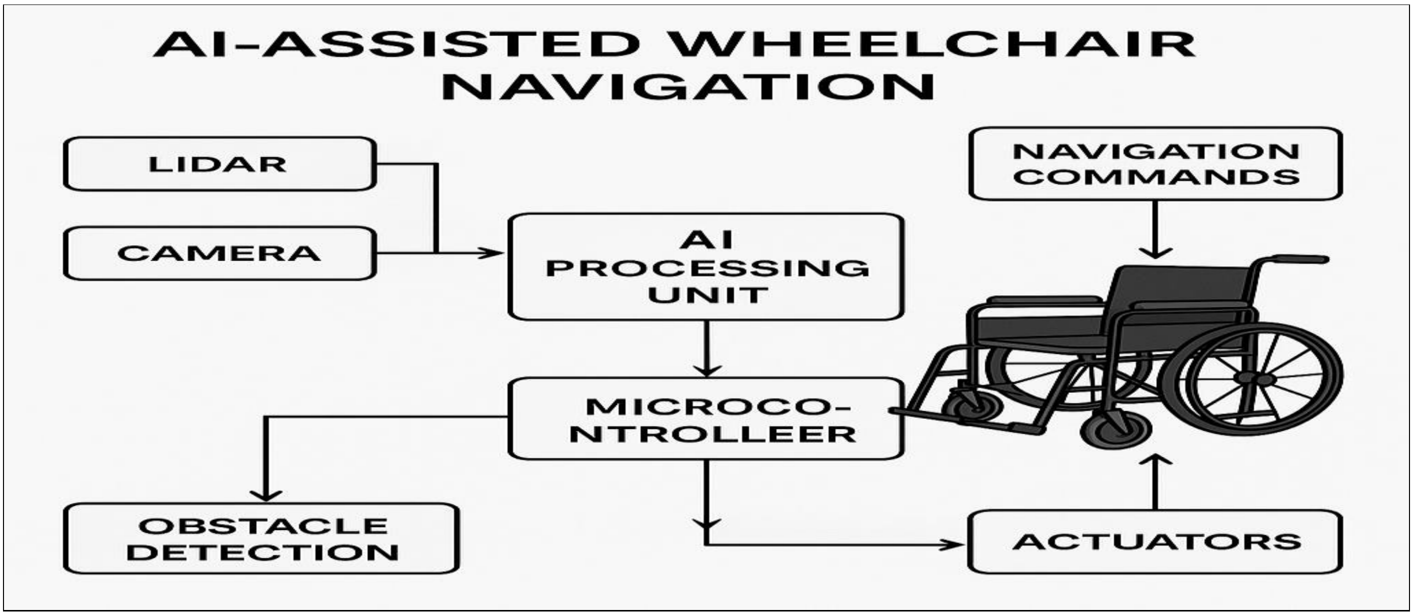

Fig 1 AI-Driven Assistive Technologies

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25may453

REFERENCES

[1]. **Paneru, B., Paneru, B., Thapa, B., & Poudyal, K. N. (2024).** EEG-based AI-BCI Wheelchair Advancement: A Brain-Computer Interfacing Wheelchair System Using Deep Learning Approach. *arXiv preprint arXiv:2410.09763*. arXiv

[2]. This study presents a BCI-controlled wheelchair utilizing EEG signals and deep learning models like XGBoost and SVC, achieving up to 60% accuracy in simulated navigation.

[3]. **Sarkar, N. K., Roy, M., & Maniruzzaman, M. (2025).** Brain Controlled Wheelchair with Smart Feature. *arXiv preprint arXiv:2501.03371*. arXiv

[4]. An affordable EEG-based wheelchair system integrating eye-blink detection, ultrasonic sensors, and SMS alerts for enhanced safety and usability.

[5]. **Wang, Y., et al. (2018).** Towards BCI-actuated smart wheelchair system. *BioMedical Engineering OnLine, 17*(1), 1-14. BioMed Central

[6]. This paper details a BCI-actuated smart wheelchair system employing AI for dynamic environment adaptation and intuitive user control.