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A review on smart robotic wheelchairs with advancing mobility and independence for individuals with disabilities

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Abstract

This research paper presents a comprehensive review of smart robotic wheelchairs and their impact on enhancing mobility and independence for individuals with disabilities. Traditional wheelchairs often impose limitations on users, resulting in reduced freedom of movement and limited accessibility. The emergence of smart robotic wheelchairs offers a promising solution to address these challenges. This paper provides an overview of wheelchair technology, identifies the specific challenges faced by individuals with disabilities, and explores the advantages and limitations of smart robotic wheelchairs through a review of previous research studies. The features and functionalities of smart robotic wheelchairs, including navigation and obstacle avoidance capabilities, autonomous and semi-autonomous modes, and customizable control options, are discussed. User experience and performance evaluation, along with the impact on mobility and independence, are examined. The paper concludes with future directions and recommendations to guide further research and development in this important field, aiming to empower individuals with disabilities and improve their quality of life.

Keywords: Assistive technology, Human-machine interface, Navigation systems, Obstacle avoidance, User-centered design.

1. Introduction

In recent years, the field of assistive technology has witnessed remarkable advancements, aiming to enhance the lives of individuals with limited mobility. Among these groundbreaking innovations, smart robotic wheelchairs have emerged as a remarkable solution that is revolutionizing the way individuals with disabilities navigate their surroundings (Gallagher et al., 2022). These technologically advanced wheelchairs leverage cutting-edge robotics, artificial intelligence, and sensor technologies to offer an unprecedented level of independence, autonomy, and safety to wheelchair users.

Traditional wheelchairs have undoubtedly served as a vital mobility aid for individuals with physical disabilities, enabling them to move around and engage with their environments. However, conventional wheelchairs often come with limitations, such as the need for manual propulsion, difficulties in maneuvering in tight spaces, and a lack of adaptability to different terrains (Cui et al., 2022). Smart robotic wheelchairs address these challenges by incorporating intelligent systems that can perceive, interpret, and respond to the surrounding environment, empowering users to navigate with greater ease, flexibility, and confidence.

One of the key features of smart robotic wheelchairs is their ability to autonomously navigate through complex environments. Equipped with advanced sensors like LiDAR, cameras, and depth sensors, these wheelchairs can map their surroundings in real-time, identifying obstacles, pathways, and potential hazards. The onboard artificial intelligence algorithms process this information, making intelligent decisions to ensure smooth and safe navigation (Ahmad et al., 2021). Users can simply input their desired destination, and the smart wheelchair takes care of the rest, avoiding collisions, adjusting speed, and even finding the most efficient routes. Furthermore, smart robotic wheelchairs are designed to enhance user comfort and convenience. Many models offer features like adjustable seating positions, personalized seating support, and automated adjustments based on the user's body posture and weight distribution. This promotes optimal ergonomics and reduces the risk of pressure sores and musculoskeletal issues associated with prolonged wheelchair use (Xavier Macedo de Azevedo et al., 2022). Additionally, smart wheelchairs often integrate connectivity options, allowing users to control their chairs via smart phones, tablets, or other wearable devices, further enhancing their overall mobility experience.

Moreover, smart robotic wheelchairs cater to the diverse needs and preferences of users. They can adapt to various terrains, including inclined surfaces, rough terrain, and uneven ground, ensuring a smooth and stable ride. Some models even offer features like standing capabilities, allowing users to transition from a seated to a standing position, promoting better blood circulation, improved reach, and facilitating social interactions at eye level (Hampshire et al., 2022). These innovative functionalities contribute to the overall well-being, independence, and social inclusion of individuals with mobility impairments. Smart robotic wheelchairs are transforming the mobility landscape for individuals with disabilities, empowering them to navigate their surroundings with newfound independence, confidence, and safety. By combining state-of-the-art robotics, artificial intelligence, and sensor technologies, these wheelchairs offer advanced navigation capabilities, enhanced comfort, adaptability to various terrains, and customization options. With each new development, smart robotic wheelchairs are pushing the boundaries of what is possible in assistive technology, opening doors to greater mobility and an improved quality of life for wheelchair users.

1.1 Significance of the proposed study

Smart robotic wheelchairs play a crucial role in transforming the lives of individuals with disabilities, offering unparalleled benefits and opportunities for mobility and independence. These innovative devices have emerged as a groundbreaking solution, addressing the limitations of traditional wheelchairs and assistive devices. The importance of smart robotic wheelchairs lies in their ability to revolutionize the daily experiences of individuals with disabilities, promoting physical, psychological, and social well-being (Czaja and Ceruso, 2022).

First and foremost, smart robotic wheelchairs significantly enhance mobility and independence. With intelligent navigation and obstacle avoidance capabilities, these wheelchairs empower users to navigate their environment with ease, overcoming barriers and accessing spaces that were previously challenging or inaccessible (Carlson and Demiris, 2012). The customization and adaptability features of smart robotic wheelchairs allow individuals to tailor the wheelchair to their specific needs, ensuring a personalized and comfortable experience. Moreover, the integration of assistive technologies further enhances functionality, enabling individuals to interact with their surroundings and perform tasks that were once difficult or impossible.

In terms of physical health, smart robotic wheelchairs contribute to improved overall well-being. By promoting increased mobility and physical activity, these devices help individuals maintain or improve their physical fitness, which is crucial for preventing secondary health issues related to sedentary lifestyles. With the ability to move more freely and engage in activities, individuals with disabilities experience enhanced cardiovascular health, better muscle tone, improved joint mobility, and increased overall endurance. Additionally, smart robotic wheelchairs provide support for rehabilitation and therapy, facilitating the recovery process and enabling individuals to regain strength and independence (Parez et al., 2022). Beyond physical health, smart robotic wheelchairs have a profound impact on psychological well-being. These devices offer a sense of empowerment and independence, enabling individuals to regain control over their lives and make choices about their daily activities. By boosting self-confidence and self-esteem, smart robotic wheelchairs help individuals overcome the emotional challenges often associated with disabilities (Lee and Cho, 2019). Moreover, these devices reduce social stigma and isolation by facilitating social interactions and promoting engagement with the community. Individuals with disabilities can actively participate in social activities, connect with others, and build meaningful relationships, ultimately improving their mental health and overall quality of life (Maalouf et al., 2018).

Furthermore, smart robotic wheelchairs promote social inclusion and accessibility (Sahoo and Choudhury, 2023a). By facilitating community integration, these devices enable individuals with disabilities to participate fully in social, educational, and professional settings. Individuals can access public spaces, educational institutions, and workplaces with greater ease, breaking down physical barriers and promoting equal opportunities. The increased mobility and independence provided by smart robotic wheelchairs also open doors to employment opportunities, fostering economic empowerment and reducing dependence on caregivers or social welfare systems. Ultimately, these devices help create a more inclusive society where individuals with disabilities can actively contribute and thrive.

The importance of smart robotic wheelchairs extends beyond individual benefits. These devices have significant economic and societal implications. From a cost-effectiveness perspective, smart robotic wheelchairs can reduce long-term healthcare costs by preventing secondary health issues and hospitalizations (Sahoo and Choudhury, 2023b). Moreover, they enhance productivity and economic contributions by enabling individuals with disabilities to participate in the workforce, leading to increased employment rates and reduced dependency on social assistance programs. By fostering inclusivity and accessibility, smart robotic wheelchairs contribute to shaping more equitable and diverse societies, where every individual can fully participate and contribute to their communities. The importance of smart robotic wheelchairs for individuals with disabilities cannot be overstated. These technologically advanced devices revolutionize mobility and independence, offering numerous physical, psychological, and social benefits. By promoting mobility, customization, and integration with assistive technologies, smart robotic wheelchairs empower individuals to navigate their environment, engage in physical activities, and regain control over their lives. The impact extends beyond the individual, with social inclusion, accessibility, and economic empowerment being key societal outcomes. As the field of smart robotic wheelchairs continues to advance, further research, development, and implementation are necessary to ensure that individuals with disabilities can enjoy the full benefits and opportunities provided by these transformative devices (Cooper and Cooper, 2019).

1.2 Objective of the proposed work

The objective of this research paper is to provide a comprehensive review of the advancements and impact of smart robotic wheelchairs in advancing mobility and independence for individuals with disabilities.

- To conduct a thorough examination of the advancements and impact of smart robotic wheelchairs in advancing mobility and independence for individuals with disabilities.
- To evaluate the various features and benefits associated with smart robotic wheelchairs, including intelligent navigation, obstacle avoidance, customization, and integration with assistive technologies.
- To investigate the challenges and limitations faced in the development and adoption of smart robotic wheelchairs, such as technical obstacles, cost accessibility, ethical considerations, and user acceptance.
- To assess the impact of smart robotic wheelchairs on the physical and psychological well-being of wheelchair users, including increased physical activity, prevention of secondary health issues, psychological empowerment, and improved mental health.

By achieving these objectives, this research paper aims to contribute to the existing knowledge on the significance of smart robotic wheelchairs in advancing mobility and independence for individuals with disabilities, providing insights for researchers, practitioners, policymakers, and individuals with disabilities themselves.

2. Literature Review

Smart robotic wheelchairs have gained significant attention in recent years as a promising solution to improve the mobility and independence of individuals with disabilities. These advanced wheelchairs incorporate various technologies, such as robotics, artificial intelligence (AI), and sensing systems, to provide enhanced functionality and assistance to users. This literature review aims to explore the recent advancements in smart robotic wheelchairs, highlighting their key features, benefits, and challenges. Additionally, it will discuss the potential impact of these technologies on the quality of life for individuals with mobility impairments.

2.1 Robotic Wheelchair Design and Control

The design and control of robotic wheelchairs play a crucial role in ensuring safe and efficient user navigation. Erdogan and Argall (2017) proposed a modular design framework that allows customization of the wheelchair's configuration based on the user's specific needs and preferences. The study emphasized the importance of user-centered design principles to enhance the overall user experience.

A modular design framework enables customization of robotic wheelchairs to meet the specific needs and preferences of individual users. Cui et al. (2023) proposed a modular design approach that allows for flexible configuration adjustments, including seat height, armrests, and control interfaces. The study emphasized the importance of user-centered design principles to enhance comfort and usability. Lightweight and compact designs are crucial in robotic wheelchairs to ensure ease of maneuverability and portability. Misch and Sprigle (2022) presented a lightweight robotic wheelchair design using carbon fiber materials, reducing the overall weight while maintaining structural integrity. The study highlighted the benefits of lightweight construction in improving energy efficiency and user experience.

Ergonomics and user comfort are essential considerations in robotic wheelchair design. Verma et al. (2022) conducted a study on the ergonomic design of robotic wheelchairs, emphasizing the importance of seat adjustability, backrest contouring, and support for optimal posture and pressure distribution. The research highlighted the potential of ergonomic design principles in reducing discomfort and enhancing user well-being.

2.2 Intelligent Navigation and Obstacle Avoidance

Intelligent navigation and obstacle avoidance are essential capabilities of smart robotic wheelchairs. Liu et al. (2022) developed a wheelchair navigation system based on AI and computer vision techniques. The system utilized deep learning algorithms to recognize and classify obstacles, enabling the wheelchair to autonomously plan optimal paths and avoid collisions. This approach demonstrated improved navigation efficiency and safety. Computer vision-based techniques have been widely explored for intelligent navigation in robotic wheelchairs.

Bhatnagar et al. (2022) proposed an AI-based navigation system that utilized deep learning algorithms for object detection and classification. The system enabled the wheelchair to autonomously plan optimal paths and avoid collisions, enhancing navigation efficiency and safety.

Lidar sensors have demonstrated significant potential for obstacle perception and mapping in robotic wheelchairs. Labbé and Michaud (2019) developed a lidar-based navigation system that combined simultaneous localization and mapping (SLAM) techniques. The system allowed the wheelchair to create a real-time map of the environment and navigate autonomously, enabling efficient obstacle avoidance. SLAM techniques play a crucial role in robotic wheelchair navigation by enabling the creation of a map of the environment and localization within it. Koide et al. (2019) proposed a SLAM-based navigation system that utilized laser range finders and odometry sensors. The system achieved accurate localization and mapping, facilitating safe and efficient wheelchair navigation.

Global path planning algorithms generate optimal paths for robotic wheelchairs considering the overall environment. Ding et al. (2023) presented a global path planning approach that combined the Rapidly-exploring Random Tree (RRT*) algorithm and potential field method. The approach generated smooth paths while avoiding obstacles, improving the navigation efficiency and user experience. Local obstacle avoidance techniques focus on maneuvering around immediate obstacles in the wheelchair's path. Gomes et al. (2023) proposed a local obstacle avoidance method that utilized a combination of lidar sensors and ultrasonic sensors. The method allowed the wheelchair to detect and avoid obstacles in real-time, ensuring safe and collision-free navigation. Semantic mapping and navigation approaches leverage semantic understanding of the environment to enhance robotic wheelchair navigation. Sahoo and Choudhury (2022) introduced a semantic mapping and navigation system that utilized a combination of deep learning-based object detection and semantic segmentation algorithms. The system enabled the wheelchair to perceive and navigate based on semantic information, improving understanding and interaction with the environment.

Collaborative navigation among multiple robotic wheelchairs can improve overall navigation efficiency and enable cooperation in complex environments. Yenugula et al. (2023) proposed a multi-robot collaboration framework that employed decentralized communication and information sharing. The framework enabled cooperative obstacle avoidance and path planning among multiple wheelchairs, enhancing navigation capabilities in crowded or dynamic environments.

2.3 Sensor Technologies

Various sensor technologies, such as lidar, ultrasound, and infrared sensors, are integrated into smart robotic wheelchairs to perceive the environment and assist with navigation. In their work, Pingali (2019) employed a fusion of lidar and vision-based sensors to create a comprehensive perception system. The combination of sensors enabled the wheelchair to accurately detect and recognize objects, facilitating safe maneuvering in dynamic environments.

Adaptive navigation techniques adjust the wheelchair's navigation behavior based on real-time sensor feedback and user preferences. Doush et al. (2020) developed a sensor-based adaptive navigation system that utilized machine learning algorithms to model user preferences and adjust navigation parameters accordingly. The system provided personalized and context-aware navigation for wheelchair users. Lidar (Light Detection and Ranging) sensors have gained significant popularity in robotics for their ability to provide accurate 3D environmental mapping and object detection. The applications of lidar sensors are discussed in mobile robots, including robotic mapping, localization, and obstacle avoidance (Sahoo and Choudhury, 2023c). The study highlighted the advantages of lidar sensors in robust and reliable perception.

Camera and vision sensors are widely used in robotics for visual perception, object recognition, and navigation. Makhataeva and Varol (2020) provided an overview of camera-based perception systems in robotics, including monocular and stereo vision, object detection, and scene understanding. The study emphasized the importance of vision sensors in enabling robots to interpret and interact with the visual world. Inertial Measurement Units (IMUs) consist of accelerometers, gyroscopes, and magnetometers, providing information about the robot's orientation, acceleration, and angular velocity. The use of IMUs in robot localization and motion tracking is discussed that highlights their suitability for applications with limited or no external references (Sahoo and Choudhury, 2021). The study emphasized the integration of IMUs with other sensors for robust and accurate motion estimation.

Force/torque sensors enable robots to perceive and measure external forces and torques exerted during interactions with the environment. The applications of force/torque sensors in robotic is reviewed for grasping, manipulation, and human-robot interaction. The study highlighted the importance of force/torque sensing for safe and precise robotic interactions (Yenugula et al., 2024). Range sensors, such as ultrasonic sensors and Time-of-Flight (ToF) cameras, provide distance measurements and obstacle detection capabilities. The use of range sensors is discussed for localization, mapping, and obstacle avoidance in robotics (Sahoo and Goswami, 2024). The study emphasized the complementary nature of range sensors with other sensor modalities for comprehensive perception.

Tactile and pressure sensors enable robots to sense and interpret physical contact with objects and the environment. Sun et al. (2022) reviewed the advancements in tactile and pressure sensors for robotic applications, including object recognition, grasping, and haptic feedback. The study highlighted the importance of tactile sensing in enabling robots to interact and manipulate objects safely and effectively.

2.4 Human-Machine Interaction

Effective human-machine interaction is crucial for smart robotic wheelchairs to meet the users' needs and preferences. Gopichand et al. (2023) developed an intelligent interface for wheelchair control using electromyography (EMG) signals. The study demonstrated that users could control the wheelchair's movement by voluntarily activating specific muscles, providing a more intuitive and personalized control interface.

Gesture-based interaction enables users to communicate with machines through natural body movements. Esposito et al. (2021) discussed the applications of gesture recognition in HMI, including robotics and virtual reality. The study emphasized the importance of accurate and robust gesture recognition algorithms for seamless and intuitive human-machine communication. Speech and voice interaction provides a natural and efficient means of communication between humans and machines. Singh and Kumar (2021) reviewed the advancements in automatic speech recognition and voice control technologies for HMI. The study highlighted the importance of robust speech processing algorithms and adaptive models for accurate and context-aware voice interaction.

Touch-based interfaces, such as touchscreens and touchpads, enable direct manipulation and tactile feedback in HMI. Sahoo et al. (2023) discussed the design principles and user experience considerations for touch-based interfaces. The study emphasized the importance of intuitive gestures, responsiveness, and haptic feedback for enhancing user interaction and satisfaction. BCIs allow direct communication between the human brain and machines, enabling control and interaction without the need for physical input. Jamil et al. (2021) reviewed the recent advancements in BCIs for HMI, focusing on non-invasive techniques such as electroencephalography (EEG). The study highlighted the potential of BCIs in enabling communication for individuals with severe physical disabilities.

Multimodal interfaces combine multiple interaction modalities, such as voice, gestures, and touch, to enhance HMI. Mohebbi (2022) reviewed the advancements in multimodal interfaces, including fusion techniques and interaction design principles. The study highlighted the benefits of multimodal interfaces in improving communication efficiency and accommodating user preferences.

2.5 Ethical and Safety Considerations

As smart robotic wheelchairs become more sophisticated and autonomous, ethical and safety considerations need to be addressed. The importance of developing robust safety mechanisms is discussed to prevent accidents and ensure user well-being (Sahoo and Goswami, 2023). The study emphasized the need for reliable fault detection, emergency stop systems, and adherence to safety standards in the design and implementation of smart robotic wheelchairs.

Robot ethics encompasses the study of moral and ethical implications associated with the design, deployment, and use of robots. Salvini et al. (2022) discussed the ethical considerations in robot design, programming, and behavior. The study emphasized the importance of incorporating ethical principles to ensure robots act in a socially responsible and acceptable manner. Safety is a paramount concern in robotics, particularly in collaborative and physical human-robot interaction scenarios. Safety measures and risk assessment methods is reviewed for human-robot collaboration (Cojocaru et al., 2022). The study highlighted the importance of risk analysis, safety standards, and protective measures to prevent accidents and ensure safe operation.

Ethical guidelines and standards provide frameworks for responsible and ethical development and use of robotics systems. The European Robotics Research Network (EUROBOTICS) and the Institute of Electrical and Electronics Engineers (IEEE) have developed ethical guidelines for robotics research and applications. The ethical and legal challenges is discussed in robotics and proposed a code of ethics for robots (Fosch-Villaronga et al., 2020). The study emphasized the need for transparent and accountable robot behavior, respect for human values, and compliance with legal and ethical norms. Transparency and explainability are crucial for building trust and understanding in robotic systems. The importance of transparency and explainability is discussed on AI and robotics and proposed an explainability framework for intelligent systems (Padfield et al., 2023). The research highlighted the need for interpretable and understandable robot behaviours to enable users to trust and collaborate with robots effectively.

2.6 Research gap and Novelty

Smart robotic wheelchairs have emerged as innovative mobility solutions, incorporating advanced technologies to enhance the mobility and independence of individuals with disabilities. While there have been significant advancements in the field of smart robotic wheelchairs, there are still some research gaps and areas for further exploration. This review aims to highlight these research gaps and identify the novel aspects and contributions in advancing mobility and independence for individuals with disabilities.

Research Gap:

- User-Centered Design: One significant research gap in the field of smart robotic wheelchairs is the need for more emphasis on user-centered design. While many advancements have been made in the technical aspects of these wheelchairs, there is still a need to involve end-users, such as individuals with disabilities and healthcare professionals, in the design process.
- Long-Term User Adaptation: Another research gap is the exploration of long-term user adaptation to smart robotic wheelchairs. While initial studies have focused on short-term evaluations and usability assessments, there is a need to investigate how individuals with disabilities adapt to these wheelchairs over an extended period.

Novelty:

- Intelligent Navigation and Obstacle Avoidance: One notable novelty in smart robotic wheelchairs is the integration of intelligent navigation and obstacle avoidance systems. Advanced algorithms and sensor technologies enable these wheelchairs to autonomously navigate through complex environments, detect and avoid obstacles, and plan efficient routes.

- Personalized Assistive Features**:** Smart robotic wheelchairs are incorporating personalized assistive features to cater to individual user needs. These features include customizable seating positions, adjustable control interfaces, and adaptive functionalities based on user preferences and capabilities. Personalization ensures that the wheelchair provides tailored support, comfort, and control, empowering users to navigate their environment more effectively.
- Enhanced User Interfaces: Another novelty in smart robotic wheelchairs is the development of enhanced user interfaces. These interfaces utilize intuitive control mechanisms, such as voice commands, gesture recognition, or brain-computer interfaces, to enable seamless and natural interaction between the user and the wheelchair. This improves user experience, reduces cognitive load, and facilitates efficient control and navigation.

While significant advancements have been made in smart robotic wheelchairs, there are research gaps that need to be addressed, including user-centered design, long-term user adaptation, and ethical and social implications. Novelty lies in intelligent navigation and obstacle avoidance, personalized assistive features, enhanced user interfaces, and integration with smart home and IoT technologies. By addressing these research gaps and incorporating novel features, smart robotic wheelchairs can continue to advance mobility and independence for individuals with disabilities, enabling them to live more fulfilling and empowered lives.

3. Components of smart robotic wheelchair

A smart robotic wheelchair is a technologically advanced mobility device that integrates various components to enhance its functionality, autonomy, and user experience. Here are the key components of a smart robotic wheelchair explained in detail:

3.1 Drive System

The drive system is responsible for the wheelchair's movement and manoeuvrability. It typically includes motors, wheels, and a control mechanism. Smart robotic wheelchairs often feature advanced motor systems, such as electric motors or brushless DC motors, which provide smooth and efficient propulsion. The control mechanism may incorporate joystick control, touchpad interfaces, or even advanced control methods like voice commands or brain-computer interfaces.

3.2 Sensors

Sensors are crucial components in smart robotic wheelchairs as they provide the necessary input for perceiving the environment and enabling autonomous functions (Pu et al., 2018). Commonly used sensors include:

- Lidar (Light Detection and Ranging): Lidar sensors use laser beams to measure distances and create detailed 3D maps of the surroundings. They help with navigation, obstacle detection, and localization.
- Camera and Vision Sensors: Cameras capture visual information, allowing the wheelchair to recognize objects, detect obstacles, and interpret visual cues. Advanced vision algorithms enable features like object recognition and tracking.
- Ultrasonic Sensors: Ultrasonic sensors emit high-frequency sound waves and measure their reflections to detect nearby objects and obstacles. They are commonly used for proximity sensing and collision avoidance.
- Inertial Measurement Units (IMUs): IMUs consist of accelerometers, gyroscopes, and magnetometers to measure acceleration, angular velocity, and orientation. IMUs are used for motion tracking, balance control, and maintaining stability.

3.3 Control System

The control system is the brain of the smart robotic wheelchair, responsible for processing sensor data, executing control algorithms, and coordinating the wheelchair's movements (Voznenko et al., 2018). It consists of microcontrollers or microprocessors that receive input from sensors, interpret the data, and generate commands for the drive system. Advanced control algorithms, such as path planning, obstacle avoidance, and navigation algorithms, are implemented to enable autonomous or semi-autonomous wheelchair operation.

3.4 User Interface

The user interface facilitates communication between the user and the wheelchair (Leaman et al., 2016). It allows users to interact with the wheelchair, provide input, and receive feedback. Common user interface elements include:

- Control Interfaces: Control interfaces can range from traditional joystick controllers to touchscreens, touchpads, or alternative control methods like voice recognition or gesture control. The interface should be intuitive and customizable to accommodate the user's abilities and preferences.
- Displays: Displays provide visual feedback to the user, displaying information such as speed, battery level, navigation instructions, or safety alerts. They can be integrated into the wheelchair's control interface or separate screens.
- Auditory Feedback: Auditory cues, such as beeps or voice prompts, can provide important feedback to users, especially those with visual impairments. They can indicate obstacle proximity, direction changes, or system status.

3.5 Connectivity and Integration

Smart robotic wheelchairs often incorporate connectivity features and integration with other devices and systems (Al-Qayasi et al., 2018). This includes:

- Wireless Connectivity: Wheelchairs may have Bluetooth or Wi-Fi capabilities, enabling connectivity with smartphones, tablets, or smart home devices. This allows users to control the wheelchair remotely or access additional features and functionalities.
- Integration with Assistive Technologies: Integration with assistive technologies like environmental control systems, speech synthesizers, or communication aids enhances the wheelchair's usability and expands its capabilities.
- Data Logging and Analytics: Some smart robotic wheelchairs can log sensor data, usage patterns, and performance metrics. This data can be analysed to optimize the wheelchair's performance, identify user preferences, or provide insights for research and improvement.

3.6 Power System

The power system of a smart robotic wheelchair consists of batteries, charging systems, and power management. Advanced wheelchairs may use lithium-ion or similar high-capacity batteries to provide sufficient power for extended use. Efficient power management systems optimize battery usage and provide information on battery status, remaining charge, and estimated range.

3.7 Mapping and Localization

Mapping and localization components enable the wheelchair to understand its position and navigate through its environment. This may involve the use of simultaneous localization and mapping (SLAM) algorithms, which combine sensor data to create a map of the surroundings and estimate the wheelchair's position within that map

(Zhang et al., 2015). Localization algorithms use this map to maintain accurate positioning information as the wheelchair moves.

3.8 Safety Features

Safety is a crucial consideration in smart robotic wheelchairs. Safety features may include:

- Collision Detection and Avoidance: Sensors and algorithms are employed to detect obstacles, both static and dynamic, and take appropriate actions to avoid collisions. This can involve adjusting the wheelchair's trajectory, slowing down, or stopping when necessary.
- Stability and Balance Control: Advanced control systems help maintain stability and balance, especially in challenging terrains or during manoeuvres. This may involve adaptive control algorithms that adjust the wheelchair's stability parameters based on sensor feedback.
- Emergency Stop and Fall Detection: Smart robotic wheelchairs may have emergency stop buttons or automatic fall detection systems to ensure user safety in critical situations.

4. User-Centered Design of smart robotic wheelchair

User-Centered Design (UCD) is an approach to design that emphasizes understanding the needs, preferences, and limitations of end-users throughout the design process (Botrel et al., 2015). When applied to the development of smart robotic wheelchairs, UCD ensures that the design and functionality of the wheelchair are tailored to the specific requirements of individuals with disabilities. Here's a detailed explanation of UCD in the context of smart robotic wheelchairs:

- User Research: The UCD process begins with comprehensive user research to gain a deep understanding of the target user group. This involves conducting interviews, surveys, and observations to identify user needs, preferences, and challenges related to mobility and independence. User research also explores individual variations, considering factors such as physical abilities, cognitive capabilities, and sensory impairments.
- User Personas and Scenarios: Based on the user research, designers create user personas and scenarios to represent different user profiles and their specific goals, capabilities, and contexts of use. User personas help in empathizing with the end-users and considering their diverse requirements and preferences during the design process. Scenarios provide a narrative of how the smart robotic wheelchair would be used in different real-life situations, aiding in designing features and functionality that align with user needs.
- Participatory Design: UCD encourages the active involvement of end-users in the design process. Participatory design methods, such as co-creation workshops and focus groups, engage users in brainstorming, idea generation, and concept evaluation. Through their input, users contribute to the design decisions, ensuring that their perspectives, desires, and practical considerations are taken into account.
- Iterative Prototyping and Evaluation: UCD emphasizes an iterative design approach with multiple rounds of prototyping and evaluation. Designers create low-fidelity and high-fidelity prototypes of the smart robotic wheelchair, allowing users to interact with and provide feedback on different design iterations. This iterative process enables designers to refine the design based on user feedback, addressing usability issues, enhancing features, and ensuring that the wheelchair meets user expectations.
- Accessibility and Inclusivity: A core principle of UCD is to prioritize accessibility and inclusivity in the design of smart robotic wheelchairs. Designers consider universal design principles to ensure that the wheelchair accommodates users with varying abilities and limitations. This includes features like

adjustable seating positions, adaptable control interfaces, and options for customization based on individual needs. By addressing accessibility and inclusivity, UCD aims to create a wheelchair that can be used by a wide range of individuals with disabilities.

- Usability Testing: Usability testing is an essential part of UCD to evaluate the effectiveness and efficiency of the smart robotic wheelchair's design. Usability tests involve observing users as they perform tasks using the wheelchair and gathering feedback on their experience. This helps identify usability issues, areas for improvement, and validation of design decisions. Usability testing ensures that the wheelchair is intuitive, easy to operate, and meets the functional requirements of the users.
- Continuous User Feedback: UCD promotes continuous user feedback even after the initial design and development phases. User feedback mechanisms, such as user surveys or feedback channels, allow users to provide ongoing input and suggestions for further improvements. This feedback loop helps in addressing emerging needs, refining features, and ensuring that the smart robotic wheelchair evolves in response to user requirements and changing contexts.

By following a user-centered design approach, smart robotic wheelchairs can be tailored to meet the specific needs and preferences of individuals with disabilities. UCD ensures that the wheelchair's design, features, and functionality align with user expectations, promoting enhanced mobility, independence, and user satisfaction.

5. Long-Term User Adaptation of smart robotic wheelchair

Long-term user adaptation refers to the process by which individuals with disabilities gradually adjust to and integrate smart robotic wheelchairs into their daily lives over an extended period (Geravand et al., 2016). It involves understanding how users adapt to the wheelchair's features, functionalities, and overall user experience over time. Here's a detailed explanation of long-term user adaptation in the context of smart robotic wheelchairs:

- Learning and Familiarization: In the initial stages of using a smart robotic wheelchair, users go through a learning process to understand its controls, functionalities, and capabilities. This involves becoming familiar with the different control interfaces, navigation modes, and assistive features. Over time, users become more proficient and gain confidence in operating the wheelchair, allowing for more efficient and effective use.
- Personalized Configuration: As users spend more time with the smart robotic wheelchair, they often discover their preferences and adjust the settings to personalize their experience. This may include customizing the control interface sensitivity, seat positioning, or fine-tuning navigation parameters. Personalization helps users optimize their comfort, efficiency, and overall satisfaction with the wheelchair.
- Task Adaptation: Long-term user adaptation also involves the ability to adapt to different tasks and environments using the smart robotic wheelchair. Users develop strategies and techniques for navigating different terrains, negotiating obstacles, and performing daily activities. Through experience, they learn how to leverage the wheelchair's capabilities to overcome challenges and accomplish tasks with greater ease and efficiency.
- Independence and Autonomy: One key aspect of long-term user adaptation is the development of increased independence and autonomy. As users become more familiar with the smart robotic wheelchair's capabilities, they gain confidence in using it to navigate their environments and perform activities independently. This newfound independence enhances their overall mobility and quality of life.
- Emotional Adaptation: Long-term user adaptation also involves emotional adjustments to the use of a smart robotic wheelchair. Initially, users may experience a range of emotions such as excitement, frustration, or apprehension. Over time, as users become more accustomed to the wheelchair, they may

develop a sense of empowerment, freedom, and increased confidence in their abilities. Emotional adaptation is a significant aspect of the long-term user experience with smart robotic wheelchairs.

- Continuous Learning and Skill Development: Long-term adaptation includes continuous learning and skill development. Users may explore new functionalities, experiment with different modes of operation, or seek opportunities to enhance their abilities and knowledge related to the smart robotic wheelchair. This ongoing learning process helps users optimize their usage, uncover new features, and adapt to changes in technology or their personal needs.
- Feedback and Support: To facilitate long-term user adaptation, continuous feedback and support mechanisms are essential. Users should have avenues to provide feedback, report issues, and seek assistance when needed. Feedback loops help manufacturers and designers identify areas for improvement, address usability issues, and refine the smart robotic wheelchair's features and functionalities based on user experiences and evolving needs.

Understanding the long-term user adaptation process is critical for the continuous improvement and optimization of smart robotic wheelchairs. By considering user feedback, tailoring features to individual needs, and promoting user independence, smart robotic wheelchairs can become increasingly integrated into users' lives, supporting their mobility, independence, and overall well-being over the long term.

6. Intelligent Navigation and Obstacle Avoidance of smart robotic wheelchair

Intelligent navigation and obstacle avoidance are essential features in smart robotic wheelchairs that enable safe and efficient mobility for individuals with disabilities (Rojas et al., 2018). These capabilities involve the integration of advanced sensors, algorithms, and control systems to navigate through complex environments while detecting and avoiding obstacles. Here's a detailed explanation of intelligent navigation and obstacle avoidance in smart robotic wheelchairs:

6.1 Sensor Technologies

Intelligent navigation relies on various sensor technologies to perceive the surrounding environment. Lidar sensors use laser beams to measure distances and create detailed 3D maps of the wheelchair's surroundings. This enables accurate detection of obstacles, precise localization, and mapping of the wheelchair's environment. Cameras capture visual information, allowing the wheelchair to recognize objects, detect obstacles, and interpret visual cues. Advanced vision algorithms analyse the camera feed to identify obstacles, determine their positions and sizes, and classify them as static or dynamic. Ultrasonic sensors emit high-frequency sound waves and measure their reflections to detect nearby objects and obstacles. They are commonly used for proximity sensing and collision avoidance, providing immediate feedback on the distance between the wheelchair and obstacles. IMUs consist of accelerometers, gyroscopes, and magnetometers to measure acceleration, angular velocity, and orientation. IMUs help in determining the wheelchair's position, velocity, and orientation, which are essential for accurate navigation and obstacle avoidance.

6.2 Mapping and Localization

Intelligent navigation relies on mapping and localization techniques to understand the wheelchair's position within its environment. Simultaneous Localization and Mapping (SLAM) algorithms combine sensor data, such as lidar or camera inputs, to create a map of the surroundings while simultaneously estimating the wheelchair's position within that map. This mapping and localization information enables the wheelchair to plan optimal paths and avoid obstacles effectively.

6.3 Path Planning and Trajectory Generation

Path planning algorithms determine the optimal path for the wheelchair to reach its destination while avoiding obstacles. These algorithms consider factors such as obstacle proximity, wheelchair dimensions, and user preferences. Trajectory generation algorithms then convert the planned path into a smooth and feasible motion trajectory that the wheelchair can follow. These algorithms take into account the wheelchair's kinematics, dynamic constraints, and safety considerations.

6.4 Obstacle Detection and Avoidance

Intelligent navigation includes real-time obstacle detection and avoidance capabilities. Using sensor inputs, the wheelchair can detect obstacles in its path and classify them based on their characteristics. Advanced algorithms analyse sensor data and make decisions on appropriate actions to avoid collisions, such as adjusting the wheelchair's trajectory, slowing down, or stopping when necessary. The wheelchair may employ reactive strategies for immediate obstacle avoidance and proactive strategies for anticipating and avoiding potential obstacles.

6.5 Adaptive Control

Intelligent navigation systems may incorporate adaptive control algorithms to adjust the wheelchair's behaviour based on environmental conditions and user preferences. These algorithms continuously monitor sensor inputs, evaluating the wheelchair's performance, and adapting control parameters in real-time. Adaptive control ensures that the wheelchair maintains stability, handles different terrains, and responds appropriately to changing circumstances.

6.6 User Interaction and Override

To ensure user control and maintain a collaborative experience, intelligent navigation systems allow for user interaction and override capabilities. Users can intervene and provide input to override the autonomous navigation functions when necessary. This may involve the use of control interfaces, such as joystick control or voice commands, to manually steer the wheelchair or modify its behaviour.

6.7 Safety Considerations

Intelligent navigation and obstacle avoidance systems prioritize user safety. Safety features can include collision detection, emergency stop buttons, and fall detection mechanisms. These features help prevent accidents and ensure user well-being during wheelchair operation. Intelligent navigation and obstacle avoidance in smart robotic wheelchairs enhance user safety, promote independent mobility, and reduce the cognitive and physical effort required for manoeuvring in complex environments. By integrating advanced sensors, mapping algorithms, trajectory planning, and adaptive control, these systems enable individuals with disabilities to navigate their surroundings confidently and efficiently.

7. Personalized Assistive Features of smart robotic wheelchair

Personalized assistive features in smart robotic wheelchairs are designed to cater to the individual needs and preferences of users with disabilities (Yoon, 2017). These features allow for customization and adaptability, enhancing user comfort, control, and overall experience. Here are some examples of personalized assistive features in smart robotic wheelchairs:

- Customizable Seating Positions: Smart robotic wheelchairs often offer adjustable seating positions to accommodate individual user requirements. This includes adjustable seat height, backrest angle, and leg rest positions. Customizable seating allows users to find the most comfortable and ergonomic positions, promoting proper posture, reducing fatigue, and minimizing the risk of pressure sores.

- Adjustable Control Interfaces: Smart robotic wheelchairs provide options for personalized control interfaces. Users can choose from different control mechanisms, such as traditional joystick control, touchscreens, or alternative control methods like sip-and-puff systems or head arrays. The ability to adjust the sensitivity, speed, or other control parameters further allows users to tailor the wheelchair's operation to their specific abilities and preferences.
- Adaptive Driving Modes: To cater to different user capabilities, smart robotic wheelchairs may offer adaptive driving modes. These modes can adjust the wheelchair's responsiveness, speed, and manoeuvrability based on user needs. For example, a user with limited upper body strength may benefit from a mode that provides greater power assistance, while a user with more control may prefer a mode with higher manoeuvrability.
- Pressure Relief and Redistribution: Pressure relief and redistribution features are important for users who may spend extended periods in the wheelchair. These features include pressure-sensitive seating surfaces or air cushions that help distribute pressure evenly, reducing the risk of pressure sores. Some smart robotic wheelchairs may also offer automatic pressure relief or shifting functions to periodically adjust seating positions and alleviate pressure points.
- User Profiles and Preferences: Smart robotic wheelchairs can store user profiles and preferences, allowing for quick and easy customization based on individual users. User profiles may include settings for seating positions, control interface preferences, driving modes, or other personalized parameters. By recalling user profiles, the wheelchair can adapt to the specific requirements of different users, making it convenient for multiple users or for users with changing needs.
- Environmental Adaptation: Personalized assistive features in smart robotic wheelchairs can also extend to environmental adaptation. For example, the wheelchair may have the ability to connect with smart home devices or Internet of Things (IoT) systems to adapt to the user's home environment. This may involve automated door opening, environmental controls, or integration with voice-activated assistants, allowing users to control their surroundings more easily.
- User Feedback and Interaction: Smart robotic wheelchairs can incorporate user feedback and interaction mechanisms to enhance personalization. This may involve gathering user input on comfort levels, control preferences, or other aspects of the wheelchair's performance. User feedback can be used to adapt and refine personalized features, improving the overall user experience and ensuring that the wheelchair meets individual needs.

By incorporating personalized assistive features, smart robotic wheelchairs provide users with greater control, comfort, and adaptability. These features promote independence, optimize user experience, and enable individuals with disabilities to tailor their wheelchair's functionalities to their specific requirements.

8. Enhanced User Interfaces of smart robotic wheelchair

Enhanced user interfaces in smart robotic wheelchairs focus on improving the interaction and communication between the user and the wheelchair (Pushp et al., 2018). These interfaces aim to make the control and operation of the wheelchair more intuitive, efficient, and user-friendly. Here's a detailed explanation of enhanced user interfaces in smart robotic wheelchairs:

- Intuitive Control Mechanisms: Enhanced user interfaces offer intuitive control mechanisms that are easy to understand and operate. This can include traditional joystick controls with ergonomic designs, touchscreens with visual icons and intuitive gestures, or alternative control methods like voice commands, head arrays, or sip-and-puff systems. The goal is to provide users with control options that suit their abilities and preferences, enabling seamless and effortless control of the wheelchair.

- Gesture Recognition: Gesture recognition is an advanced user interface feature that enables users to control the wheelchair through hand or body gestures. Using sensors, cameras, or depth-sensing technologies, the wheelchair can detect and interpret specific gestures to perform actions such as stopping, turning, or changing speed. Gesture recognition interfaces enhance user experience by providing a more natural and intuitive means of control.
- Voice Control and Natural Language Processing: Voice control interfaces allow users to interact with the smart robotic wheelchair using natural language commands. Integrated with speech recognition algorithms and natural language processing techniques, the wheelchair can understand and interpret spoken instructions. Users can perform actions like navigation, speed adjustment, or mode selection by simply speaking commands, making the interaction more accessible and hands-free.
- Visual Feedback Displays: Enhanced user interfaces incorporate visual feedback displays to provide users with important information about the wheelchair's status, settings, and environment. These displays can include high-resolution screens that show real-time data such as speed, battery level, navigation instructions, obstacle alerts, or system diagnostics. Clear and informative visual feedback helps users make informed decisions and enhances their situational awareness.
- Auditory Feedback and Alerts: Auditory feedback and alerts are important components of enhanced user interfaces. The wheelchair can provide auditory cues such as beeps, tones, or voice prompts to indicate specific events or conditions. Auditory feedback can convey information about obstacle proximity, battery warnings, system status, or navigation instructions. This assists users, particularly those with visual impairments, in understanding and responding to important feedback from the wheelchair.
- Haptic Feedback: Haptic feedback involves the use of touch-based interfaces to provide tactile sensations and feedback to users. Enhanced user interfaces may incorporate haptic feedback through vibration or tactile actuators integrated into the control interface. This feedback can confirm successful actions, indicate mode changes, or provide alerts, enhancing the user's sense of control and engagement with the wheelchair.
- Customization and Personalization: Enhanced user interfaces allow for customization and personalization based on user preferences and needs. Users can adjust settings such as control sensitivity, display layout, colour schemes, or font sizes to optimize the interface for their individual comfort and usability. Customization options ensure that the user interface accommodates varying abilities, preferences, and visual or cognitive impairments.
- Multimodal Interaction: Multimodal interaction combines multiple input and output modalities to create a rich and flexible user interface. Smart robotic wheelchairs may support a combination of touch-based input, voice commands, gestures, and haptic feedback. Multimodal interfaces offer users the flexibility to choose the most suitable interaction mode or a combination of modes based on their abilities and preferences, enabling a more inclusive and adaptable user experience.

Enhanced user interfaces in smart robotic wheelchairs improve the usability, accessibility, and overall user experience. By incorporating intuitive controls, gesture recognition, voice commands, visual and auditory feedback, haptic feedback, customization options, and multimodal interaction, these interfaces empower users to interact with the wheelchair more naturally, efficiently, and comfortably.

9. Conclusion

This research paper has provided a comprehensive review of smart robotic wheelchairs and their significant contributions to advancing mobility and independence for individuals with disabilities. Through an exploration of the literature, we have identified the various components, technologies, and advancements that make smart robotic wheelchairs innovative and transformative mobility solutions.

The review highlighted the research gaps and areas for further exploration in the field of smart robotic wheelchairs. User-centered design emerged as a critical research gap, emphasizing the need to involve end-users in the design process to ensure that the wheelchairs meet their specific needs, preferences, and limitations. Long-term user adaptation also emerged as an area requiring further investigation to understand how individuals with disabilities adapt to and integrate smart robotic wheelchairs into their daily lives over an extended period.

The review also discussed the novel aspects and contributions in the field of smart robotic wheelchairs. Intelligent navigation and obstacle avoidance systems were identified as significant advancements, allowing for autonomous and efficient movement while ensuring user safety. Personalized assistive features, such as customizable seating positions and adaptive control interfaces, enhance user comfort, control, and overall user experience. Enhanced user interfaces, including intuitive control mechanisms, gesture recognition, and voice control, make interaction with the wheelchair more natural and user-friendly.

Smart robotic wheelchairs have the potential to revolutionize the field of mobility assistance, providing individuals with disabilities the freedom, autonomy, and improved quality of life they deserve. Continued research, development, and user-centered design will pave the way for further advancements, making smart robotic wheelchairs even more effective, accessible, and empowering for individuals with disabilities worldwide.

9.1 Practical Implication

The research conducted on smart robotic wheelchairs and their potential to advance mobility and independence for individuals with disabilities has several practical implications. These implications provide guidance for various stakeholders involved in the development, implementation, and use of smart robotic wheelchairs. Here are the practical implications derived from the review:

- Designing User-Centered Wheelchairs: The findings emphasize the importance of adopting a user-centered design approach when developing smart robotic wheelchairs. Designers and manufacturers should involve individuals with disabilities in the design process to understand their unique needs, preferences, and limitations. This involvement ensures that the wheelchairs are tailored to individual requirements, leading to improved user satisfaction, comfort, and usability.
- Enhancing Long-Term User Adaptation: Long-term user adaptation is a critical aspect of using smart robotic wheelchairs. Practitioners should focus on understanding and supporting the long-term adaptation process of individuals with disabilities to these advanced mobility devices. This involves providing ongoing training, support, and opportunities for users to customize and personalize their wheelchairs based on changing needs and preferences.
- Promoting Education and Awareness: The practical implications highlight the need for education and awareness initiatives among healthcare professionals, caregivers, and individuals with disabilities themselves. These initiatives should emphasize the benefits, functionalities, and potential of smart robotic wheelchairs. By promoting awareness, stakeholders can ensure that individuals with disabilities have access to the latest technologies and can make informed decisions about their mobility needs.
- Collaboration and Interdisciplinary Research: The development and implementation of smart robotic wheelchairs require collaboration among various stakeholders, including researchers, engineers, healthcare professionals, and end-users. Interdisciplinary research efforts can lead to innovative solutions and address the complex challenges associated with smart robotic wheelchair design, usability, and integration into existing healthcare systems.
- Ethical Considerations and Safety Regulations: The practical implications highlight the need for ethical considerations and safety regulations in the development and use of smart robotic wheelchairs.

Developers and policymakers should ensure that these technologies prioritize user safety, maintain privacy and data security, and adhere to ethical standards. Establishing clear guidelines and regulations will instill confidence among users, caregivers, and healthcare providers.

- Training and Support for Healthcare Professionals: Healthcare professionals play a crucial role in facilitating the successful implementation and use of smart robotic wheelchairs. Training programs should be provided to equip healthcare professionals with the knowledge and skills to assess, recommend, and support individuals in using these advanced mobility devices. This includes training on customization, programming, troubleshooting, and maintenance of smart robotic wheelchairs.
- Financial Accessibility: Smart robotic wheelchairs often come with a higher cost compared to traditional manual or powered wheelchairs. Practical implications emphasize the need for financial accessibility and reimbursement options to ensure that individuals with disabilities can afford and access these advanced technologies. Advocacy efforts should be made to promote insurance coverage, funding programs, and assistive technology grants to support the affordability and availability of smart robotic wheelchairs.

By considering these practical implications, stakeholders can work towards maximizing the benefits and impact of smart robotic wheelchairs for individuals with disabilities. These implications guide the development, implementation, and support processes, ensuring that smart robotic wheelchairs are designed to meet user needs, promote independence, and enhance the overall well-being of individuals with disabilities.

9.2 Limitation

While the research paper on smart robotic wheelchairs and their impact on advancing mobility and independence for individuals with disabilities provides valuable insights, there are certain limitations that should be acknowledged. These limitations highlight areas where further research or considerations are needed. Here are some limitations to be addressed:

- Generalizability of Findings: The review may have focused on specific studies, prototypes, or commercially available smart robotic wheelchairs, which may limit the generalizability of the findings. Different models, manufacturers, or user populations may exhibit variations in performance, features, or user experiences. Further research should aim to encompass a broader range of smart robotic wheelchairs to enhance the generalizability of the findings.
- Lack of Longitudinal Studies: The review may have relied primarily on cross-sectional studies or short-term evaluations, which may not capture the long-term impact and effectiveness of smart robotic wheelchairs. Longitudinal studies are needed to assess the durability, user adaptation, and overall long-term benefits of using these devices. Understanding the changes and challenges that individuals with disabilities face over extended periods will provide valuable insights for improving smart robotic wheelchair design and support systems.
- Limited User Perspectives: The review may have primarily focused on objective measures, technical aspects, and expert opinions, potentially overlooking the subjective experiences and perspectives of individuals with disabilities. Future research should incorporate qualitative methods, such as interviews or surveys, to gather firsthand user experiences, preferences, and challenges. Capturing the user perspective is crucial for refining smart robotic wheelchair design and ensuring that they meet the diverse needs and preferences of individuals with disabilities.
- Accessibility and Affordability: The review may not have extensively covered the accessibility and affordability challenges associated with smart robotic wheelchairs. The cost, availability, and reimbursement options for these advanced technologies can limit their accessibility for individuals with disabilities. Future research should explore the barriers and potential solutions related to financial

accessibility, insurance coverage, and funding programs to ensure that smart robotic wheelchairs are accessible to a wider population.

- Ethical and Social Considerations: While the review touched upon ethical considerations, such as safety and privacy, further exploration of ethical and social implications is necessary. This includes examining the potential impact on social interactions, identity, and autonomy, as well as considering ethical dilemmas related to decision-making, consent, and user agency. Incorporating interdisciplinary perspectives, including ethics, sociology, and disability studies, can provide a more comprehensive understanding of the ethical and social considerations associated with smart robotic wheelchairs.
- User-Centered Design Challenges: The review acknowledges the importance of user-centered design, but the challenges and limitations in implementing this approach may not have been extensively explored. Future research should address the barriers to effective user involvement, such as cognitive or communication impairments, varying user preferences, and the complexities of accommodating diverse user needs within the design process. Overcoming these challenges will lead to more inclusive and user-responsive smart robotic wheelchair designs.

By acknowledging and addressing these limitations, future research on smart robotic wheelchairs can provide a more comprehensive understanding of their impact, usability, accessibility, and ethical implications. Overcoming these limitations will contribute to the ongoing development and optimization of smart robotic wheelchairs, ensuring that they truly advance mobility and independence for individuals with disabilities.

9.3 Future scope

The research paper on smart robotic wheelchairs and their impact on advancing mobility and independence for individuals with disabilities opens up several avenues for future research and development. These opportunities aim to further enhance the functionality, usability, and accessibility of smart robotic wheelchairs. Here are some future scopes derived from the review:

- Longitudinal Studies: Future research should focus on conducting longitudinal studies to assess the long-term impact and effectiveness of smart robotic wheelchairs. These studies would track users' experiences, adaptations, and outcomes over an extended period, providing insights into the durability, user satisfaction, and changes in mobility and independence over time.
- User-Centered Design: Expanding on the user-centered design approach, future research can explore innovative methods to involve individuals with disabilities in the design process. This includes incorporating participatory design techniques, co-creation workshops, or virtual reality simulations to gather user feedback, preferences, and insights. The aim is to ensure that the design of smart robotic wheelchairs aligns with the specific needs, preferences, and limitations of the end-users.
- Enhanced Sensor Technologies: Continued advancements in sensor technologies, such as lidar, vision sensors, and IMUs, hold promise for improving the perception and navigation capabilities of smart robotic wheelchairs. Future research can focus on developing more compact, accurate, and cost-effective sensor systems that can enhance obstacle detection, mapping, localization, and environmental perception.
- Artificial Intelligence and Machine Learning: Integration of artificial intelligence (AI) and machine learning techniques can further enhance the autonomy and adaptability of smart robotic wheelchairs. Future research can explore the use of AI algorithms for real-time decision-making, personalized assistance, and learning from user interactions. Machine learning can be leveraged to analyze data collected from users, enabling the wheelchair to adapt and improve its performance based on individual preferences and needs.

- Enhanced User Interfaces: Future research can explore novel user interface designs and interaction modalities to improve the usability and accessibility of smart robotic wheelchairs. This includes advancements in gesture recognition, natural language processing, haptic feedback, and multimodal interfaces. User-centric research should be conducted to assess the effectiveness and acceptance of these enhanced user interfaces among individuals with disabilities.
- Integration with Assistive Technologies: Smart robotic wheelchairs can be further integrated with other assistive technologies to expand their functionalities and enhance user capabilities. Future research can explore seamless integration with communication aids, environmental control systems, robotic arms, or smart home devices. This integration would enable individuals with disabilities to perform a wider range of activities and improve their overall independence.
- Ethical Considerations and Policy Development: As smart robotic wheelchairs become more prevalent, future research should address ethical considerations and guide policy development. This includes ensuring user privacy and data security, addressing ethical challenges related to decision-making and consent, and developing guidelines for responsible development and use of these technologies. Research in this area will help shape ethical frameworks, standards, and regulations for the responsible deployment of smart robotic wheelchairs.

By focusing on these future scopes, researchers can contribute to the ongoing development and advancement of smart robotic wheelchairs. These opportunities aim to improve user experiences, address limitations, and push the boundaries of mobility and independence for individuals with disabilities. Collaborative efforts among researchers, engineers, healthcare professionals, and end-users are vital for realizing the full potential of smart robotic wheelchairs in transforming the lives of individuals with disabilities.

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