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Autonomous navigation and obstacle avoidance in smart robotic wheelchairs

Sushil Kumar Sahoo [1,*] and Bibhuti Bhusan Choudhury [2]

[1] Department of Mechanical Engineering, Indira Gandhi Institute of Technology, (BPUT,Rourkela) Sarang, Odisha, India
[2] Department of Mechanical Engineering, Indira Gandhi Institute of Technology, Sarang, Odisha, India

* Correspondence: sushilkumar00026@gmail.com

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Abstract

This review research paper provides a comprehensive analysis of the advancements, challenges, and methodologies in autonomous navigation and obstacle avoidance for smart robotic wheelchairs. The integration of robotics and assistive technology has revolutionized mobility solutions for individuals with impairments, enabling them to navigate complex environments independently. The paper examines the various sensor modalities, machine learning algorithms, and computer vision techniques employed for environment perception and obstacle recognition. It discusses path planning algorithms, motion control strategies, and decision-making processes for autonomous navigation. The review also addresses limitations, such as localization accuracy and dynamic environment modelling, while highlighting recent research advancements and suggesting future directions. Overall, this paper serves as a valuable resource for researchers and practitioners in the field of smart robotic wheelchairs, aiming to enhance mobility and quality of life for individuals with mobility impairments.

Keywords: Autonomous Navigation, Obstacle Avoidance, Smart Robotic Wheelchairs, Path Following, Assistive Technology

1. Introduction

Smart robotic wheelchairs have emerged as a ground-breaking advancement in the field of assistive technology, revolutionizing mobility solutions for individuals with impairments. These intelligent wheelchairs incorporate robotics, sensing technologies, and advanced algorithms to provide enhanced functionality and independence to users (Bakouri et al., 2022). By enabling autonomous navigation and obstacle avoidance, smart robotic wheelchairs empower individuals to navigate complex environments with greater ease and confidence.

Traditional manual wheelchairs require constant physical exertion and control from the user, limiting their ability to traverse challenging terrains or navigate crowded spaces. In contrast, smart robotic wheelchairs employ a range of sensors, such as depth cameras, LiDAR (Light Detection and Ranging), and ultrasonic sensors, to perceive the surrounding environment and detect obstacles (Pradeep et al., 2022). This environment perception is further enhanced through the integration of machine learning algorithms and computer vision techniques, enabling the wheelchair to recognize and classify objects and obstacles in real-time.

The autonomous navigation capabilities of smart robotic wheelchairs rely on sophisticated path planning algorithms, motion control strategies, and decision-making processes. These algorithms analyse sensor data, map the environment, and determine the safest and most efficient routes for navigation. By autonomously steering and maneuvering through obstacles, the wheelchair can alleviate the burden on the user and enhance their overall mobility experience.

Moreover, smart robotic wheelchairs address critical safety considerations. They employ robust localization and mapping techniques to ensure accurate positioning and enable seamless navigation even in dynamic environments. Real-time monitoring and adaptive control mechanisms allow the wheelchair to respond to unexpected changes in the surroundings, ensuring a high level of user safety (Ghezala et al., 2022).

The potential impact of smart robotic wheelchairs extends beyond physical mobility. By promoting independence, these devices enhance the psychological well-being and confidence of individuals with mobility impairments (Sahoo and Choudhury, 2023a). They provide a means for users to engage more actively in social activities, participate in community events, and experience greater freedom in their daily lives.

In this rapidly evolving field, ongoing research and development efforts are focused on addressing challenges such as optimizing navigation algorithms, improving obstacle detection and classification accuracy, and exploring novel sensor modalities. By harnessing the power of emerging technologies, smart robotic wheelchairs hold the promise of transforming the lives of individuals with mobility impairments and ushering in a new era of inclusive and accessible mobility solutions.

1.1 Importance of proposed study

The importance of autonomous navigation and obstacle avoidance in smart robotic wheelchairs cannot be overstated. These capabilities have a profound impact on the lives of individuals with mobility impairments, providing them with increased independence, mobility, and overall quality of life.

First and foremost, autonomous navigation allows individuals using smart robotic wheelchairs to navigate complex environments without relying on constant manual control. This eliminates the physical and mental strain associated with maneuvering a wheelchair, especially in challenging situations such as crowded spaces, narrow corridors, or uneven terrains. By autonomously steering and avoiding obstacles, these wheelchairs enable users to focus on other activities, interact with their surroundings, and engage more actively in their environment (Sahoo and Choudhury, 2023b). Obstacle avoidance is a crucial aspect of autonomous navigation in smart robotic wheelchairs. Traditional wheelchairs often face difficulties when encountering obstacles, leading to frustration and limitations in movement for the user (Ramaraj et al., 2023). This empowers users to explore new environments, visit public spaces, and navigate independently in their homes or communities, thereby increasing their freedom and participation in society.

The integration of sensors, such as depth cameras, LiDAR, and ultrasonic sensors, plays a vital role in obstacle detection and avoidance. These sensors provide a comprehensive view of the wheelchair's surroundings, allowing for precise identification of obstacles, people, and objects in the environment (Bausaeed et al., 2022). By leveraging machine learning algorithms and computer vision techniques, the wheelchair can differentiate between static and dynamic obstacles, determine their size and distance, and make informed decisions to navigate around them. This capability significantly reduces the risk of collisions and accidents, promoting user safety and confidence (Mallik et al., 2023). Furthermore, autonomous navigation and obstacle avoidance in smart robotic wheelchairs have a positive impact on mental well-being. For individuals with mobility impairments, the ability to move independently and navigate their environment is closely tied to their sense of autonomy and self-esteem.

By empowering users to control their own movement and actively participate in daily activities, these wheelchairs enhance their overall psychological well-being and quality of life.

Autonomous navigation and obstacle avoidance in smart robotic wheelchairs also have broader societal implications. These technologies promote inclusivity by breaking down barriers and enabling individuals with mobility impairments to access public spaces and facilities that were previously challenging to navigate. By facilitating independent mobility, smart robotic wheelchairs contribute to a more equitable and inclusive society, fostering greater participation and integration of individuals with disabilities. In addition to the immediate benefits for individuals with mobility impairments, autonomous navigation and obstacle avoidance in smart robotic wheelchairs also have long-term advantages. These technologies can contribute to reducing the burden on caregivers and healthcare systems. By enabling users to navigate independently, smart robotic wheelchairs reduce the need for constant assistance and support from caregivers, allowing them to allocate their time and resources more efficiently (Nawrat and Krawczyk, 2023). This, in turn, promotes greater independence and self-reliance for individuals with mobility impairments.

Moreover, the implementation of autonomous navigation and obstacle avoidance in smart robotic wheelchairs aligns with the broader advancements in robotics and artificial intelligence. These technologies have the potential to transform the field of assistive technology and healthcare, paving the way for innovative solutions that enhance the overall well-being and quality of life for individuals with disabilities (Sahoo and Choudhury, 2022). By integrating cutting-edge sensor technologies, machine learning algorithms, and navigation strategies, smart robotic wheelchairs serve as a test bed for developing and refining these technologies, thereby contributing to advancements in the broader field of robotics. The research and development in autonomous navigation and obstacle avoidance for smart robotic wheelchairs also foster collaborations among various disciplines. Engineers, computer scientists, healthcare professionals, and individuals with disabilities work together to design and refine these technologies. This multidisciplinary approach encourages knowledge sharing, innovation, and the application of diverse perspectives to address the complex challenges associated with autonomous navigation and obstacle avoidance (Sahoo and Choudhury, 2021). The collaborative nature of this field has the potential to generate new insights and breakthroughs that can be applied not only to smart robotic wheelchairs but also to other domains, such as autonomous vehicles and robotic systems.

Additionally, the continuous advancement of autonomous navigation and obstacle avoidance in smart robotic wheelchairs can drive policy changes and create a supportive environment for the adoption of these technologies. Governments, regulatory bodies, and healthcare institutions recognize the potential benefits and importance of autonomous assistive technologies. They may develop guidelines, standards, and funding initiatives to encourage the integration of smart robotic wheelchairs into healthcare systems, public spaces, and accessibility regulations (Wang et al., 2022). This support can further accelerate the deployment and adoption of these technologies, ensuring that individuals with mobility impairments have access to the latest advancements in assistive technology.

The significance of autonomous navigation and obstacle avoidance in smart robotic wheelchairs goes beyond individual mobility and accessibility. These technologies contribute to the well-being of individuals with mobility impairments, reduce caregiver burden, foster advancements in robotics and artificial intelligence, and promote interdisciplinary collaboration. With continued research, innovation, and support, smart robotic wheelchairs have the potential to transform the lives of individuals with disabilities and shape the future of assistive technology.

1.2 Objective of the proposed study

The objective of this review research paper is to provide a comprehensive analysis of the advancements, challenges, and methodologies in autonomous navigation and obstacle avoidance in smart robotic wheelchairs. The paper aims to:

- To examine the current state-of-the-art technologies and components involved in smart robotic wheelchairs, including sensor modalities, machine learning algorithms, and computer vision techniques used for environment perception and obstacle recognition.
- To investigate the different approaches and methodologies employed for autonomous navigation, path planning, motion control, and decision-making in smart robotic wheelchairs.
- To address the challenges and limitations associated with autonomous navigation, such as localization and mapping accuracy, dynamic environment modelling, and semantic understanding of objects.
- To present recent research advancements in the field, highlighting novel techniques, algorithms, and solutions proposed by researchers.

2. Literature Review

Smart robotic wheelchairs have emerged as a promising solution for enhancing the mobility and independence of individuals with mobility impairments. This literature review aims to provide an overview of the current state-of-the-art technologies, methodologies, and challenges in the field of smart robotic wheelchairs, specifically focusing on autonomous navigation and obstacle avoidance.

Sensor technologies play a crucial role in perceiving the wheelchair's surrounding environment and detecting obstacles. Depth cameras, such as Microsoft Kinect, have been widely used for environment perception due to their ability to capture depth information and generate 3D maps (Wang et al., 2021; Fu et al., 2022). LiDAR sensors have also shown promise in creating accurate maps of the environment, allowing for efficient obstacle detection (Lopac et al., 2022). Ultrasonic sensors are commonly employed for proximity sensing and obstacle detection at close ranges (Dahmani et al., 2020). These sensor modalities enable smart robotic wheelchairs to perceive the environment and provide essential input for autonomous navigation.

Machine learning algorithms and computer vision techniques have been integrated into smart robotic wheelchairs to enhance environment perception and obstacle recognition. Convolutional Neural Networks (CNNs) have shown remarkable performance in object detection and classification tasks, enabling the wheelchair to recognize and distinguish obstacles in real-time (Zhang et al., 2019). Additionally, semantic segmentation algorithms, such as DeepLab and U-Net, have been employed to provide a semantic understanding of the environment, allowing the wheelchair to differentiate between different types of objects and obstacles (Xu et al., 2023).

Path planning algorithms are essential for determining the optimal route for the wheelchair to navigate while avoiding obstacles. Traditional approaches, such as the A* algorithm, have been adapted and integrated into smart robotic wheelchairs (Sahoo and Choudhury, 2023c). Reactive navigation strategies, such as potential field methods, enable the wheelchair to respond to immediate obstacles and adjust its trajectory accordingly (Zacharaki et al., 2020). Proactive approaches, such as Model Predictive Control (MPC), consider future states and optimize the motion control of the wheelchair to achieve smoother and more efficient navigation (Guillen-Ruiz et al., 2023). Despite the significant progress in the field of smart robotic wheelchairs, several challenges remain. Localization and mapping accuracy are critical factors for effective navigation, and research efforts are focused on developing robust localization algorithms that can adapt to dynamic environments (Xia et al., 2020). Dynamic obstacle modelling, including predicting the intentions and trajectories of moving objects, presents another challenge that requires further exploration. Additionally, ensuring the safety and ethical implications of autonomous systems in healthcare settings is of utmost importance, emphasizing the need for user-centric design, transparent decision-making processes, and user trust.

Smart robotic wheelchairs with autonomous navigation and obstacle avoidance capabilities hold great promise in improving the mobility and quality of life for individuals with mobility impairments. The integration of sensor technologies, machine learning algorithms, and path planning strategies enables these wheelchairs to navigate complex environments, avoid obstacles, and provide users with greater independence. However, further research is needed to address challenges related to localization, dynamic obstacle modelling, and ethical considerations. With continued advancements, smart robotic wheelchairs have the potential to revolutionize assistive technology and promote inclusivity for individuals with mobility impairments.

2.1 Previous study on autonomous navigation of wheelchair

Reactive navigation methods have been widely employed for autonomous wheelchair navigation, focusing on immediate obstacle detection and avoidance. One popular approach within reactive navigation is the use of potential field methods. These methods generate attractive and repulsive forces based on the proximity of obstacles and desired target location to guide the wheelchair's trajectory away from obstacles and towards the target. Houshyari and Sezer (2022) proposed an obstacle avoidance method based on potential field methods for a mobile robot, which can be adapted for wheelchair navigation. This method allows the wheelchair to reactively adjust its path in real-time based on the sensed obstacles, enabling safe navigation.

Reactive navigation methods often rely on sensor data to detect obstacles and guide navigation decisions. Vision-based sensors, such as cameras, have been widely used for obstacle detection in reactive navigation approaches. Kolar et al. (2020) developed a vision-based intelligent wheelchair system for autonomous navigation in dynamic environments. The system utilized a single camera to detect and track objects in real-time, enabling reactive obstacle avoidance. By leveraging computer vision algorithms, the wheelchair can reactively adjust its trajectory based on the detected obstacles, ensuring safe navigation. Furthermore, machine learning techniques have been incorporated into reactive navigation methods to enhance obstacle detection and classification. Utaminingrum et al. (2022) proposed a real-time obstacle detection and classification method for intelligent wheelchairs using deep convolutional neural networks. By training the neural network on labelled data, the wheelchair can autonomously detect and classify obstacles in its path, allowing for reactive navigation decisions based on obstacle type and severity.

Despite the advancements in reactive navigation of wheelchairs, several challenges remain. One challenge is the trade-off between avoiding obstacles and achieving the desired target location efficiently. The reactive nature of these methods may result in suboptimal paths and longer navigation times. Balancing efficient navigation and obstacle avoidance is an ongoing research focus. Path planning algorithms are essential for enabling autonomous navigation in wheelchairs by determining optimal paths while avoiding obstacles. This literature review provides an overview of the current state-of-the-art technologies, methodologies, and challenges in the field of autonomous path planning algorithms for wheelchairs.

A popular algorithm used in path planning for wheelchair navigation is the A* (A-star) algorithm. Thirugnanasambandam et al. (2021) proposed an A*-based optimal path planning algorithm for intelligent wheelchairs. The algorithm considers the wheelchair's kinematic constraints and the environment's characteristics to generate collision-free and efficient paths. A* algorithm and its variants are widely used due to their ability to find the shortest path efficiently by considering the cost of traversal and heuristic estimates.

Another commonly used algorithm in path planning for wheelchairs is Rapidly-exploring Random Trees (RRT). Wang et al. (2020) proposed an A*-RRT hybrid algorithm for autonomous wheelchair navigation. The algorithm combines the global exploration capabilities of RRT with the efficient path planning abilities of A*. By integrating these two algorithms, the wheelchair can rapidly explore the environment while efficiently finding optimal paths to the target. In recent years, machine learning techniques have been employed to enhance path planning algorithms for wheelchairs. Reinforcement learning algorithms have been used to train agents that can learn optimal navigation policies. Gil et al. (2021) proposed a path planning method based on a reactive and predictive approach using reinforcement learning for robotic wheelchairs in dynamic environments. The approach combines a reactive strategy for immediate obstacle avoidance and a predictive strategy using reinforcement learning to anticipate and plan for future obstacles, enabling efficient and proactive path planning.

Simultaneous Localization and Mapping (SLAM) techniques play a vital role in enabling autonomous navigation in wheelchairs by simultaneously creating maps of the environment and localizing the wheelchair within the map. SLAM algorithms typically utilize sensor data, such as visual or depth information, to create a map of the environment while simultaneously estimating the wheelchair's position within that map. Patoliya et al. (2022) proposed a novel SLAM approach based on an enhanced graph SLAM algorithm for wheelchair navigation. The algorithm incorporates loop closure detection, graph optimization, and data association techniques to improve mapping accuracy and localization performance.

Vision-based SLAM methods have been widely explored for wheelchair navigation. These methods leverage camera sensors to capture visual data and extract relevant features for mapping and localization. Udupa et al. (2021) developed a vision-based SLAM system for wheelchair navigation, combining feature tracking and bundle adjustment techniques to create a map of the environment and estimate the wheelchair's position. By utilizing visual information, vision-based SLAM techniques provide rich environmental representation and robust localization capabilities. In addition to vision-based SLAM, LiDAR-based SLAM techniques have also been employed for wheelchair navigation. LiDAR sensors capture 3D point cloud data, enabling accurate mapping and localization in complex environments. Zheng et al. (2023) proposed a LiDAR-based SLAM approach for wheelchair navigation using a multi-layer grid map representation and extended Kalman filtering. This method enables real-time mapping and localization in dynamic environments, enhancing the wheelchair's autonomy.

The integration of SLAM with other sensor modalities, such as wheel encoders and inertial measurement units (IMUs), has been explored to improve localization accuracy. Madake et al. (2023) proposed an optimized wheel odometry method for mobile robot positioning, incorporating wheel encoder data and IMU measurements to enhance localization accuracy. By fusing multiple sensor inputs, the SLAM system can compensate for individual sensor limitations and provide more accurate and robust localization. Challenges in SLAM for wheelchair navigation include handling dynamic environments, loop closure detection, and real-time performance. Dynamic environments with moving objects or changing scenes can pose challenges for SLAM algorithms. Handling loop closures, where the robot revisits previously mapped areas, is crucial for accurate map creation and localization. Additionally, real-time performance is a critical factor, as SLAM algorithms need to operate in real-time for responsive and dynamic navigation.

Model Predictive Control (MPC) is a control strategy that has been widely employed for autonomous navigation in wheelchairs. MPC considers the dynamics of the wheelchair and predicts future states based on a dynamic model. By optimizing a cost function over a finite time horizon, MPC generates control commands that minimize the cost while satisfying constraints such as obstacle avoidance and wheelchair dynamics. Minnetoglu and Conkur (2022) proposed a novel MPC approach for wheelchair navigation, considering both global path planning and local obstacle avoidance. The method utilized a receding horizon optimization scheme to generate control commands, enabling the wheelchair to navigate smoothly and safely in dynamic environments. Yenugula et al. (2023) presented a vision-based Model Predictive Control method for autonomous robotic wheelchairs. The approach combined a visual perception system with MPC to enable the wheelchair to navigate based on visual information. The system optimized control commands considering both current and predicted visual states, providing accurate and responsive control. One of the challenges in MPC for wheelchair navigation is the formulation of the cost function. The cost function should appropriately balance various objectives, such as obstacle avoidance, smoothness of motion, and energy efficiency.

Model Predictive Control (MPC) offers a powerful control strategy for autonomous navigation in wheelchairs. MPC leverages dynamic models and optimization techniques to generate control commands that optimize objectives and constraints. The integration of visual perception systems, multi-objective cost functions, and trust-based control architectures enhances the capabilities of MPC-based navigation. However, challenges related to formulating cost functions, computational requirements, and ethical considerations remain. Further research is needed to develop advanced MPC algorithms that address these challenges and improve the autonomy and safety of wheelchair navigation systems.

2.2 Previous study on obstacle avoidance of wheelchair

There are various types of obstacle avoidance techniques used in wheelchair navigation to ensure safe and efficient movement in complex environments. Machine learning techniques have been increasingly applied to obstacle avoidance in wheelchair navigation, enabling intelligent and adaptive decision-making based on sensor data. This literature review provides an overview of the current state-of-the-art technologies, methodologies, and challenges in the field of machine learning-based obstacle avoidance for wheelchairs. One of the key applications of machine learning in obstacle avoidance is object detection and classification. D’Angelo and Palmeieri (2023) proposed a real-time obstacle detection and classification method for intelligent wheelchairs using deep convolutional neural networks (CNNs). The method trained a CNN model on labelled data to detect and classify obstacles in the wheelchair's path. By leveraging the capabilities of CNNs, the wheelchair can autonomously recognize different types of obstacles and adjust its trajectory accordingly.

Transfer learning has also been employed in machine learning-based obstacle avoidance for wheelchairs. Transfer learning allows pre-trained models to be fine-tuned on specific wheelchair navigation tasks. Farheen et al. (2022) proposed a transfer learning approach for wheelchair obstacle avoidance, where a pre-trained CNN model was fine-tuned using wheelchair-specific data. This approach reduces the need for extensive data collection and training, enabling faster deployment of obstacle avoidance systems. Challenges in machine learning-based obstacle avoidance for wheelchairs include the availability of labelled training data, generalization to unseen environments, and real-time performance. Collecting diverse and representative labelled data can be challenging, especially for rare or complex obstacles. Ensuring that the learned models generalize well to unseen environments is also crucial for reliable obstacle avoidance. Additionally, real-time performance is critical for responsive navigation, requiring efficient inference and decision-making processes.

Dynamic obstacle tracking and prediction techniques are crucial for effective obstacle avoidance in wheelchair navigation, enabling proactive and adaptive decision-making based on the anticipated future trajectories of moving obstacles. This literature review provides an overview of the current state-of-the-art technologies, methodologies, and challenges in the field of dynamic obstacle tracking and prediction for wheelchair obstacle avoidance. One of the commonly used methods for dynamic obstacle tracking and prediction is the Kalman filter. The Kalman filter is a recursive estimation algorithm that combines measurements and predictions to estimate the state of a dynamic system. Khan et al. (2021) proposed a Kalman filter-based approach for dynamic obstacle tracking and prediction in wheelchair navigation. The method utilized sensor measurements, such as LiDAR or camera data, to track the motion of obstacles and predict their future positions. By leveraging the Kalman filter, the wheelchair can anticipate and avoid potential collisions with moving obstacles.

Challenges in dynamic obstacle tracking and prediction for wheelchair navigation include dealing with occlusions, handling uncertainties in motion estimation, and maintaining real-time performance. Occlusions occur when obstacles are partially or completely hidden from the sensors' view, making it challenging to accurately track their motion. Uncertainties in motion estimation, such as sensor noise or unpredictable behaviour of moving objects, can lead to errors in prediction. Maintaining real-time performance is critical for responsive navigation, requiring efficient algorithms and sensor fusion techniques.

2.3 Research Gap and Novelty

While there have been significant advancements in autonomous navigation and obstacle avoidance in smart robotic wheelchairs, several research gaps and opportunities for novelty remain. This section highlights the research gap and potential areas of novelty in the field:

- One research gap lies in the integration of multiple navigation techniques to create robust and adaptive systems. While individual navigation methods such as reactive navigation, path planning, SLAM, or machine learning-based approaches have been extensively studied, there is a need to explore novel ways of combining these techniques synergistically. Developing hybrid navigation systems that intelligently switch or fuse different methods based on the environment's characteristics can lead to enhanced navigation performance and adaptability.
- User-centered design and human-robot interaction (HRI) are crucial aspects that require further exploration. Designing smart robotic wheelchairs that can seamlessly interact with users, understand their intentions, and adapt to their preferences and needs is a research gap. Novelty can be found in the development of intuitive and efficient interfaces, such as voice or gesture-based control, to improve user experience and enable more natural interaction between the wheelchair and its user.
- Safety remains a critical concern in autonomous navigation of smart robotic wheelchairs. Addressing safety challenges, such as collision avoidance, handling dynamic obstacles, and ensuring fail-safe mechanisms, is an ongoing research gap. Additionally, ethical considerations, including decision-making in complex scenarios and handling uncertain situations, require further exploration. Novelty lies in the development of ethical frameworks and decision-making algorithms that prioritize user safety while considering the ethical implications of autonomous actions.
- While many research studies focus on laboratory or controlled environments, there is a need for more extensive real-world deployment and validation of autonomous navigation systems for smart robotic wheelchairs. Conducting studies in diverse environments, including indoor, outdoor, and crowded public spaces, will help identify the challenges and limitations of existing approaches. Novelty can be found in field trials, user studies, and long-term evaluations that provide valuable insights into the practical deployment of these systems and their impact on users' daily lives.

While significant progress has been made in autonomous navigation and obstacle avoidance in smart robotic wheelchairs, several research gaps and opportunities for novelty exist. Integrating multiple navigation techniques, focusing on human-robot interaction and user-centric design, addressing safety and ethics considerations, real-world deployment and validation, promoting accessibility and inclusive design, and addressing ethical concerns are areas that offer ample scope for further research and innovation in the field.

3. Navigation and obstacle detection strategies used in wheelchair

There are several navigation strategies used in wheelchairs to enable autonomous movement and efficient navigation in various environments. Here are some commonly employed navigation strategies:

3.1 Point-to-Point Navigation

Point-to-point navigation involves specifying a target location or goal point for the wheelchair, and the wheelchair autonomously plans and executes a path to reach that target. This strategy is suitable for situations where the wheelchair needs to navigate from one specific location to another (Chaudhary et al., 2023). The navigation system calculates a path from the current location of the wheelchair to the target destination and executes the necessary control actions to follow that path. Here is a stepwise explanation of how Point-to-Point navigation works:

Step-1. Localization: The first step is to determine the current location of the wheelchair. This can be achieved using various localization techniques, such as GPS, inertial sensors, wheel encoders, or visual odometry. The localization system provides the wheelchair with an estimate of its position and orientation in the environment.

Step-2. Path Planning: Once the current location is known, the next step is to plan a path from the current location to the target destination. Path planning algorithms, such as A* (A-star) or Dijkstra's algorithm, consider the environment's map, obstacles, and wheelchair constraints to generate an optimal or feasible path. The path planning algorithm takes into account factors like distance, obstacles, terrain, or user preferences to determine the most suitable path.

Step-3. Trajectory Generation: With the planned path, the navigation system generates a trajectory that the wheelchair will follow to reach the target destination. The trajectory specifies the desired position and orientation of the wheelchair at each point in time along the path. The trajectory can be a sequence of waypoints or a continuous curve that smoothly guides the wheelchair.

Step-4. Control and Actuation: The generated trajectory is used by the wheelchair's control system to generate appropriate control commands for the actuators, such as the motors or steering mechanism. The control system computes the necessary velocities or motor commands to follow the desired trajectory. It adjusts the wheelchair's speed, acceleration, and steering to ensure accurate tracking of the trajectory.

Step-5. Sensing and Feedback: Throughout the navigation process, the wheelchair's sensors continuously monitor the environment to detect any changes or obstacles. This may include using proximity sensors, LiDAR, or cameras to sense obstacles or other dynamic elements in the surroundings. The sensor data is processed to detect potential collisions and trigger appropriate avoidance maneuvers if necessary.

Step-6. Obstacle Avoidance: If the sensors detect obstacles along the planned path, the navigation system employs obstacle avoidance algorithms to modify the trajectory. These algorithms can dynamically adjust the path or generate alternative paths to avoid obstacles while ensuring progress towards the target destination. The obstacle avoidance strategy can be reactive, where the wheelchair responds to immediate obstacles in real-time, or predictive, where it anticipates future obstacles based on their motion patterns.

Step-7. Progress Monitoring: The navigation system continuously monitors the wheelchair's progress towards the target destination. It compares the current position with the planned trajectory to ensure accurate tracking and makes adjustments if deviations occur. This monitoring helps the wheelchair to make real-time corrections and ensure that it remains on the desired path.

Step-8. Arrival at the Destination: Once the wheelchair reaches the target destination or is in close proximity, the navigation system signals the completion of the navigation task. This may involve providing audio or visual cues to the user, indicating the successful arrival at the designated location.

By following these steps, the Point-to-Point navigation strategy enables the wheelchair to autonomously navigate from one specific location to another, allowing users to reach their desired destinations with greater independence and ease.

3.2 Path Following

Path following is the strategy of autonomously following a predefined path or trajectory. The path can be defined using waypoints or through a continuous curve. Path following is often used in scenarios where the wheelchair needs to traverse a known trajectory, such as following a predetermined route in a building or following a designated pathway in an outdoor setting (Sezer 2022). Here is a stepwise explanation of how path following works:

Step-1. Path Definition: The first step in path following is to define the desired path. The path can be predefined and stored in the system's memory or generated dynamically based on user input or environmental factors. The path can be represented as a series of waypoints or a continuous curve, depending on the specific application and requirements.

Step-2. Localization: The wheelchair's localization system determines the current position and orientation of the wheelchair within the environment. This can be achieved using various localization techniques, such as GPS, inertial sensors, wheel encoders, or visual odometry. Accurate localization is crucial for aligning the wheelchair with the desired path.

Step-3. Trajectory Generation: Based on the predefined path and the current location, the navigation system generates a trajectory that the wheelchair will follow. The trajectory specifies the desired position and orientation of the wheelchair at each point in time along the path. The trajectory ensures that the wheelchair smoothly follows the desired path while considering factors such as curvature, speed, and acceleration.

Step-4. Control and Actuation: The generated trajectory serves as a reference for the wheelchair's control system. The control system calculates the necessary control commands, such as velocities or motor commands, to accurately track the desired trajectory. It adjusts the wheelchair's speed, acceleration, and steering based on the trajectory to ensure precise path following.

Step-5. Sensing and Feedback: Throughout the path following process, the wheelchair's sensors continuously monitor the environment to provide feedback and make necessary adjustments. This may involve using proximity sensors, LiDAR, or cameras to detect any obstacles or deviations from the desired path. The sensor data is processed to detect potential collisions or deviations and trigger appropriate corrective actions.

Step-6. Deviation Correction: If the sensors detect any deviations from the desired path, the navigation system initiates correction maneuvers to bring the wheelchair back on track. This can involve adjusting the wheelchair's steering or speed to align it with the predefined path. The correction maneuvers ensure accurate and smooth path following, even in the presence of external disturbances or minor errors in localization.

Step-7: Progress Monitoring: The navigation system continuously monitors the wheelchair's progress along the path. It compares the current position with the desired trajectory to determine if the wheelchair is accurately following the path. This monitoring allows the system to make real-time adjustments and corrections to ensure precise path following.

Step-8. Termination or Recalculation: The path following process continues until the wheelchair reaches the end of the predefined path or the specified destination. At this point, the navigation system can either terminate the path following task or recalculate a new path if necessary. The termination or recalculation depends on the specific requirements of the navigation task and the user's intentions.

By following these steps, the path following strategy enables the wheelchair to autonomously follow a predefined path or trajectory with accuracy and reliability. Path following is particularly useful in scenarios where the wheelchair needs to traverse known routes, follow designated pathways, or perform specific tasks along a predetermined trajectory.

3.3 Dynamic Obstacle Avoidance

Dynamic obstacle avoidance involves continuously sensing the environment and adapting the wheelchair's path in real-time to avoid moving obstacles Sharma et al. (2022). This strategy is crucial in crowded or dynamic environments where obstacles, such as pedestrians or other vehicles, can enter the wheelchair's path. Dynamic obstacle avoidance algorithms utilize sensor data and navigation algorithms to make reactive or proactive decisions to avoid collisions. The objective is to continuously sense the environment, detect and track moving obstacles, and generate appropriate control actions to avoid collisions. Here is a stepwise explanation of how dynamic obstacle avoidance works:

Step-1. Environment Perception: The first step is to sense the environment using sensors such as cameras, LiDAR, or ultrasonic sensors. The sensor data provides information about the surrounding objects and obstacles, including their positions, velocities, and trajectories.

Step-2. Obstacle Detection and Tracking: The sensor data is processed to detect and identify moving obstacles in the wheelchair's vicinity. Object detection algorithms, such as deep learning-based methods, can be employed to recognize and classify obstacles. Once detected, the navigation system tracks the obstacles over time to estimate their positions and velocities.

Step-3. Path Planning and Trajectory Generation: Based on the detected and tracked obstacles, the navigation system plans a collision-free path for the wheelchair. Path planning algorithms, such as the A* algorithm or Rapidly-exploring Random Trees (RRT), consider the current position, the desired destination, and the obstacle information to generate a safe and optimal path. The trajectory generation phase converts the planned path into a sequence of desired positions and velocities over time.

Step-4. Control and Actuation: The generated trajectory serves as a reference for the wheelchair's control system. The control system calculates the necessary control commands, such as velocities or motor commands, to follow the desired trajectory while avoiding obstacles. It adjusts the wheelchair's speed, acceleration, and steering based on the trajectory and the obstacle information to ensure safe and collision-free navigation.

Step-5. Dynamic Obstacle Prediction: In addition to detecting and tracking obstacles, the navigation system can employ prediction algorithms to estimate the future trajectories of moving obstacles. By anticipating the future positions of the obstacles, the wheelchair can proactively plan its path to avoid potential collisions. Predictive algorithms can use techniques such as Kalman filters, particle filters, or machine learning-based models to estimate future obstacle trajectories.

Step-6. Collision Avoidance Maneuvers: As the wheelchair navigates, it continuously monitors the positions and velocities of the detected obstacles. If an obstacle's predicted trajectory indicates a potential collision, the navigation system initiates collision avoidance maneuvers. These maneuvers can include adjusting the wheelchair's velocity, changing its path, or even coming to a complete stop to avoid a collision. The specific avoidance strategy depends on the obstacle's position, velocity, and the available space for maneuvering.

Step-7. Real-Time Updates: Dynamic obstacle avoidance is an ongoing process, and the navigation system continually updates its plans and control commands based on the evolving obstacle positions and trajectories. The system periodically re-evaluates the environment, detects new obstacles, and adjusts the path and control actions accordingly. This real-time updating ensures that the wheelchair can respond to changing obstacle situations and maintain safe navigation.

By following these steps, the dynamic obstacle avoidance strategy enables the wheelchair to autonomously navigate in environments with moving obstacles. It continuously senses the environment, detects and tracks obstacles, plans collision-free paths, and generates appropriate control actions to ensure safe and efficient navigation while avoiding potential collisions with dynamic obstacles.

3.4 Static Obstacle Avoidance

Static obstacle avoidance focuses on detecting and avoiding stationary or fixed obstacles in the environment. Wheelchairs employ sensors such as LiDAR, ultrasonic sensors, or cameras to detect and map the locations of static obstacles (Dairi et al., 2018). The objective is to detect and avoid these obstacles to ensure safe and collision-free navigation. Here is a stepwise explanation of how static obstacle avoidance works:

Step-1. Environment Perception: The first step is to perceive the environment using sensors such as cameras, LiDAR, or ultrasonic sensors. The sensor data provides information about the surrounding objects and obstacles, including their positions, shapes, and sizes.

Step-2. Obstacle Detection: The sensor data is processed to detect and identify static obstacles in the wheelchair's vicinity. Object detection algorithms, such as computer vision-based methods or point cloud processing techniques, can be employed to recognize and locate obstacles. The detection algorithms analyse the sensor data to identify regions or points corresponding to the static obstacles.

Step-3. Environment Modelling: Once the obstacles are detected, the navigation system constructs a model or representation of the environment. This can be in the form of a 2D map, a 3D point cloud, or a grid-based representation. The model captures the locations and shapes of the static obstacles, allowing the wheelchair to plan collision-free paths.

Step-4. Path Planning: Based on the environment model, the navigation system employs path planning algorithms to generate a safe and optimal path for the wheelchair. The path planning algorithms consider the current position, the desired destination, and the obstacle information to compute a collision-free path. Techniques such as the A* algorithm, Rapidly-exploring Random Trees (RRT), or potential field methods can be used to plan the path.

Step-5. Trajectory Generation: The planned path is converted into a trajectory that the wheelchair will follow. The trajectory specifies the desired position and orientation of the wheelchair at each point in time along the path. The trajectory generation phase ensures that the wheelchair smoothly follows the desired path while considering factors such as curvature, speed, and acceleration.

Step-6. Control and Actuation: The generated trajectory serves as a reference for the wheelchair's control system. The control system calculates the necessary control commands, such as velocities or motor commands, to accurately track the desired trajectory while avoiding static obstacles. It adjusts the wheelchair's speed, acceleration, and steering based on the trajectory and the obstacle information to ensure safe navigation.

Step-7. Collision Avoidance: As the wheelchair navigates, it continuously monitors its surroundings and compares its current position with the environment model. If the wheelchair detects that it is on a collision course with a static obstacle, the navigation system initiates collision avoidance maneuvers. These maneuvers can include adjusting the wheelchair's velocity, changing its path, or coming to a complete stop to avoid a collision. The specific avoidance strategy depends on the obstacle's position, the available space for maneuvering, and the wheelchair's capabilities.

Step-8. Real-Time Updates: The static obstacle avoidance strategy requires continuous monitoring of the environment and updates to the path and control commands. The navigation system periodically re-evaluates the environment, detects new obstacles, and adjusts the path and control actions accordingly. This real-time updating ensures that the wheelchair can respond to changes in the environment and safely navigate around static obstacles.

By following these steps, the static obstacle avoidance strategy enables the wheelchair to autonomously navigate in environments with stationary or fixed obstacles. It employs sensors for obstacle detection, constructs an environment model, plans collision-free paths, generates appropriate control actions, and continuously updates its plans to avoid static obstacles and ensure safe navigation.

3.5 Wayfinding

Wayfinding strategies involve providing navigation instructions or guidance to the wheelchair user to reach a desired destination (Prandi et al., 2021). This can be achieved through audio cues, visual indicators, or tactile feedback. Wayfinding techniques are particularly useful for individuals with visual impairments who may require assistance in navigating complex environments. Here is a stepwise explanation of how wayfinding works:

Step-1. Destination Input: The user specifies their desired destination or target location to the wayfinding system. This can be done through various means, such as voice commands, touchscreen input, or selecting from a list of predefined destinations.

Step-2. Route Calculation: Once the destination is provided, the wayfinding system calculates the optimal route or path to reach the destination. This can involve considering factors such as the user's preferences (e.g., shortest route, barrier-free path), the environment's layout, and available information about obstacles or accessible pathways.

Step-3. Information Presentation: The wayfinding system presents the calculated route to the user in a clear and accessible manner. This can be through visual indicators, audio instructions, or a combination of both. The system may use maps, arrows, or symbols to indicate the directions and landmarks along the route.

Step-4. Orientation and Guidance: As the user starts navigating, the wayfinding system provides continuous guidance and orientation cues. These cues can include audio instructions or prompts that inform the user of upcoming turns, landmarks, or points of interest. Visual cues, such as arrows on signage or on a display, can also assist in guiding the user along the intended path.

Step-5. Obstacle Awareness: The wayfinding system takes into account obstacles or barriers that may hinder the user's navigation. It can provide notifications or alternative routes to avoid obstacles, such as stairs, narrow passages, or closed pathways. The system may utilize obstacle detection sensors or pre-existing obstacle databases to identify and navigate around these obstacles.

Step-6. Feedback and Confirmation: Throughout the navigation process, the wayfinding system provides feedback to the user to ensure they are on the correct path. This can include confirmation messages, visual or auditory feedback upon reaching milestones or checkpoints, or alerts when deviating from the intended route. Feedback helps users gain confidence in their navigation and provides reassurance about their progress.

Step-7. User Interaction: The wayfinding system allows for user interaction and engagement during the navigation process. Users can ask for additional information, request alternative routes, or seek clarification on instructions. The system can incorporate voice commands, touchscreens, or other user interfaces to facilitate this interaction.

Step-8. Destination Arrival: Once the user reaches the desired destination, the wayfinding system provides confirmation or cues to indicate the successful completion of the navigation. This can include visual or auditory messages, signage, or notifications on the user interface. The system may also offer additional information or assistance related to the destination, such as nearby amenities or services.

By following these steps, the wayfinding strategy assists wheelchair users in navigating complex environments by providing guidance, instructions, and cues. It takes into account user preferences, calculates optimal routes, offers continuous guidance, and addresses obstacles to ensure a successful and accessible navigation experience.

The choice of navigation strategy depends on factors such as the user's capabilities, the environment's complexity, and the level of autonomy desired. Wheelchair navigation systems often incorporate a combination of these strategies to provide a comprehensive and versatile navigation experience that caters to the user's specific needs and the challenges of the environment.

4. Challenges and limitations associated with autonomous navigation

Autonomous navigation in complex environments presents several challenges and limitations that need to be addressed to ensure accurate and reliable performance. Here, we will delve into three key challenges: localization and mapping accuracy, dynamic environment modeling, and semantic understanding of objects.

4.1 Localization and Mapping Accuracy

Accurate localization is crucial for autonomous navigation, as it enables the wheelchair to determine its position and orientation within the environment. However, achieving high localization accuracy can be challenging due to various factors:

a) Sensor Limitations: Localization relies on sensor inputs such as GPS, inertial sensors, or visual odometry. These sensors may have limitations in terms of accuracy, reliability, or susceptibility to noise. For example, GPS signals can be affected by signal blockage or multipath interference, leading to errors in position estimation.

b) Environmental Factors: Environmental conditions, such as poor lighting, complex indoor structures, or reflective surfaces, can pose challenges for localization accuracy. These factors can affect the performance of sensors like cameras or LiDAR, leading to inaccuracies in feature detection or depth estimation.

c) Long-Term Localization Drift: Over time, localization algorithms can suffer from drift, where accumulated errors result in deviations from the true position. Maintaining accurate long-term localization remains a challenge, particularly in environments with limited distinctive features or dynamic changes.

To address these challenges, advanced localization techniques like sensor fusion, simultaneous localization and mapping (SLAM), and loop closure detection are employed. These techniques integrate multiple sensor inputs, refine mapping accuracy, and incorporate loop closures to correct localization drift.

4.2 Dynamic Environment Modeling

Autonomous navigation requires modeling and understanding dynamic environments, including moving obstacles, changing terrain conditions, and the presence of pedestrians. Some challenges in dynamic environment modeling include:

a) Dynamic Obstacle Tracking: Tracking and predicting the movements of dynamic obstacles, such as pedestrians or other vehicles, is crucial for safe navigation. However, accurately estimating the trajectory and intentions of moving objects in real-time can be challenging due to occlusions, uncertainties, or sudden changes in their motion.

b) Real-Time Updates: Dynamic environment modeling requires updating the environment representation in real-time to account for changes. Processing sensor data, detecting and tracking moving objects, and incorporating this information into the navigation system pose computational challenges. Real-time performance is crucial to ensure timely response and avoidance of dynamic obstacles.

c) Perception-Action Latency: The time delay between perceiving an obstacle and generating an appropriate action can affect the ability to avoid collisions. Minimizing perception-action latency is essential for ensuring the wheelchair can respond quickly and effectively to dynamic changes in the environment.

To overcome these challenges, techniques such as object detection and tracking, motion prediction algorithms, and real-time sensor data processing are utilized. Advanced approaches, including deep learning-based methods, can enable more accurate and robust modeling of dynamic environments.

4.3 Semantic Understanding of Objects

Semantic understanding involves identifying and categorizing objects in the environment to make informed navigation decisions. Some challenges in semantic understanding include:

a) Object Recognition and Classification: Recognizing and categorizing objects in the environment, such as doors, stairs, or furniture, can be challenging due to variations in appearance, occlusions, or cluttered scenes. Achieving robust and accurate object recognition is essential for understanding the environment's semantic context.

b) Semantic Mapping: Creating maps that not only represent the physical layout but also provide semantic information about objects and their attributes is crucial for intelligent navigation. Generating such semantic maps requires accurate object recognition and integration of object-related information into the mapping process.

c) Scene Understanding: Understanding the relationships between objects and the environment is vital for making context-aware navigation decisions. This involves reasoning about object affordances, navigation constraints, and the semantic meaning of objects in the environment.

Addressing these challenges is essential for enhancing the accuracy, reliability, and safety of autonomous navigation systems in complex environments. Ongoing research and advancements in sensor technology, machine learning, and robotics algorithms are continuously improving the state-of-the-art in these areas, bringing us closer to robust and intelligent autonomous navigation solutions.

5. Recent research advancements in this field

Recent research in autonomous navigation and obstacle avoidance in smart robotic wheelchairs has witnessed significant advancements. Here are some notable research areas and advancements:

- Machine Learning-Based Approaches: Machine learning techniques, such as deep learning, have been extensively applied to enhance perception, obstacle detection, and decision-making in autonomous navigation. Researchers have utilized convolutional neural networks (CNNs) for object detection, semantic segmentation, and scene understanding, enabling robust perception in complex environments. Reinforcement learning (RL) has been employed to train agents for adaptive navigation and obstacle avoidance, allowing wheelchairs to learn from interactions and optimize their navigation behavior.
- Sensor Fusion and Perception: Research has focused on integrating multiple sensors, such as cameras, LiDAR, radar, and depth sensors, to improve perception accuracy and robustness. Sensor fusion techniques, including Kalman filtering, particle filtering, and probabilistic models, have been employed to combine sensor data and obtain a comprehensive understanding of the environment. This fusion enables reliable obstacle detection, tracking, and localization in dynamic scenarios.
- Real-Time Mapping and Localization: Recent advancements have targeted improving mapping and localization accuracy in real-time. Simultaneous Localization and Mapping (SLAM) techniques have evolved to provide more accurate and efficient mapping, even in dynamic environments. Visual SLAM methods, leveraging visual odometry and feature-based mapping, enable the creation of detailed environment maps while estimating the wheelchair's position accurately.
- Dynamic Obstacle Tracking and Prediction: Researchers have focused on developing algorithms for real-time dynamic obstacle tracking and prediction. These algorithms utilize sensor data to estimate the motion and intent of moving obstacles, enabling proactive obstacle avoidance and safe trajectory planning. Machine learning techniques, including recurrent neural networks (RNNs) and long short-term memory (LSTM) networks, have been employed to model and predict the trajectories of dynamic obstacles.
- Semantic Understanding and Scene Analysis: Advances have been made in semantic understanding and scene analysis to enhance navigation decision-making. Researchers have explored methods to recognize and classify objects in the environment, enabling the wheelchair to understand the semantic meaning and context. Scene analysis techniques, such as affordance estimation and spatial reasoning, have been utilized to derive meaningful navigation strategies and adapt to the environment's characteristics.
- Human-Robot Interaction and User-Centric Design: Recent research has focused on improving the interaction between smart robotic wheelchairs and users. User-centric design principles have been integrated into the development of autonomous navigation systems, considering user preferences, comfort, and safety. Efforts have been made to develop intuitive interfaces, including voice commands, gestures, or brain-computer interfaces, to enable seamless control and interaction with the wheelchair.
- Field Trials and Real-World Deployments: Researchers have conducted field trials and real-world deployments of autonomous navigation systems in smart robotic wheelchairs. These studies assess the performance, reliability, and user acceptance of the systems in various environments, such as indoor spaces, outdoor pathways, and healthcare facilities. Field trials provide valuable insights and feedback to further refine the navigation algorithms and address real-world challenges.

These recent advancements in autonomous navigation and obstacle avoidance in smart robotic wheelchairs offer promising prospects for enhanced independence and mobility for wheelchair users. Continued research in these areas, along with interdisciplinary collaborations, holds great potential for further improving the capabilities and effectiveness of smart robotic wheelchairs in real-world scenarios.

6. Conclusion

This review paper has provided a comprehensive overview of autonomous navigation and obstacle avoidance in smart robotic wheelchairs. The research and advancements in this field have demonstrated great potential for enhancing the mobility and independence of wheelchair users. By leveraging technologies such as machine learning, sensor fusion, and semantic understanding, smart robotic wheelchairs have made significant strides in addressing the challenges associated with navigation in complex environments.

The review highlighted various navigation strategies, including point-to-point navigation, path following, dynamic obstacle avoidance, static obstacle avoidance, wayfinding, and adaptive navigation. Each strategy offers unique advantages and addresses specific navigation scenarios. The selection of the appropriate strategy depends on factors such as the user's capabilities, the environment's complexity, and the desired level of autonomy.

Furthermore, the paper discussed key challenges and limitations associated with autonomous navigation, such as localization and mapping accuracy, dynamic environment modelling, and semantic understanding of objects. These challenges require ongoing research and development to improve the robustness, accuracy, and reliability of navigation systems in real-world scenarios.

The review also highlighted recent research advancements in the field, including machine learning-based approaches, sensor fusion, real-time mapping and localization, dynamic obstacle tracking and prediction, semantic understanding, and user-centric design. These advancements have significantly contributed to enhancing perception, decision-making, and user interaction, paving the way for more intelligent and adaptive navigation systems.

Autonomous navigation and obstacle avoidance in smart robotic wheelchairs have the potential to revolutionize mobility and improve the quality of life for wheelchair users. By addressing the challenges and leveraging the latest research advancements, we can develop more reliable, efficient, and user-centric navigation systems that empower individuals with greater independence, safety, and accessibility. Continued research, interdisciplinary collaborations, and real-world validations are essential to further advance the field and unlock the full potential of autonomous navigation in smart robotic wheelchairs.

6.1 Practical Implication

The review paper on autonomous navigation and obstacle avoidance in smart robotic wheelchairs holds several practical implications for various stakeholders. These implications highlight the potential benefits, applications, and considerations for the adoption and implementation of autonomous navigation systems in smart robotic wheelchairs.

- Enhanced Independence for Wheelchair Users: The development and deployment of autonomous navigation systems offer wheelchair users greater independence and mobility. By enabling wheelchairs to navigate autonomously in complex environments, users can overcome physical limitations and have more control over their daily activities and movements. This increased independence can lead to improved quality of life and a greater sense of empowerment.
- Improved Safety and Collision Avoidance: Autonomous navigation systems equipped with obstacle avoidance capabilities contribute to enhanced safety for wheelchair users. By leveraging sensors, perception algorithms, and real-time decision-making, these systems can detect and avoid obstacles,

thereby reducing the risk of collisions and accidents. This feature is particularly valuable in crowded or dynamic environments where manual navigation may be challenging.

- Access to a Broader Range of Environments: Autonomous navigation technology expands the range of environments that wheelchair users can confidently navigate. Smart robotic wheelchairs can be designed to traverse diverse terrains, including indoor spaces, outdoor pathways, and public facilities. This opens up opportunities for users to engage in various activities, such as shopping, socializing, or exploring new environments, with improved accessibility and reduced dependence on assistance.
- Customization and Personalization: The review paper highlights adaptive navigation strategies that consider individual user preferences, needs, and abilities. This aspect emphasizes the potential for customization and personalization of autonomous navigation systems in smart robotic wheelchairs. By tailoring the navigation behaviour to suit each user's specific requirements, these systems can provide a more tailored and user-centric experience.
- Technological Advancements and Collaboration: The research advancements discussed in the review paper highlight the ongoing technological progress in the field of autonomous navigation. These advancements are driven by interdisciplinary collaborations involving robotics, artificial intelligence, human-computer interaction, and healthcare professionals. The practical implication is the need for continued collaboration and knowledge exchange among researchers, engineers, clinicians, and end-users to accelerate the development and deployment of effective autonomous navigation systems.
- Ethical and Social Considerations: The adoption of autonomous navigation systems in smart robotic wheelchairs also raises ethical and social considerations. The review paper emphasizes the importance of addressing these concerns, including issues related to privacy, trust, and the human-robot interaction. Practical implications include the need for clear guidelines, regulatory frameworks, and user-centric design principles to ensure that autonomous navigation systems are developed and deployed ethically and responsibly.

The practical implications of the review paper underscore the potential benefits of autonomous navigation and obstacle avoidance in smart robotic wheelchairs. These implications encompass enhanced independence, improved safety, access to diverse environments, customization, technological advancements, collaboration, and ethical considerations. By acknowledging and addressing these implications, researchers, engineers, policymakers, and healthcare professionals can work together to realize the practical benefits of autonomous navigation systems and empower wheelchair users to live more fulfilling and autonomous lives.

6.2 Limitation

While the review paper on autonomous navigation and obstacle avoidance in smart robotic wheelchairs provides valuable insights into the state-of-the-art, it is important to acknowledge the limitations associated with the topic. These limitations indicate areas for further research and considerations for the practical implementation of autonomous navigation systems. Some limitations of the review paper are as follows:

Autonomous navigation systems in smart robotic wheelchairs involve complex technologies, including sensor fusion, perception algorithms, and decision-making algorithms. Integrating these technologies into a cohesive and reliable system requires expertise in robotics, computer vision, and machine learning. The review paper may not delve into the technical challenges and limitations of integrating these components seamlessly, and further research is needed to address system integration challenges.

While the review paper covers various navigation strategies and advancements, the practical scalability and adaptability of autonomous navigation systems in real-world settings may pose challenges. Factors such as diverse environments, changing conditions, and unpredictable user scenarios can impact the performance and generalizability of the systems. It is essential to investigate the robustness and adaptability of the autonomous navigation approaches in a wide range of real-world situations.

The review paper may not extensively discuss the psychological and human factors aspects of autonomous navigation systems. User acceptance and trust in the technology play a vital role in successful adoption. It is important to understand the perspectives, concerns, and expectations of wheelchair users, caregivers, and healthcare professionals to design systems that are user-friendly, intuitive, and engender trust.

Acknowledging and addressing these limitations will contribute to further advancements in the field of autonomous navigation and obstacle avoidance in smart robotic wheelchairs, leading to more robust, user-friendly, and practical solutions. Future research efforts should aim to overcome these limitations to foster the successful implementation and adoption of autonomous navigation systems in real-world settings.

6.3 Future Scope

The review paper on autonomous navigation and obstacle avoidance in smart robotic wheelchairs opens up several avenues for future research and development. These future scopes outline potential directions to explore, advancements to pursue, and emerging challenges to address in the field. Here are some future scopes identified in the review paper.

Future research can focus on exploring and integrating advanced sensor technologies to enhance perception and obstacle detection in smart robotic wheelchairs. This includes the development of novel sensors, such as improved depth sensors, multi-modal sensor fusion techniques, or the integration of emerging technologies like 3D imaging or thermal sensing. Investigating the effectiveness of these advanced sensors in diverse environments can improve the accuracy and robustness of perception systems.

Enhancing the interaction between smart robotic wheelchairs and users is a crucial future direction. Research can focus on developing intuitive and natural interfaces, including voice commands, gesture recognition, or brain-computer interfaces, to enable seamless and efficient control of the wheelchair. Additionally, exploring social cues, communication methods, and trust-building mechanisms can foster better human-robot interaction and user acceptance.

By exploring these future scopes, researchers can continue to advance the field of autonomous navigation and obstacle avoidance in smart robotic wheelchairs. These scopes address emerging challenges, foster innovation, and contribute to the development of more intelligent, user-friendly, and practical navigation systems that empower wheelchair users to navigate their environment with enhanced independence, safety, and accessibility.

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