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Design of Intelligent Wheelchair for the Disabled Elderly of Mild and Moderate Type

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Abstract. In order to improve the current problem of poor usability, comfort, and low user motivation in traditional wheelchairs. The physiological status, psychological emotions, and lifestyle of elderly people with mild to moderate disability and caregivers was analyzed through the method of user observation, user interviews and literature research, so as to clarify the multi-level and diverse needs of users and the design positioning. Three usage modes of sitting and driving, reclining and lying flat, and the intelligent control mode of assistant path planning, intelligent obstacle avoidance has been conceived, and the main dimensions and structure have been optimized according to the design positioning. In conclusion, from the perspective of the needs of users and caregivers, an intelligent wheelchair solution that combines aesthetic appearance and ease using functions, nursing burden reducing, and positive emotions enhancing of users' can be obtained, which providing a certain reference for the design of intelligent products for disability assistance.

Keywords. product design, intelligent wheelchair, disabled elderly of mild and moderate type, caregivers, user requirement.

1. Introduction

Modern design emphasizes design ethics and humanistic care for vulnerable groups [1]. The "14th Five-Year Plan for Healthy Aging" proposes to promote the sustainable development of the elderly health industry and support the age-appropriateness of intelligent products for the elderly, including enhancing assistive products for the elderly with disabilities. Currently, many scholars have conducted research on the modular application of functional modules and human-computer comfort of smart wheelchairs [2-3]. Zhang Hang [4], from a modular perspective, designed a multimodal control smart wheelchair. Zhao Yufei [5] conducted research on the mechanical structure of wheelchairs based on ergonomics and designed a flexible and fully functional smart wheelchair. Yang Kaisi [6] built the overall hardware framework and control system for a smart wheelchair bed using SolidWorks and Matlab/Simulink software. However, the above studies have paid less attention to user segmentation among the elderly with

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disabilities, with a focus on intelligent control design, virtual simulation validation, and human-computer relationship optimization. Meanwhile, traditional wheelchair products in the market lack aesthetics, have poor usability, and fall short in enhancing users' motivation and preserving their dignity, and they also pay little attention to the health, emotions, and feelings of caregivers.

This article focuses on the sub-group of mildly to moderately disabled elderly individuals, employing user research methods [7] to understand the physiological conditions, psychological emotions, and lifestyles of disabled elderly individuals and caregivers. This approach allows for insights into the diverse needs of users, leading to the key design principles of smart wheelchairs. Throughout the design process, there is a strong emphasis on intelligent technology that better aligns with product functionality and caters to the emotional needs of disabled elderly individuals. The result is a smart wheelchair that combines aesthetic appeal, user-friendly features, and the ability to enhance the positive emotions of users.

2. User Analysis

In this paper, the primary focus is on elderly individuals with mild to moderate disabilities who have upper limb weakness for manual wheelchair operation, lower limb functional impairments, and limited mobility [8-9]. The physiological and psychological characteristics of caregivers were also analyzed. The research indicates that the caregiving burden has a direct impact on the quality of life of disabled elderly individuals. It emphasizes that only by fully considering the feelings of each individual during the research process can valuable and genuine needs for the design phase be obtained [10].

2.1. Physiological Condition Analysis

In this study, the behavior habits of several disabled elderly individuals using wheelchairs were observed. A total of 20 elderly individuals aged 65 and above with mild to moderate disabilities, as well as 13 caregivers from the northern Zhejiang region, were selected as research samples. Through home interviews lasting 25-30 minutes, their physiological conditions, including physical muscle strength, medical conditions, cognitive abilities, and perceptual capabilities, were analyzed. The conditions are summarized in Table 1. Therefore, the design of the smart wheelchair should consider the following factors: (1) reducing accidents that may occur during travel or caregiving processes, (2) minimizing the physiological injuries resulting from prolonged sitting or lying for disabled elderly individuals, (3) reducing the physical burden on caregivers, and (4) addressing the cognitive decline and diminished judgment of disabled elderly individuals by improving product usability, reducing operational steps, enriching product semantics, and making the operation methods more obvious and user-friendly[11].

Table 1. Results of the analysis of physiological condition

	Disabled elderly in mild and moderate type	**Caregiving staff**
Body muscle function	Muscle strength decreased obviously	Mostly female, less physically powerful

Disease status	Complications, eczema and lumbar injury	Severe muscle and bone strain, waist injury, back injury, excessive fatigue caused poor immunity
Thinking ability	Memory deterioration, poor judgment	--
Sensory ability	Basic senses gradually decline	--

2.2 Psychological and Emotional Aspects Analysis

(1) Analysis of Psychological Characteristics of Mild to Moderate Disabled Elderly Individuals: Mild to moderate disabled elderly individuals often experience psychological conditions such as loneliness, insecurity, anxiety, and a sense of diminished self-esteem due to the decline in physical muscle strength and changes in their living environment [12]. Some of them lack self-confidence when it comes to mobility and are hesitant to use mobility aids like wheelchairs in public places. Others may experience caregiving conflicts due to dissatisfaction with the care they receive. Therefore, in the design, emphasis should be placed on enhancing the positive and optimistic emotions of users, boosting their acceptance and confidence in using smart wheelchairs, improving emotional trust between disabled elderly individuals and caregivers, and reducing the occurrence of caregiving conflicts.

(2) Analysis of Psychological Characteristics of Caregivers: Prolonged and demanding caregiving tasks often lead caregivers to experience depressive emotions, which have negative effects on both the caregivers and the elderly individuals they care for [13]. Caregivers also carry a heavy psychological burden due to concerns about neglect or mistakes leading to secondary injuries for disabled elderly individuals. Therefore, product improvements should be implemented to assist caregivers in performing heavy tasks, such as helping mildly to moderately disabled elderly individuals get in and out of bed or use the restroom. Functional safety design can also be employed to prevent caregiving accidents, thereby alleviating the psychological burden on caregivers.

2.3 Lifestyle Analysis

Compared to severely disabled elderly individuals, those with mild to moderate disabilities have greater mobility and some social needs. They also maintain a strong sense of belonging to society. The paper delves into the lifestyle of mild to moderately disabled elderly individuals from aspects such as daily routines, modes of transportation, typical behaviors, social interactions, and their personal and societal relationships, to fully understand the characteristics of their lifestyle (Table 2). Based on these characteristics, the conclusion is drawn that not only should efforts be made to enhance their self-care abilities, but also to develop features that promote independent mobility and interactive experiences. This would assist these individuals in venturing out actively and gracefully, expanding their social circles, and increasing avenues for emotional communication. Additionally, it is crucial to address the need for cost-effective caregiving.

Table 2. Description of lifestyle and stylistic characteristics

Lifestyle	Description of type characteristics
Work and rest habit	Regular work and rest, indoor and outdoor fixed place activities, due to the deterioration of body muscle can lead to toilet, up and down, go out becomes more difficult
Travel mode	Travel alone with crutches, a wheelchair or with the assistance of a caregiver
Typical behavior	Pay attention to rehabilitation exercise, short outdoor travel, willing to accept rehabilitation technology products
Communication mode	Focus on personal image development and be willing to communicate with children, caregivers and peers
Social contact	Gradually withdraw from the original social circle, desire to participate in more social activities, and receive more emotional support from relatives and communities
Value consumption view	Advocating frugality, feel that the cost of care is expensive, do not want children to bear too much

3. User Requirements Refinement and Design Positioning

By using a card-sorting method, common requirements between mild to moderately disabled elderly individuals and caregivers were organized to determine the design positioning of the product (Table 3).

Table 3. Requirement mining and functional positioning

User Requirements	Design positioning
Security requirements to prevent accidents	Reduce the product volume, save the use of space, not easy to roll over the stable structure, a key start SOS function design
Reduce the need to sit and wait for physical harm	Wheelchair posture adjustable design to achieve different rest modes
Easy-to-use functionality required	The integrated and simplified design of the components reduces the cognitive load, and the operation interface is intuitive and easy to understand
Reduce the physical and mental burden of caregivers, reduce nursing conflicts, and reduce nursing costs	Help with self-care, help go to bed and toilet, save the caregiver's energy and time
Enhance the self-care ability of activities, the need to go out actively and gracefully	Intelligent travel function to assist independent driving, increase the product endurance, obstacle sensing ability, travel direction change
Intelligent interaction needs	Control fun, enjoyable intelligent interactive experiences
Improve the user's positive emotions, improve the user's acceptance of the wheelchair, and improve the user's travel confidence	Light and compact, simple, stylish, a certain sense of sports appearance

Based on the summarized findings, the design of the smart wheelchair should take into consideration the following aspects: (1) Functional Design: Design safe and user-

friendly features, provide multiple rest modes, and support the ability of mild to moderately disabled elderly individuals to enhance self-care and travel independently. This not only saves the energy and time of caregivers but also aims to improve the physical and mental health of both parties, reduce negative emotions, prevent caregiving conflicts, and lower caregiving costs. (2) Structural Design: Consider stability and practicality in the design of the structure. (3) Interaction Experience: Design an intuitive and comprehensible interface with satisfying smart interactive experiences and autonomous driving enjoyment. (4) Exterior Design: Focus on lightweight and compact aesthetics that save space, with a minimalistic, fashionable design that exudes a sense of sportiness.

4. Smart Wheelchair Design

4.1 Conceptual design

4.1.1 Function Design

In order to conceive a solution that reduces caregiving burdens, the paper analyzed the main factors affecting the quality of care: long caregiving hours, physical effort required to move elderly individuals, lowered caregiving trust due to conflicts, and a lack of dignity. Based on these factors, a new smart wheelchair design concept was formulated, as shown in Figure 1. The structure of the smart wheelchair was optimized using a clever folding mechanism that allows the backrest, seat, and legrest to maintain the same level after adjustment. Additionally, the armrests can be folded downward to reduce obstacles and distance hindrances when mildly to moderately disabled elderly individuals are transferring to and from the bed or the restroom. This design not only reduces the risk of accidental falls during the process of moving elderly individuals but also minimizes the risk of musculoskeletal injuries for caregivers due to prolonged lifting.

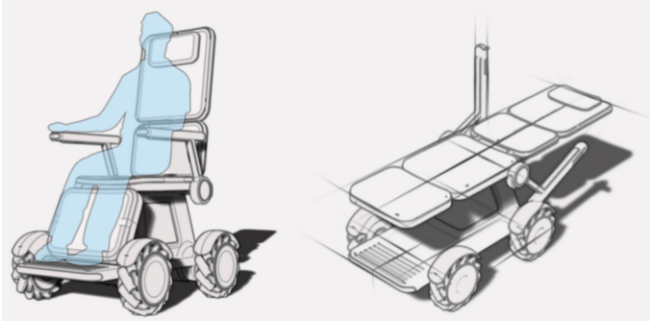


Fig. 1 Sketch of concept idea

Furthermore, three usage modes were designed: sitting and driving, reclining, and lying flat, as illustrated in Figure 2. These flexible functional modes provide comfortable driving and resting experiences for mild to moderately disabled elderly individuals, preventing issues such as body tension reflex and inadequate compensatory control abilities that can arise from maintaining the same posture for extended periods[11]. The integration of a one-key startup feature enables this innovative usage mode to transition from the bed to the wheelchair without the assistance of a caregiver[14], empowering

disabled elderly individuals to develop self-care skills, reduce caregiving time, and alleviate negative emotions.

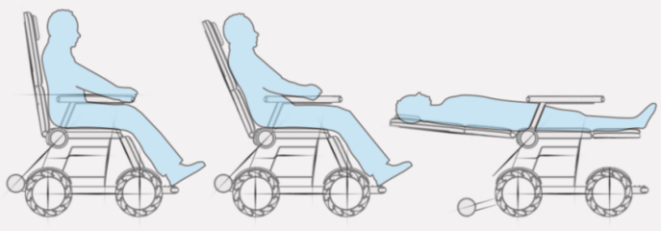
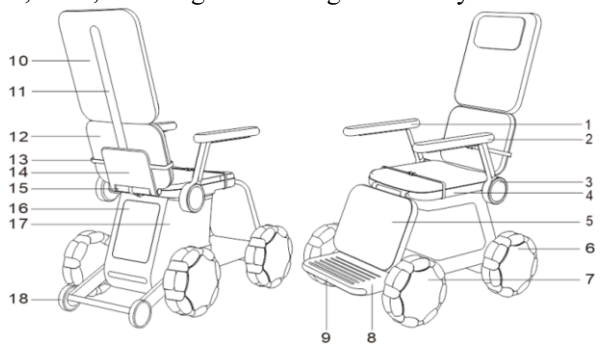


Fig. 2 Schematic diagram of three usage modes

In the design, addressing the issue of aesthetics in traditional wheelchairs, the paper focused on a design positioning that emphasizes lightweight, simplicity, and fashion. Figure 3 showcases the utilization of chassis space to conceal various exposed components typically found in traditional wheelchairs, including shock absorbers, lift systems, batteries, and cruise sensing systems. This integration results in a streamlined exterior appearance that exudes a sense of solidity and stability. The seat, lumbar support, and backrest are fixed by backrest supports and back connecting rods, with the elongated back connecting rods emphasizing a lightweight visual feature. The left and right armrests can be folded downward through the armrest pivot axis. The drive wheels are positioned at the front of the wheelchair for maneuverability both indoors and outdoors, while the auxiliary wheels are located at the rear of the driven wheels, providing balance support when users are lying flat for rest. The overall design layout breaks away from the loose structure of traditional wheelchairs, providing the foundational framework for creating a modern, sleek, and integrated intelligent mobility aid.



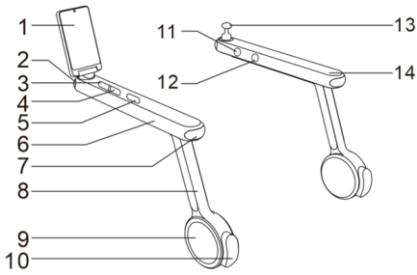
1 left armrest; 2 Right armrest; 3 handrail rotating shaft; 4 seats; 5 leg leans; 6 driving wheels; 7 driven wheel; 8 foot pedal; 9 Cruise sensing system; 10 Lean back; 11 back connecting rod; 12 lumbar support; 13 Seat belt; 14 backrest bracket; 15 Connecting shaft; 16 battery; 17 chassis; 18 training wheels

Fig. 3 Design of the key part

4.1.2 Smart control system design

A smart wheelchair should consist of three main modules: wireless communication, wheelchair propulsion, and intelligent detection, to enhance its safety, intelligence, and convenience[15]. This design adopts a simplified and integrated approach, and after multiple design tests, it was determined to integrate the intelligent module into the armrest position. The main purpose of this integration is to make it convenient for disabled elderly individuals to perform relevant operations within easy reach.

As shown in Figure 4, the intelligent control armrest design includes integrated modules in both the left and right armrests. The left armrest integrates the central control navigation wireless communication module and the drive module for adjusting the legrest and backrest tilt angles. The right armrest integrates drive modules for adjusting the direction control lever, emergency calls, brakes, and wheelchair height adjustment to accommodate various operations during driving. The front and rear side of both left and right armrests feature built-in object sensing modules, which promptly detect pedestrians or objects approaching the wheelchair, allowing for automatic evasion or stopping to prevent collisions. The central control navigation wireless communication module is positioned at the front of the left armrest, primarily assisting users with navigation and communication functions. It records the locations where elderly individuals frequently use the wheelchair, plans the most commonly used routes, and thereby enhances travel efficiency [16-17]. The control lever module is located at the front of the right armrest, with a visually intuitive and understandable design that aligns with user cognitive experience and operating habits, helping users better control the wheelchair's direction.



1 Central control navigation panel; 2 armrest front sensing device; 3 legs by tilt Angle adjustment button; 4 backrest tilt Angle adjustment button; 5 Wheelchair height adjustment button; 6 Left armrest; 7 armrest rear induction device; 8 armrest bracket; 9 Decorative cover; 10 brake lights; 11 brake button; 12 Emergency distress button; 13 adjusting the direction of the remote rod; 14 Right armrest

Fig. 4 Design of the intelligent control armrest

Furthermore, based on the design positioning of reducing cognitive load, an intuitive user interface, and a pleasurable interactive experience, the armrest interface was designed. As shown in Figure 5, the angle adjustment buttons for various wheelchair components are arranged on the inner side of the left armrest to meet the user's need for flexible operation with their thumb. The direction control lever, brake button, and emergency call button are placed on the right armrest for smooth adjustment of travel direction and alerts. This armrest interface design allows elderly users to quickly enjoy the smart control fun brought by one-key startup, even with reduced assistance from caregivers. This, in turn, stimulates a joyful driving experience and enhances the user's attachment to the smart wheelchair.

Fig. 5 Interface design of the armrest

4.2 Three-Dimensional Design

(1) Exterior Design. To further increase the acceptance of the smart wheelchair among disabled elderly individuals, an overall design was created that is harmonious, simple, and conveys a sense of motion. As shown in Figure 6, the bottom chassis of the smart wheelchair and the top seat form an aesthetic visual contrast: the large-volume chassis features bold edges and a cool dark color, enhancing driving stability while conveying a sense of motion and technology. The seat part incorporates rounded lines and a light beige color tone, adding softness and warmth to the overall design. The slightly concave seat surface in the middle and the shock-absorbing mechanism effectively cushion vibrations from the ground, improving the product's support and comfort. The inclusion of safety buckles prevents users from tilting to the side, increasing the product's sense of security. The design of the handles follows a smooth and rounded cross-sectional shape that is flat on the top and bottom, providing an ergonomic grip.

Fig. 6 Design scheme of intelligent wheelchair

The stylish and sporty appearance imparts an elegant outdoor travel experience, not only enhancing the user's affinity for the smart wheelchair but also boosting their confidence and dignity during travel. Importantly, it helps disabled elderly individuals actively integrate into outdoor activities and gain more emotional support from the outside world. An outdoor usage scenario is depicted in Figure 7.

Fig. 7 Scenario diagram of outdoor usage

(2) Overall Dimension Design. Based on the design positioning of space-saving and reducing overall volume, size parameters were determined using Chinese elderly size models and biomechanical parameters [18], considering various postures adopted by disabled elderly individuals during wheelchair use. As shown in Figure 8, the main dimensions of the wheelchair are: length 1210mm, width 770mm, height 1100mm, seat height 460mm, armrest height 210mm, and central control screen height 170mm. When in the expanded state, the wheelchair's length dimension is 1780mm, meeting the usage needs of most disabled elderly individuals. The seat dimensions are: width 450mm, depth 460mm. Additionally, three reclining positions were determined through three-dimensional virtual simulation experiments: sitting at 100 degree, reclining for a short rest at 112 degree, and lying down at 175 degree, allowing disabled elderly individuals to achieve various relaxation positions.

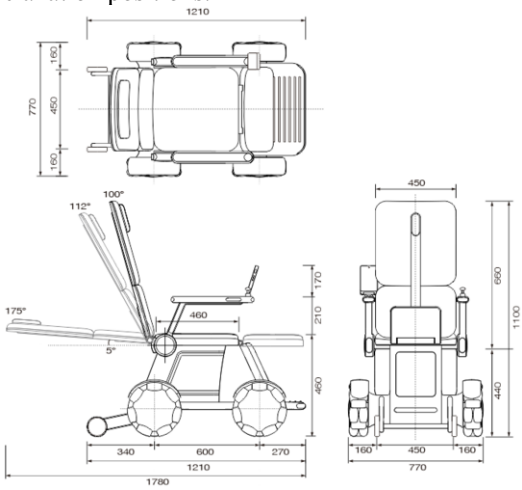
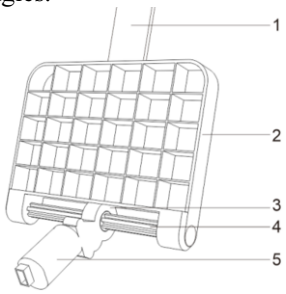


Fig. 8 Diagram of dimensional design

4.3 Structural Design

(1) Backrest Adjustment Structure Design. Multiple degrees of freedom adjustment for the backrest are achieved using direct-drive control technology. As shown in Figure 9, the core components consist of a die-cast aluminum backrest frame and an electric motor. The die-cast aluminum backrest frame is fixed to the back of the lumbar support, while the motor is fixed inside the seat. The motor drives a worm gear transmission

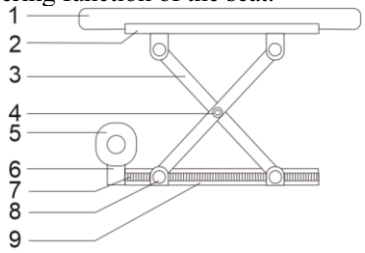
device, which in turn drives the rotating gear to maintain a constant speed of operation, thereby moving the backrest frame. The backrest linkage rod serves to connect the lumbar support and the backrest. Users can easily adjust the reclining position of the wheelchair by pressing the backrest angle adjustment button on the inside of the left armrest. Compared to traditional hydraulic adjustment methods, electric power-driven control provides better positioning accuracy and flexibility, allowing users to achieve the desired backrest adjustment angles.



1 back connecting rod; 2 backrest bracket; 3 Turboworm transmission device; 4 rotation gear; 5 Motor

Fig. 9 Structure design of electric drive

(2) Height Adjustment Structure Design. The wheelchair's height adjustment is achieved using a lift platform height adjustment structure to reduce height differences during body movement for disabled elderly individuals. As shown in Figure 10, an electric motor drives a worm gear transmission device to rotate. This rotation drives the lead screw in synchronization, which, in turn, moves the movable rollers forward and backward [19]. Support bars connect to the seat fixed bracket, and a rotating axis serves to connect the two support bars, enabling relative movement of the movable rollers to achieve the lifting and lowering function of the seat.



1 seat surface; 2 seat surface fixed bracket; 3 support rod; 4 axis of rotation; 5 Motor; 6 Turbo worm transmission device; 7 screw rod; 8 Activity roller; 9 Baseplate

Fig. 10 Structure design of height adjustment

5. Conclusion

This design proposal, with its thoughtful humanistic care, satisfaction of emotional needs for mildly and moderately disabled elderly individuals, and effective reduction of caregiving costs, was awarded the 2022 Red Dot Design Award in Germany. The approach primarily involved user research methods to understand the common needs of disabled elderly individuals and caregivers, leading to a well-defined design positioning.

Significant improvements were made to the main functions, external aesthetics, dimensions, and core structure of the smart wheelchair. The resulting design offers three resting modes and a novel smart control experience. It is characterized by low caregiving burden and excellent driving experience. It not only effectively reduces the physical and mental burden on caregivers but also helps disabled elderly individuals build confidence

and dignity in their mobility. This design provides valuable insights for the development of intelligent assistive devices for vulnerable groups.

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