Layout Guide for Design of a Novel Wheelchairs with Circumferential Linkage using Microsoft Word

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Abstract. In recent decades, the aging of the world's population has intensified, and the number of people with disabilities caused by various disasters and diseases has gradually increased. Most of the elderly, frail and disabled people will choose wheelchairs as their means of transportation. However, ordinary wheelchairs are unable to climb stairs, especially in cities, which seriously limits the range of activities of wheelchair users and affects their daily life. Hence, it is of great significance and value to design an intelligent building climbing wheelchair with appropriate price, stability and safety. This paper designs a multi-functional planetary height adjustable building climbing wheelchair with simple structure and low price. Firstly, a multi-functional building climbing wheelchair based on planetary gear train is designed by using modular design idea, including ground walking mechanism, in place steering mechanism, center of gravity adjustment mechanism and Seat leveling mechanism. The working principle and design characteristics of each mechanism are analyzed in detail. Then, through the analysis of the mathematical model of the climbing mechanism, the dimensional parameters of the three-star wheel set are determined. According to the power demand of wheelchair, the power system is selected and analyzed. It provided a new possibility for the wheelchair application and also for those in need.

1. Introduction
After entering the new century, aging problem is increasingly serious in the world. According to the forecast data of the United Nations, from 2015 to 2055, the proportion of China's population aged 60 and over will increase at an average annual rate of 2.35%.[1]

At the same time, due to heredity, accidents, natural disasters etc., the number of disabled people is also increasing year by year. According to the data analysis of 2018 statistical yearbook of China's undertakings for the disabled, the total number of disabled persons in China was 85.02 million at the end of 2017, including 24.72 million with physical disabilities.[2]

With more intense aging and more people with physical disabilities, the demand for auxiliary medical devices has increased significantly. Nowadays, wheelchair is still the most important auxiliary travel equipment with a variety of functions. The problems of traditional wheelchairs are obvious: the scope of activities is small, and the work efficiency is relatively low. In particular, it is difficult to meet the needs of the elderly and the disabled to go up and down the stairs freely. Hence, the design and research of intelligent building climbing wheelchair can help users travel more conveniently, enjoy life better, and reduce the burden of family and society, which has positive social and practical significance.

Researchers have developed different wheelchairs according to the application fields, including crawler type, walking type, planetary wheel type, and the compound mechanism which is the
combination of the two or three of the above ones. The research of crawler climbing mechanism is relatively mature. The advantages are the small subsidence, large contact area with the ground and strong adaptability to the terrain. However, the speed of the crawler climbing mechanism is slow when driving on flat ground and it is difficult to turn around, limiting the use in narrow corridors. [3] The walking building climbing wheelchair is mainly designed based on the principle of bionics and the movement form of animal legs. But the bearing capacity is poor, and the structure is complex, which is cumbersome to control. [4] The planetary wheel stair climbing wheelchair uses the alternating turnover of the planetary wheel set to realize the floor climbing action. The planetary wheel climbing wheelchair has simple structure and flexible movement, but due to the influence of climbing mode, the center of gravity will fluctuate in the process of climbing. [5] In addition, the adaptability of planetary wheel climbing wheelchairs to step height and size is poor, and most domestic planetary wheel wheelchairs do not have anti-skid devices. The compound mechanism integrates the advantages of the corresponding building climbing mechanism, makes up for the shortcomings of a single building climbing mechanism, and has good obstacle crossing function, but it brings the problem of coordinated control among various mechanisms. [6]

According to the analysis of the existing building climbing wheelchairs at home and abroad, the design principle of planetary wheel building climbing wheelchairs is the simplest, with low cost and easy operation, but it also has an obvious disadvantage as poor adaptability. With the rapid development of the construction industry and the great difference in the height of stairs in different buildings, it is difficult for the users to adapt to all kinds of scenarios. Based on the existing planetary climbing mechanism, this paper proposed a novel design of wheelchair with circumferential linkage, which can adjust the climbing height of planetary gears. Considering the safety and stability of wheelchairs, the difficulty of controlling and the comfort of passengers, a multi-functional building climbing wheelchair based on planetary gear train is designed by using modular design idea, including ground walking mechanism, in place steering mechanism, center of gravity adjustment mechanism and Seat leveling mechanism. Then the dimensional parameters of the three-star wheel group and the height of the stairs are determined. Finally, the motor power required by wheelchair climbing stairs is calculated.

2. The holistic model of the intelligence wheelchair

As shown in Figure 1, the wheelchair is mainly composed of a stair climbing mechanism and a seat leveling mechanism. The star wheel mechanism includes of planetary gears and planetary gear carrier.
Each planetary gear can not only revolve around the central axis of the gear carrier, but also rotate around its own axis. When driving on the flat ground, the planet carrier is fixed relative to the main shaft, and the grounding planet wheels rotate around their respective axes; When walk on stairs, each star wheel is locked, and the star wheel in the wheel set rotates around the main shaft with the planet carrier. According to the number of planetary wheel groups, planetary wheel climbing wheelchairs can be divided into single wheel group and double wheel group. Single wheel set type means that only one pair of planetary wheel sets is used for the front and rear axles of the wheelchair, and the other pair uses ordinary wheels. Double wheel set type means that a pair of planetary wheel sets are used on the front and rear axles of the wheelchair. In this paper, we adopt the double wheel style.

When the wheelchair climbs the stairs, if the seat has no adjustment ability, it will cause discomfort to the passengers. In serious cases, it may fall due to the change of center of gravity. Therefore, the wheelchair shall have seat leveling function to ensure the comfort and safety of passengers.

Different from the previous research for wheelchair with planetary gears, the adjustable stair climbing mechanism is the focus of this paper. The planetary wheel structure of the building climbing wheelchair is based on the ordinary planetary wheel and added with a circumferential connecting rod mechanism, so that the height of the stairs it can climb can be adjusted according to the actual situation. It enhances the adaptability of planetary wheel climbing wheelchair.

3. The mechanism design of the wheelchair with adjustable planetary gears
As the core part of the building climbing wheelchair, the three-star wheel group is mainly composed of star wheel as simplified in Figure 2, circumferential linkage and gearbox. The dimensional parameters of the star wheel and gearbox will determine the stair climbing trajectory of the wheelchair.

When the wheelchair climbs the stairs, all the star-wheels are self-locking and cannot rotate freely. The synchronous turnover of the front and rear three-star wheel groups drives the whole body to complete the climbing action, ignoring the relative sliding between the star wheels and the step plane. Because the three-star wheel group of wheelchair has the same overall dimensions and climbs the stairs at the same turnover speed under the action of chain transmission system, it is only necessary to study the dimensions of one group of three-star wheels. The schematic of the overturning process of the three-star wheelchair group is shown in the Figure 2.

![Figure 2. The simplification schematics of planetary gear and stair climbing process](image)

The solid line in the figure describes the initial state and end state when the three-star wheel group is overturned, and the dotted line describes the state during the overturning of the three-star wheel group. Assuming that the stair climbing wheelchair can keep the front and rear position relative to
each step unchanged after one cycle of turnover when the three-star wheel group turns synchronously and the landing star wheel does not slip, this is the ideal climbing state of the wheelchair. In this state, it can not only better control the whole process of climbing stairs, but also reduce the friction and collision between the star wheel and the steps, avoid the sliding of the wheelchair, and greatly improve the stability of the wheelchair.

In a climbing cycle of the ideal climbing state, the star wheel landing point of the step above the three-star wheel group is the turning point for turning. In the process of turning, the other two-star wheels have left the ground, and only the landing star wheel rolls purely on the steps. After completing a turnover cycle, the landing star wheel rolls a total of 120 degrees, which can be obtained according to the geometric relationship,[7]

\[ R = \frac{\sqrt{3 \times [(a - 2\pi r/3)^2 + b^2]}}{3} \]

(1)

Where R is the radius of the star wheel and set as constant for the following analysis.

It can be seen from the above that there is a nonlinear inverse relationship between the star wheel radius R and the planet carrier length r when the stair size is determined. When the star wheel radius R is determined, the size of the whole three-star wheel set is determined. However, in reality, the size of three-star wheel group of wheelchairs and the size of stair steps often cannot meet the relationship in equation (1). When the climbing height remains unchanged and the width changes, the climbing state of the three-star wheel set needs to change accordingly. The specific changes are as follows:[7]

1. When the step width changes little, the end state of each cycle of the three-star wheel set will deviate from the front and rear position of the step compared with its initial state. During a period of building climbing, the deviation of the wheelchair at each step accumulates. After the building climbing process, the distance between the three-star wheel group and the side of the stairs is compared with that at the initial turnover of the three-star wheel group. If the accumulated deviation is not large and the wheelchair will not slip during the whole climbing process, this climbing state can also be regarded as an ideal climbing state.

2. When the step width is less than the original design size, the three-star wheel group will move forward a certain distance than the ideal climbing position after completing a cycle of turnover. When the wheelchair turns over to the nth step in the process of building climbing, the deviation of the wheelchair at each step accumulates. After the building climbing process, the distance between the three-star wheel group and the side of the stairs is compared with that at the initial turnover of the three-star wheel group. If the accumulated deviation is not large and the wheelchair will not slip during the whole climbing process, this climbing state can also be regarded as an ideal climbing state.

3. When the step width is larger than the original design size, the three-star wheel group will move backward for a certain distance than the ideal climbing position after completing a cycle of turnover. During the climbing process of Samsung wheel group, the previous M-1 turnover can also be regarded as an ideal climbing state. When the three-star wheel set is overturned for the m time, the star wheel that should have been built on the step cannot be built on the step due to the cumulative absolute deviation in the process of wheelchair climbing the stairs. At this time, the three-star wheel set collided with the edge and corner of the step, and the wheelchair slipped to the previous step. This climbing process failed. The collision and sliding in the whole building climbing process are uncertain, resulting in the unpredictable overturning process of the M + 1 of the three-star wheel set, and the wheelchair cannot climb the stairs according to a certain preset track. The stability and mechanical strength of wheelchair will be affected by sliding collision. The unpredictable climbing process cannot ensure the comfort and safety of passengers. Therefore, when the wheelchair climbs the stairs with excessive step width, it is necessary to adjust the dimensions of the three-star wheel set to meet the really conditions. As shown in Figure 3, the importing of the circumferential linkage can resolve this
problem by changing the radius of the star wheel, which greatly increases the applicational field of the wheelchair for stairs with different height.

Figure 3. The schematic of the circumferential linkage

4. Structural parameter design and theoretical analysis

Figure 4 presents the driving part of the wheelchair, where the motor in the middle provides the power for motion (moving and climbing etc.). The stair climbing process of wheelchair is converting electric energy into gravitational potential energy. During the turning process of the three-star wheel set on the
stairs, the wheels in contact with the ground only roll, ignoring the small rolling friction couple, then the average output power of the motor required by the wheelchair to climb the stairs is the absolute value of the output power of gravity to the wheelchair. Therefore, the average output power $P_3$ required by the wheelchair when climbing stairs is

$$P_3 = Gv\sin\alpha$$  \hspace{1cm} (2)$$

Where $V$ is the average speed of the wheelchair rising along the slope of the stairs, and the average speed in the vertical direction when the wheelchair climbs the stairs is the ratio of the height $H_2$ of the wheelchair climbing the stairs per minute to the time $t$,

$$V\sin\alpha = \frac{h_2}{t}$$  \hspace{1cm} (3)$$

According to the designed wheelchair climbing parameters, the wheelchair climbs 9 steps per minute and each step is 150mm. Therefore, when $h_2 = 1350$mm and $T = 60$s are brought into equations (2) and (3), the average power required for the wheelchair to climb the building is:

$$P_3 = 32$W$$  \hspace{1cm} (4)$$

When the wheelchair climbs the stairs, the overall center of gravity of the wheelchair and the passenger fluctuates up and down with the turnover of the three-star wheel group, and the torque effect of the total gravity of the wheelchair and the passenger on the front and rear three-star wheel groups also changes. Therefore, when the wheelchair climbs the stairs, the output torque of the motor is also changing, and it is difficult to determine the size of the motor output torque at each time, but the maximum value of the motor output torque can be solved. Assuming that the seat is always horizontal during the turnover of the three-star wheel set, ignoring the initial rotation acceleration of climbing the building, the maximum torque to be output by the motor when the wheelchair climbs the stairs is the product of the maximum force borne by the central axis of the three-star wheel set and the maximum action distance. Obviously, the maximum force borne by the three-star wheel set is the total gravity $g$ of the passenger and the wheelchair, and the maximum action distance is the length $r$ of the planetary carrier of the three-star wheel set. Therefore, the maximum instantaneous power $P_4$ output by the motor when the wheelchair climbs the stairs is:

$$P_4 = 53$W$$  \hspace{1cm} (5)$$

According to the power requirements and many factors such as price and assembly, yb3-280s-4 motor is selected, and the maximum output power of each motor is 75$W$.

5. Conclusion

In view of the increasing number of the elderly and the disabled, this paper designs a multifunctional planetary wheel stair climbing wheelchair, which has simple structure and diverse functions. It can change the climbing height according to the actual situation of the stairs, which has good practical value and research significance. Firstly, according to the motion characteristics of the stair climbing mechanism, the ideal climbing state of the wheelchair was put forward. Then, the relationship between the dimensional parameters of the three-star wheel group and the height of the stairs is determined based on the dimensional constraints of the wheelchair in the motion state. Finally, the motor power required by wheelchair climbing stairs is obtained as 53$W$ and the certain type was determined. Although the multifunctional stair climbing wheelchair designed this time can realize the basic functions, it still has a long way to go from market promotion. We believe that it provides a new possibility for the elder and disabled people who need the assistance of intelligence wheelchair.

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