Leg-wheel composite wheelchair based on parallelogram mechanism

Baoping Deng*, Jiangyue Dong and Yuhe Chen
Wuhan University of Technology, Wuhan, China

*Corresponding author: baoping@whut.edu.cn

Abstract. with the aging society in China, the demand for wheelchairs is increasing for the elderly with mobility disabilities. At the same time, the number of people with physical disabilities caused by accidents and natural disasters is also rising. This paper designs a kind of electric wheelchair which can adapt to many kinds of terrain, which integrates climbing stairs, crossing obstacle function and safety and comfort to meet the living needs of specific people.

Keywords: climbing wheelchairs, self-balancing, mechanical safety.

1. Master design
The project aims to help the elderly and physically disabled, design a low-cost and high-functional wheelchair, hoping to help such people travel independently. The device is mainly composed of three modules: main frame module, obstacle crossing mechanism module and seat balance mechanism module.

![Chart of the Overall Structure](image)

Figure 1. Chart of the Overall Structure

(1) Design Analysis of Main Frame Module
In order to ensure the safety and convenient transportation of wheelchairs, aluminum alloy with high strength and light quality can be selected as the main frame material. At the same time, in order to avoid
overturning during climbing, the selection of the whole center of gravity should meet the mechanical
requirements in a certain range. Considering that the wheelchair should be easy to carry, the main frame
is composed of three parts and can be folded X, so the installation position of motor and transmission
mechanism should be designed reasonably.

(2) Design analysis of the mechanism module for crossing obstacles
By analyzing the characteristics of the four mainstream climbing wheelchairs on the market, the
following table is summarized.

|                | Safety performance | Wear resistance | Stair slope requirements | Working noise | Comfort |
|----------------|--------------------|-----------------|--------------------------|---------------|---------|
| Planetary wheel| Middle East        | Middle          | No requirement           | Middle        | Low     |
| Tracked        | Low                | Weak            | Less than 45°            | Large         | High    |
| Stepping Support| High              | Strong          | No requirement           | Small         | Middle  |
| Self-driving   | Low                | Weak            | Less than 45°            | Middle        | High    |

As can be seen from the above table, the comprehensive advantage of step support is obvious, and
the stair slope is not required so that it can be applied to cross more different obstacles except steps.
However, due to the limitation of motion mode and trajectory, step support comfort is not the best.
The wheel hub motor is used to drive the flat ground, and the transmission gear connected by
the telescopic rod is meshed with the rack inside the telescopic rod when crossing the obstacle, which drives
the telescopic rod to do the telescopic movement, so as to realize the overall rising and falling motion
of the wheelchair. Two sets of support devices form parallelogram mechanism, alternately supporting
wheelchair uplink or downlink, one set of support device is two supporting legs, the other set is front
and rear wheel, in order to make wheelchair adapt to different obstacle crossing activity, the degree of
intelligence is improved.

(3) Design and Analysis of Seat Balance Mechanism Module
In order to ensure the smooth running of the wheelchair on the ground and the obstacle crossing
process, it has the ability of cushioning and reducing the level of the seat, and sets up adjustable lever
support device and electromagnetic shock absorber device. The wheelchair can be kept stable and
adaptable by adjusting the lever at the bottom of the support rod.

(4) Design and Analysis of Control Module
In order to make up for the existence of a certain visual dead angle, a sensor is installed under the
wheelchair to identify specific ground obstacles, such as sharp stones, nails. After the image recognition
is successful, a warning lamp is issued at the handle to protect the safety of the rider and prolong the
service life of the wheelchair to a certain extent.

2. Project research implementation plan and proposed research methods and technical routes

2.1. Overall structural design
The integral structure of the leg wheel composite wheelchair consists of three parts: the obstacle crossing
mechanism, the seat balance mechanism and the control mechanism. As shown in Figure2.
2.2. Cross-bar mechanism design

The parallelogram mechanism diagram is shown in figure 3. The essence of the scheme is to add a parallelogram mechanism on both sides of the ordinary wheelchair. The four walking wheels of the mechanism form two sets of supporting devices. When the wheelchair goes up and down the stairs, the two sets of supporting devices alternately play a supporting role. Support legs should be telescopic to meet the needs of different terrain. When moving on a flat road, the supporting legs on both sides are removed from the ground through the control of the handle, which does not affect the normal ground driving.

When the user pulls the lever to the "upstairs" command, the wheelchair begins to go upstairs, and the process decomposition is similar to that shown in figure 3. For convenience of elaboration, it is assumed that the supporting leg is a rigid non-stretchable structure. When the wheelchair is located in the figure (a) position, the supporting leg begins to support, the front and rear wheels are locked under motor control to prevent slipping, the supporting legs lift the front and rear wheels, and the parallelogram mechanism begins to move through the (b) process. The parallelogram moves again to the next step to the d. After that, the above motion process is repeated to realize the reverse motion of the above process, and the process of overturning is similar to that of the upstairs process when the road meets other obstacles.

Figure 2. General Structure Diagram

Figure 3. Breakdown of climbing process
2.3. Seating Balance Structure
When the laser ranging sensor under the seat measures that the center of gravity of the wheelchair is inclined or floating up and down, it will independently control the rotation of each member and adjust the level of the seat, and lock it at the appropriate length and size with the telescopic support leg. In order to reduce the sense of subversion.

![Figure 4. Seating Balance Structure](image)

3. Feasibility analysis
The feasibility analysis mainly starts from the safety and stability of the institutions studied, taking the climbing process of crossing obstacles as an example, it is divided into the dimension analysis of each component of the cross-obstacle mechanism, the design of the seat and its balance adjustment structure.

3.1. Dimension Analysis of Components of Cross Barrier Mechanism
(1) Wheel size analysis:
The wheel size of the wheelchair studied in this project is limited to a large extent by the height and width of the staircase steps. In order to ensure that the speed of flat ground is not too slow and the supporting function of crossing obstacles, the wheel size should not be too small to meet certain support strength.
The national standard has the related stipulation to the residential building staircase size, the step width is minimum 250 mm, the height is maximum 180 mm, in order to satisfy the above analysis condition, the big wheel diameter design is about 290 mm, the small wheel diameter design is about 110 mm.

(2) Analysis of the distance between wheels and two supporting legs:
If the spacing is too large, the flexibility in climbing stairs is insufficient. If the spacing is too small, the overall center of gravity is unstable and easy to overturn. Taking into account the possible disadvantages in the course of exercise, the relationship between the distance between wheels and two supporting legs and the size of staircase steps should be established, two special positions of wheelchairs in the process of climbing buildings should be analyzed, and simple Pythagorean theorem should be used. The distance between two wheels is about 280 mm and 400 mm. Because the wheel function is similar to that of the two supporting legs in the climbing process, the distance between the front and rear supporting legs should be similar to that of the center of the wheel.

3.2. Feasibility Analysis of Seat and Balance Adjustment Structure
The seat itself can imitate the car seat design idea, design for the height adjustable, each part angle adjustable seat.
In the balance adjusting mechanism, the distance between the seat bottom plate and the ground is measured in real time by using laser sensor to judge how to adjust the height and tilt angle of the seat to ensure the safety and stability to the greatest extent.

Acknowledgments
National innovation and entrepreneurship training program for college students 202010497057.

References
[1] Ikeda Hidetoshi, Toyama Takafumi, Maki Daisuke, Sato Keisuke, Nakano Eiji. Cooperative step-climbing strategy using an autonomous wheelchair and a robot [J]. Robotics and Autonomous Systems, 2021, 135.

[2] Giwnewer Uriel, Rubin Guy, Friedman Alex, Rozen Nimrod, Manton KG, LaPlante MP, Kaye HS, Cooper RA, Cooper RA, Thorman T, Cooper R, Cooper RA, Cooper R, Boninger ML, DiGiovine MM, Cooper RA, Boninger ML, Lawrence BM, VanSickle DP, Rentschler AJ, Nishiyama K, Taoda K, Kitahara T, Seide H, Heide R, Van Sickle DP, Cooper RA, Boninger ML, VanSickle DP, Cooper RA, Boninger ML, DiGiovine CP, Cooper RA, Wolf E, Fitzgerald SG, Boninger ML, Ulerich R, Ammer WA, Wolf EJ, Cooper MS, DiGiovine CP, Boninger ML, Guo S, Wolf E, Pearlman J, Cooper RA, Jianghong Z, Long T, Hulshof C, van Zanten BV, Pope MH. User Assessment of a Novel Suspension for a Wheelchair—A Prospective, Randomized, Double Blind Trial [J]. Geriatric Orthopaedic Surgery & Rehabilitation, 2020, 11.

[3] Geilen Bart G, de Witte Luc, Norman Gift, George Carolin Elizabeth. Quality of wheelchair services as perceived by users in rural Bangalore district, India: a cross-sectional survey. [J]. Disability and rehabilitation. Assistive technology, 2020.

[4] Kai Sasaki, Yosuke Eguchi, Kenji Suzuki. Stair-climbing wheelchair with lever propulsion control of rotary legs [J]. Advanced Robotics, 2020, 34 (12).

[5] Michael Hinderer, Petra Friedrich, Bernhard Wolf. An autonomous stair-climbing wheelchair [J]. Robotics and Autonomous Systems, 2017, 94.

[6] Giuseppe Quaglia, Matteo Nisi. Design of a self-leveling cam mechanism for a stair climbing wheelchair [J]. Mechanism and Machine Theory, 2017, 112.