A Stair-clamping Wheelchair for Elder People Based on Compound Structure

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Abstract. In China, there is still a lot of the buildings which are without elevator, meaning that the floors can only be accessed by walking up and down stairs. It is slow, time-consuming and energy-consuming. At the same time, due to social enhancement like rising life expectancy, population aging has become a common phenomenon in majority regions of China. As there are more old people in the residential system, the challenge of climbing staircases is beginning to be considered as a potential social issue. Indeed, it is easy to find a stair-climbing wheelchair on the market nowadays, but not much device is able to provide the proper help for the majority of old ones who suffer through a daily double challenge of carrying some heavyweights from the vegetable markets and climbing the stair just to access residents. At present, the stair-climbing mobility has already been developed for several years, and there are a lot of different mechanical structures with different features. My design attains the maximized efficiency of stair-climbing and is able to consistently maintain the weights in the box structure always horizontal relative to the ground, under a device-body angle self-adjusting system. And it is able to do the job stably and efficiently, it will further facilitate the elders’ lives.

1. Introduction

1.1. Motivation
Nowadays, a lot of advanced and outstanding technologies are becoming a part of people’s lives, but there are few eyes that pay attention to the significant issues that seem negligible in our community. However, while ensuring safety, this is my opportunity to demonstrate my invention that solves one challenge in the Chinese community. There are numberless olds and others who are having trouble walking stairs, and this inconvenience makes stair-climbing a challenge and danger to them. The invention can free their hands to provide improvements on safety and releasements on stress.

According to 6.3.2 in “Residential Design Standard” GB 50096-2011, a standard staircase in an apartment building has a riser of 175mm and a tread of 260mm. This is an important information for me to refer to when I’m designing the crank length.

An outstanding stair-climbing invention proposes leg-wheel hybrid stair-climbing that supports a stable and heavy body device. Its eight simplified legs can climb the stairs/move across obstacles just by sitting on it or can carry people (Yuan, 2004). Due to its complicated kinetic mechanism and large body movement, the process becomes relatively slow. However, providing efficient carrying is significant in a
busy and narrow living region. The size of the carrier should also be carefully determined due to different dimensions of the staircase and geographical limitations. Yuan’s Zero Carrier shows to have a large size, which will potentially cause dangers and jams in the narrow or slant situation (more likely to be apartments or domiciliary regions). Another example introduces a quadruped-hybrid structure and the practice of tri-lobe wheels. It features lightness and efficiency while generating enough force and power for the device to achieve its moving or climbing purpose. In Herber’s design of the stair-climbing robot, it is able to overcome many of the challenges especially associated with search operations in an urban setting (Herber, 2008). Nevertheless, although it can go through a lot of complicated terrains, it lacks the efficiency to move on a horizontal plane due to its lack of rotational wheels and loading maintenance (instead, there are only four legs that can only be used as climbing and fundamental moving tools). Specifically, due to the fact that staircases are usually slanted surface with a great slope, it’s likely that the loads are going to move around in the basket and, by chance, pour out. Thus, it is significant to improve its loading capability and stability. Most stair-climbing related projected have been mainly focusing on wheel-chair and human transporting, they are extremely helpful to those who completely lost their mobilities on stairs; however, they tend to be less efficient and overly functional for the olds who need help for carrying while climbing stairs. Additionally, a lot of devices are costly and large in size, which will be unpractical to be commonly used in common communities in China where people live economically in relatively small passing spaces. Different from the previous inventions, I will be using a crank system to achieve stair-climbing and 4 wheels driving to achieve agile movements on horizontal surfaces. This improvement is In addition, the major specialty of the design is that it has a body angle self-adjusting system, consisted mainly of a gyroscope module and a linear actuator, which makes the carrying basket automatically parallel to the horizontal plane.

Hence, I designed a stair-clamping wheelchair based on compound wheel structure, which is low-cost, low operating noise, and large carrying capacity. And the experiments results shows the efficiness of the method proposed in this project.

2. Structure Design

2.1. Overall Design

I included a fundamental idea of how to separate the different functions in different sections of the device body in the original sketching of the device, and this includes the distribution of six different motors along with wheels and cranks, a linear actuator and a movable device body. Then I used SolidWorks to create a detailed design drawing. I started by parts including different mechanical standard parts and motors. I electronically assembled them in SolidWorks and fixed all the interference detected when the parts are moved to their extreme angles respectively. After I obtained all the necessary parts and physically assembled them according to the drawing, I built a hardware controlling system to operate the device. I also spent some time coding and debugging on Arduino and checking for short circuit.

The design is shown in Fig.1.

![Figure 1. Overall design. diagram](image)
2.2. Wheel structure Design
The device is initially built as a rectangular frame made of 20*20 European standard profile in the SolidWorks design. I then added four separate legs perpendicular to the main body on the bottom which also attaches four motor models. After providing the structure with a steady base, I begin to add up two heavy motors to each side of the frame to balance the weight of the entire device. In order to provide firm support and handle the power during stair climbing created by the collision of the floor and the crank, the motors were assembled on a large fortified profile structure on the device body. It is important to ensure the balance of the design, so the motors were attached to the side of the body, putting the majority of the weights on the base motors and wheels. For creating the body angle self-adjusting system, I added four rotating shafts to enable the body to change its angle relative to the legs.

As shown in Fig.2, the wheel is designed as compound structure, which have a normal wheel and two stair-climbing wheel.

![Figure 2. Structure design diagram.](image)

3. Controller Design

3.1. Controller hardware Design
The controller hardware design consists of an Arduino Mega, two motor drivers, a Bluetooth module, and a JY-901 gyroscope module. The built system initially receive Bluetooth signal by a Bluetooth module and the Arduino Mega is able to send the corresponding command to the motor drivers which are able to control both the direction and the speed of the motors. Due to the combination of large voltage motors, the power was distributed parallelly by a large voltage battery using multiple motor drivers.

3.2. Key algorithm design
To achieve the design goal, i.e. stair-climbing, the most important is linear actuator model selection, which can be calculate by below method:

Adding this linear actuator on the flexible device not only enables the structure to move and maintain the angle change but also balance the force distribution on the structure evenly by having this extra support. However, in order to choose the correct length of the linear actuator, simple geometrical calculations have to be done. The expecting angle change for the device body is from -45 degrees to 45 degrees, and this range of change includes the angle of a residential staircase.

Throughout the calculation, I assumed the total length of the linear actuator when assembled when the device body is at its normal stage is 330. The equation is built on Pythagorean Theorem and the sin value of 45 degree.
4. Project Output And Testing

4.1. Experiment 1: Steps Passing Experiment

Experimental Objective: To evaluate the performance of robots in passing through obstacles via testing the height of steps that robots can pass through, and in the meanwhile to verify if robots can pass through road steps designed in line with the national standards so as to obtain the attitude angle for the verification of stability of the vehicle body.

Experimental Content: place the stair climbing robot 1 meter in front of the stairs, activate the robot forward gear until it gets to the steps and then activate the climbing auxiliary arm of the robot to test if the front and rear wheels can pass through smoothly and test the attitude angle range during the passing through process.

The experimental result is shown in Tab.1 as below:

| Height of Steps | Pass or Not | Range of Attitude Angle |
|----------------|-------------|-------------------------|
| 160mm          | Yes         | -2°~1°                   |
| 165mm          | Yes         | -1°~1°                   |
| 170mm          | Yes         | -2°~0°                   |
| 175mm          | Yes         | -1°~0°                   |
| 180mm          | Yes         | 0°~1°                    |
| 185mm          | Yes         | 1°~2°                    |
| 190mm          | No          | -2°~1°                   |

Based on the test, the robot can pass stairs with maximum height at 185mm. Since the road steps designed in accordance with the national standards are lower or equal to 175mm, this robot can completely satisfy the requirements to pass regular road steps.

4.2. Experiment 2: Stair Passing Test

Experimental Objective: To test if the designing requirements are satisfied via the specifications of stairs passed through by the robot, inspect the balance performance via obtaining the range of attitude angle of the robot, and evaluate stair climbing efficiency with the passing time recorded.

Experimental Content: Place the robot 1 meter in front of the stairs, activate the robot forward gear until it gets to the stairs and then activate the climbing auxiliary arm of the robot to test if the robot can smoothly climb the stairs and verify if the robot can maintain horizontal attitude and test the attitude angle range during the climbing process and record the time for passing stairs with different specifications at the same time.

The experimental result is shown in Tab.2 as below:

| Width and Height of Stairs | Range of Attitude | Time used to pass each stair |
|---------------------------|-------------------|-------------------------------|
| 280mm, 160mm             | -1°~+1°           | 4.7s                          |
| 260mm, 175mm             | -2°~1°            | 4.8s                          |
| 250mm, 180mm             | 1°~2°             | 5s                            |

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| 250mm, 180mm             | 1°~2°             | 5s                            |
Based on the test, the minimum width and height of stairs the robot can pass is at 250mm and 180mm respectively.

Experimental Analysis: Through the test, it is recorded that the minimum width and height of stairs which are the national standards for stairs were at 250mm and 180mm respectively. The control of attitude angle during the climbing process is sufficient enough for use with good climbing performance. Since it is required to help with the seniors, the climbing speed is low for now, but it satisfies the design requirements in general. And the climbing speed can be improved with three swing arms.

4.3. Experiment 3: Test on Balance Maintaining
Experimental Objective: To test if the stair climbing robot can maintain the attitude range and verify if it meets the balance requirements for normal ramp ways.

Experimental Content: To adjust the test platform to horizontal level, and place the stair climbing robot on the inclined ramp, adjust the slope from 0° to 50° and then from 0° to -50°, and repeat it for three times to test the attitude of robot and read the real-time attitude angle range.

The experimental result is shown in Tab.3 as below:

| Angle of the Platform | Attitude Angles of the Robot |
|-----------------------|-------------------------------|
| 0°                    | -1°~0°                        |
| 5°                    | 1°                            |
| 10°                   | 0°                            |
| 15°                   | 0°~1°                         |
| 20°                   | 0°~2°                         |
| 25°                   | -1°~0°                        |
| 30°                   | 1°~2°                         |

According to the test, the robot can maintain its climbing slope balance to the maximum of 45°.

Experimental Analysis: Through the test, the stair climbing robot can maintain its balance when the slope is less than 45° and adjust itself in a timely manner according to the changes of outside slope, which satisfies the international standard for slopes at 8%(about 4.6°).

4.4. Experiment analysis
Based on experiment 1, the robot can pass stairs with a maximum height at 185mm. Since the road steps designed in accordance with the national standards are lower or equal to 175mm, this robot can completely satisfy the requirements to pass regular road steps.

Based on the test, the minimum width and height of stairs the robot can pass is at 250mm and 180mm respectively.

Through experiment 2, it is recorded that the minimum width and height of stairs which are the national standards for stairs were at 250mm and 180mm respectively. The control of attitude angle during the climbing process is sufficient enough for use with good climbing performance. Since it is required to help with the seniors, the climbing speed is low for now, but it satisfies the design requirements in general. And the climbing speed can be improved with three swing arms.

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5. Conclusion
In this project, a stair-clamping wheelchair based on compound structure is designed to help the elder people get upstairs and convenient their daily life. On structure, this paper chooses a compound wheel
to achieve the goal, and it is low-cost and user-friendly. On controller design, the project chooses portable, concise and user-friendly compartment to improve users’ experience and is able to control system accurately. At last, in order to test the designed wheel-chairs, several experiments is carry out, and the results show the effectness of the stair-climbing wheel-chairs of this project.

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